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Frederic S. Lee

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VOLUME LXVI

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PHYSIOLOGY OF BODILY EXERCISE

BY

FERNAND LAGRANGE, M. D.

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PART I.

MUSCULAR WORK.

THE ORGANS OF WORK—MOVEMENTS—HEAT—COMBUSTION.

CHAPTER I.

THE ORGANS OF MOVEMENT.

Exercise and Work—Muscle—Nerve: Avalanche Theory. The Spinal Cord; Reflex Actions; Unconscious Movements—The Brain; Reflex Movements; Voluntary Movements—The Motor Centres; associated Muscular Actions. The Will, Agent of Work. Muscular Contraction—Course of a Voluntary Stimulus; Mode of Transmission—Nervous Vibration and the Muscular Wave—Time of Transmission; *Latent Period.*

BY *bodily exercise*, we mean work done with the object of perfecting the human organism from the point of view of strength, skill, or health.

Scientifically speaking, there is no difference between the professional labour which circumstances demand from the peasant or workman, and the more or less refined exercise to which a sportman devotes himself. The manual labourer who chops wood, and the gentleman who fences, both perform *muscular work.* But the gentleman has his exercise at his own hours, regulates to his own taste the time he allots to it, following the calls of hygiene, diet and rest, while the poor man works too much, feeds badly, and sleeps little.

This is why work wears out the one, while exercise strengthens the other.

But what the workman does of necessity, the man enamoured of violent exercises can do by excessive ardour. In the two cases the result is the same, and the abuse of athletic exercise causes exhaustion and overwork as surely as does excessive labour.

Bodily exercise and labour are then synonymous from the physiological point of view, and we shall blend them in our study by referring them to their fundamental principle, *muscular contraction.*

I.

The immediate agents in movement are the *muscles,* bundles of reddish fibres which collectively form the fleshy masses surrounding the different parts of the skeleton.

The muscles form, by weight, more than half of the human body. Hence the importance of muscular exercise in modifying nutrition. Work in fact, changes profoundly the physiological condition and the chemical composition of muscles, and many exercises cause all the muscular regions of the body to work at once. We can understand that the whole system associates in the modifications produced in so important a member of the living tissues.

The muscular tissues of the body are divided into larger or smaller bundles of fibres, which are generally of an elongated shape, and have two extremities, each usually ending in a tendon attached to a bone. Each of these masses forms a muscle, and every muscle consists of secondary fasciculi. Finally, these secondary fasciculi may be split up into *primitive fibres,* the fundamental elements of the organ.

The primitive muscle-fibres are essentially made up of a kind of membranous sheath called the *sarcolemma,* enclosing the *muscular juice.*

The muscular juice or *plasma* is quite fluid at a low temperature. Kühn gives us a curious proof of this: he saw a parasitic worm swimming in a lively manner in the interior of a primitive fibre. But we can only prove the fluidity of the plasma by the considerable degree of cold which congeals the other constituents of muscle. To see it in a liquid state it must be observed above 3° C. When cooled, it already tends to coagulate at 0° C., and when heated up to 45° C. it suddenly becomes solid.

The plasma does not only coagulate under the influence of heat. It also tends to solidify when treated with certain acids, notably lactic acid, which is formed in muscles in action.

We shall see, in discussing the phenomena of fatigue, how important a part in acute overwork is played by the coagulation of the muscle-plasma under the influence of excessive heat and of the numerous acid products which develop in the *over-driven* muscle.

Muscles possess the property of contraction, that is to say, of shortening, and bringing their extremities nearer to each other, after the manner in which a stretched caoutchouc cord returns to its former size.

When a muscle contracts it exercises a tension on the bones to which it is attached. Thanks to the varied effects of levers, pulleys, pivots, etc., of which the joints are made up, the fundamental movement of traction is very variously transformed, and the limbs are flexed, extended, turned and returned in all directions.

The muscles are charged with the performance of movements, but they cannot bring them about independently, without the assistance of an agent which throws them into contraction. The contractile force of muscles is a latent energy comparable to that of gunpowder, which cannot explode without a spark. A muscle left to itself remains inert, and cannot arise from its inaction, from its *repose*, unless made to do so by some stimulus.

The stimulus most commonly employed is the *will*, but many other agents can bring into play the contractile properties of muscle. Any mechanical, physical, or chemical action on a muscle, a blow, a pinch, an electric discharge, the contact of a strong acid, etc., can play the part of a stimulus, and cause contractions and movements.

In order to bring into play the *irritability* of a muscle, the property which causes the organ to contract when stimulated, it is sufficient to apply the stimulus directly to the muscular fibre. Thus, in an animal just killed, it is enough to expose a muscle and pinch its fibres strongly, and the muscle is seen to contract, and to move the bones to which it is attached.

At first sight we are disposed to think that the will, like other muscle-stimuli, acts directly on the motor organ.

Willing and doing seem so intimately connected with each other, that they appear to fuse. At the slightest command our hand seizes an object, places or displaces it, and obeys with such punctuality and quickness, that the will seems to stimulate the muscles directly. But it is not so, and the faculty of will needs, for the transmission of its orders, a very complicated mechanism of intermediate organs, without which its action is ineffectual.

These intermediate organs are the *nerves*, the *spinal cord*, and the *brain*.

If the nerves of the arm are cut, the most energetic will in vain exhausts itself in the endeavour to move the limb ; the muscles contract no longer.

It is generally stated that the section of motor nerves *paralyses* muscles. The expression is inaccurate ; these muscles have not lost the power of contraction, but they are removed from the influence of the will, and receive its orders no longer. Acted on by other stimuli, they would still contract and move the bones to which they are attached. If we galvanise these muscles which seem paralysed, if indeed we simply pinch them strongly, we produce contractions and movements.

Section of the spinal cord, lesion of the brain, have the similar result of putting the muscles out of reach of the will, without, for all that, destroying their contractility.

Contractility is a force inherent in muscle, and is not supplied to it by its motor nerve. If we carefully destroy all the nervous filaments going to a muscle, the latter, reduced to its own elements, nevertheless retains the power of contracting under the influence of a stimulus.

A muscle has an individuality and a power peculiar to itself, independent of any nervous action.

If a muscle be detached from the leg of a recently killed dog, this muscle, thus isolated, being no more than a fragment of the body of the animal, may be made to do work. If we attach the muscle by a nail at one end, and fasten to the other end a hanging weight, it is enough, the muscle being in this manner stretched, strongly to pinch the fibres to cause the muscle to contract and to raise the weight

Muscle has great vital energy, and long retains the power of action, provided that it receives a sufficient stimulus. Thus in many cases the loss of power of action shown by a fatigued man must not be attributed to the muscular system. Almost always, in the ordinary course of life, it is the will—the stimulus of muscular contraction—which first gives out, long before the muscle has lost its contractile powers, under the influence of prolonged work.

II.

We may compare *motor nerves* to the wires which conduct electricity from an electro-motor to a receiving apparatus. They convey to the muscles the stimuli emanating from the brain. They convey also all stimuli which can come from outside agents. A pinch, an electric shock, the contact of an acid, can throw the muscle into action by the mediation of the nerve. If a nerve be electrified the effect produced on the muscle to which this nerve is distributed will be identical with that which would be produced by electrifying the muscle directly.

The will needs the help of the nerves to transmit to the muscles the orders to act. In the most vigorous and energetic man, it suffices to cut one of these slender little filaments, to see the muscles supplied by it become inert. The will then exhausts itself in useless efforts, and gives in vain repeated orders. Its call is unheard.

Similarly the breaking of the wires between two telegraphic stations, renders all communication impossible.

The nerves have not in themselves any power of producing movements Their function is merely to transmit to the muscles the stimuli which bring their vital properties into play.

We must mention, however, that according to certain physiologists, a nerve has, besides the power of conducting a stimulus received by it, the further power of reinforcing that stimulus.

According to Pflüger, when a nerve is stimulated, whether by a mechanical shock, an electrical discharge, or by the action of the will, a phenomenon occurs which this physiologist calls the *nervous avalanche*. Just as a lump of snow detached from a mountain top grows as it descends the snowy slope, and when it reaches the valley is of larger size than when it set out, so the stimulus received by the nerve is amplified in its passage through the conducting filament, and is much more intense when it reaches the muscle than it was when first produced.

The nerve would then be a reinforcing as well as a conducting apparatus : it would increase the intensity of the stimuli which it transmits, as the microphone increases the intensity of the sounds which pass through it.

If Pflüger's theory is correct, and if the nerve really has the power of amplifying the stimuli which it conveys to the muscle, we may believe that this power is developed by exercise, like all the physiological functions of working organs. The motor nerves of a man who devotes himself to bodily exercise should then become more capable of reinforcing the voluntary stimuli.

This property could be a partial cause of the sometimes surprising increase of power displayed by *trained* men, which cannot always be explained by an increase of the muscular tissues ; it would render it possible to produce, with a moderate effort of will, a more intense stimulation of the motor fibre, and consequently a more energetic contraction.

Of all nervous tissues the nerves have the simplest structure, for they have only one fundamental tissue, the *white matter*. This is made up of elongated elements in the form of hollow fibres, or *tubes* in which is seen, with the microscope, a kind of filament called the axis-cylinder. At the point where the motor nerve is distributed to a muscle, the axis-cylinder ends in a discshaped expansion called the motor end-plate, which is intimately connected with the enveloping sheath of the ultimate muscle fibres. The motor end-plate is the junction which unites nerve and muscle. By its means a communication is established between the motor organ and the conductor which conveys to it the orders of the will.

III.

The *spinal cord* seems to be formed by the union of all the nerves of the trunk and limbs. It has the shape of a thick white cord, in connection with which are both the motor and the sensory nerves, and which is continuous with the brain, of which it is in a certain sense a prolongation.

It is made up of two kinds of tissue : one is white like the tissue of the nerves, and the other has a grey colour.

The *white matter* forms the external layers of the cord. It has the same elementary structure as the nerves and possesses the same conducting properties as these organs ; but being formed of sensory as well as of motor fibres, it has mixed functions : the posterior region conducts sensory impressions, whilst the anterior region transmits motor stimuli.

As far as the white matter is concerned, the spinal cord does not differ at all from the nerves. If we make a transverse section, the voluntary movements of all muscles which receive their nerves from the cord below the section are abolished. If, however, we pinch strongly, or electrify the anterior tracts, we produce involuntary contractions in the muscles innervated by the points to which the stimulus is applied.

The *grey matter* makes the spinal cord a *nerve-centre*, that is to say, an organ capable not only of conducting a motor stimulus, but also of spontaneously bringing about a movement in the muscular system. It is made up of irregularly spherical cells which have filamentous processes putting them in communication one with the other, and anatomically and physiologically with the motor and sensory nerve fibres. The *nerve-cell* is the most exalted element in the hierarchy of living tissues: when we find one in any part of the nervous system, we may be certain that this region possesses a power proper to itself and independent of any other part.

The special power of the spinal cord is shown by the faculty which it has of calling forth motor stimuli in the muscles without the help of the brain and without the order of the will.

Decapitated animals can make spontaneous movements, provided that their spinal cord is untouched.

A duck whose head has just been cut off flaps its wings and can even walk a few steps.

On the body of a man just decapitated, if we strongly pinch the arm or the leg, the limb is drawn away as if the executed man felt the impression received by the skin, and tried to escape from it.

All these movements have the appearance of voluntary movements; they are however unconscious and involuntary, like all those executed without the concurrence of the brain. To give an idea of the power of the spinal cord when reduced to its own resources and acting without the aid of the brain, we cannot do better than quote the following curious experiment:—

"If we cut off the head of a frog, the animal jumps and twists for an instant, and then is still. It would for ever remain motionless if kept under a bell-glass, in a damp atmosphere, and sheltered from all stimulation. But if we touch one of its legs, or drop on it a little vinegar, the frog immediately tries to escape and to put at a distance the cause of disturbance. If the drop of vinegar is on the right leg, it endeavours to wipe it off with the left, and *vice versa.*"

At first sight this appears intelligent, and the frog seems to have made a conscious voluntary act; if however we continue the experiment we see that the movement of the decapitated frog is nothing but a *mechanical response* to a lively stimulus, and in no sense an action calculated with a view of escaping danger.

"Goltz and Portes, having taken a frog, removed the brain and then plunged the animal into water in a glass vessel. When touched, it swam as if to escape, and even jumped out of the vessel. But on warming the water very slowly, in such a manner as to reach a very high temperature without any abrupt transition, the frog did not move, nor try to jump out of the vase, but in the end was boiled without having made any action indicating a consciousness of danger." *

The movements of a decapitated frog are *reflex* movements. In reflex movements the will has no place. That which excites the muscular action is a sensation which runs up the whole length of a sensory nerve to a given point of the spinal cord, from which a motor nerve starts. The end of the sensory nerve and the beginning of the motor nerve join in the same cell of the cord, from which is given off a third nervous filament in the direction of the brain.

When the sensory impression, in place of travelling towards the head by this third ascending filament, stops in the spinal cord, the latter sends it on transformed into movement in the direction of the muscle, whither it is conducted by the motor nerve. The impression is *reflected* at the motor centre and returns upon its steps instead of continuing its journey, just as are reflected the sonorous waves of the voice, which, striking against a wall, rebound to produce an echo.

We may say that a reflex movement is the *echo* of a sensory impression.

It is not necessary that the brain should be destroyed for the production of reflex movements: it is enough that it takes no part in the muscular action. This being the case, the latter is not *willed* and is produced unconsciously, as may be observed in a sleeping man, or even one preoccupied, who, according to a common expression, "has his head in the clouds," and does not think about what he is doing. We may constantly see a preoccupied man walk past his own doorway which he intended to enter. We say that he is distracted, and that his legs work with an *automatic*

* *Mosso.* La Peur.

movement. This automatic movement of walking was at first very laboriously acquired by the infant, later it has become so easy of execution that the brain takes no part in it. The sensation which the ground produces on the sole of the foot resting on it determines, as a reflex effect, a movement of the other leg which comes in its turn to a position in front of the first, and so on. This regular succession of movements of the legs, which now rest on the ground, now are raised from it, can take place without the will playing any part in it, or the brain being conscious of it.

In bodily exercise a number of movements become automatic by habit, and it comes to pass that, during their performance, the will can be occupied about other things, without participating in the action of the muscles In this case the spinal cord alone presides over these movements without any intervention of the brain.

We shall have an opportunity, in discussing the therapeutical applications of exercise, of profiting by the summary of ideas we have just expounded. We shall show how important it is that a man suffering from mental overwork should seek by preference automatic exercises, which do not bring the action of the brain into play.

In many cases the spinal cord is able, thanks to its auto-motor power, to take the place of the brain, and preside alone over very complicated movements. But its absolute integrity is necessary for the performance of automatic or reflex actions. If a probe be thrust down the spinal canal of a recently decapitated frog, its reflex power is completely annihilated, consequent on the destruction of the cord, which is broken up by the instrument. At the same moment the animal loses all power of reaction to an agent which calls forth the sensibility of the skin : no movements can be produced in the limbs except by directly exciting the muscles or their motor nerves.

IV.

The *Brain* is a rounded, soft, greyish mass. It is composed, like the spinal cord, of grey and white matter, and like the cord, consists of nerve fibres and cells. But—just the opposite of what we observed in the cord—the grey matter occupies the periphery, the *cortex* of the brain, while the white matter is in the centre: further, in the thickness of the white matter are important nuclei of grey matter, indicating the presence, in certain central regions of the organ, of nerve cells, foci of independent activity.

In the brain, as in the cord, the white matter conducts the stimuli it receives, while the power of sending forth spontaneous motor stimuli devolves on certain cells of the grey matter.

The grey matter of the brain can, like that of the cord, manifest its proper activity by reflex effects. The brain gives origin to motor and sensory nerves, and a sensory impression can give rise to a reflex movement in muscles supplied by cranial nerves. It is in this manner that, in a recently decapitated animal, a drop of vinegar applied to the surface of the eye produces a closure of the eyelids.

The brain is then, like the spinal cord, a centre of reflex motion; but it is further a centre of *voluntary* motion.

This is, from the point of view of movements, the characteristic of the brain: when the brain is removed, every *willed* muscular action disappears with it.

It is not necessary to remove the whole of the brain in order to deprive an animal of the power of manifesting its will by conscious actions. It is sufficient for this purpose completely to destroy the grey matter, for it is in the interior of this tissue that the voluntary stimuli, the nature of which is, up to the present time, unknown, are elaborated. It is practicable to keep dogs deprived of this part of the brain alive, and we may be certain that all their movements are reflex actions aroused by the medium in which they live, and directed by habit. They only move now *automatically*.

Like the spinal cord and the motor nerves, the brain possesses the power of transmitting mechanical or electrical stimuli applied to it. But it is easy to foretell what effects the stimulation of a nerve will produce on the organs of movement, for we know exactly to what muscles this nerve is distributed, while it is difficult to specify the effect of a motor stimulus applied to the brain. In fact we do not always know which groups of muscles correspond to the nerve-fibres which we stimulate. Hence the often unexpected, and sometimes very remarkable results of wounds of the brain.

While out shooting, we sometimes see wounded animals make singular movements.

A partridge, for instance, wounded in a particular part of the head, rises all at once vertically to a great height in the air, and falls back dead.

We once observed a wounded hare turning round and round with great rapidity. The movement was made round the longitudinal axis of the body; that is to say, the animal seemed to revolve round a rigid rod, traversing it from head to tail. We thought at first that the wounded hare was endeavouring to run away, and we were surprised at the awkwardness of its attempts to escape. But we were soon convinced that these singular revolutions were quite involuntary; they were produced by an irresistible impulse. The hare had received a shot in the head, and this shot, perforating the skull, had injured one of the crura of the cerebellum. The shock received by the motor nerve-fibres had stimulated all the muscles with which they were connected, and these muscles, contracting all together, had produced in the animal a *gyratory* movement with which the will had nothing to do.

Other wounds of the brain can produce various motor phenomena which are no less surprising, Thus, by puncturing certain definite points of the encephalon, we produce what are known as *circus* movements, in which the wounded animal does not turn on its own axis, but goes round and round like a horse in a circus.

The physiological explanation of these movements is still unsatisfactory, but they undoubtedly show that a stimulus applied to a single very localised part of the brain can produce contractions of several groups of muscles at once.

We see then, that owing to a peculiar anatomical arrangement, a great number of motor nerve-fibres, radiating towards different muscles, can start from the same very limited area of cerebral substance. In this manner a stimulus, which acts on a very small surface of the organ, can be simultaneously transmitted to several groups of muscles, just as by means of the multiple communication established by a network of wires, a single button can throw into action the bells of several electric apparatus.

In 1874, Ferrier showed that by applying an electric stimulus to certain cerebral convolutions, movements were produced in the eyes, the tongue, or the neck of the animal under experiment. He has called these regions of the brain to which appear to converge a number of motor nerve-fibres, corresponding to well-determined, and sometimes very extensive muscular groups, *motor centres.*

Bartholow, an American doctor, with a disregard for the human subject to which we have not yet attained in Europe, has reproduced on a man whose brain was exposed by a gun-shot wound, the experiments which Ferrier made on dogs. He has been able to prove that in man, as in other animals, there are motor centres, circumscribed areas of the brain, which have under their control the movements of particular regions of the body.

The localisation of the motor power for a whole group of muscles in a limited region of the brain, explains the common action of certain muscles, and the difficulty experienced in making one muscle act without another. The will, for instance, is unable to produce an isolated contraction in a single flexor, or a single extensor muscle When the will commands, it is obeyed by a whole associated group. At times, however, associated movements are less intimately connected, and it is possible, by a great effort of the will and by continual practice, to learn to dissociate two movements which are ordinarily in combination.

V.

We have now considered the organs of movement. The nerves, the spinal cord, and the brain are so many instruments of transmission interposed between the will and the muscles.

The brain, with its motor centres, may be compared to a kind of keyboard, each key of which corresponds to a certain group of muscles, and on which the will strikes with more or less force, according as it wishes to produce a more or less energetic muscular effort.

How is the communication established between the will, a force of the psychical order, and a material substance like the grey matter of the cerebral convolutions?

This is a problem which is concerned in that of the relation between physical and moral phenomena, and which has not yet been solved. But, whatever may be its mode of action, the will is one of the most important factors in the performance of movements, one of the most active of the forces concerned in muscular work.

Muscle possesses a motor force, but an outside agent must intervene that this force may come into action.

Similarly, a bow contains a specific energy, capable of discharging an arrow, but an archer is needed to bring into play the elastic force of the wood. The will is just as necessary to bring the muscles into action as the arm of the archer to bend the bow and dispatch the shaft.

The will is the exciting cause of the movement, and the movement is always produced with a vigour proportional to that of the exciting cause. A muscle will remain inert if we endeavour to make it contract by means of too feeble an electric current; it will similarly be incapable of action if stimulated by a will without energy. Do we not see vigorous men lose all at once their muscular power when their will is paralysed by a depressing emotion, such as fear? An exciting passion, like anger, on the other hand, increases muscular power, because it stimulates the will.

Thus is explained the great difference between the capabilities for work of two equally muscular persons. One, better gifted in the matter of will, can produce from his muscles a force which the other leaves in them, as it were, latent.

The will has no direct action on muscles any more than it has on the spinal cord or on the motor nerves. It can only act directly on the grey matter of the cerebral convolutions. It is powerless to bring the muscular fibres into action without the help of the brain, the only organ with which it is in immediate relation.

The brain is then as indispensable an organ for the performance of voluntary movements as for the accomplishment of mental work, and we must not attribute exclusively to intellectual occupations the privilege of making this organ work. Bodily exercises bring it into action every time they call for the intervention of the will.

By what mechanism is an order of the will transmitted to the muscles through the conducting fibres of the brain, the spinal cord, and the motor nerves?

It is now admitted that *volition*, or the act of will, produces a molecular disturbance in the cells of the grey matter, and that this disturbance, passing along the nerve fibres, is communicated by their means to the muscular fibres. This molecular movement has been compared to the wave produced on the surface of smooth water, which gradually invades the liquid sheet, as soon as one single point of the whole mass has been disturbed by a blow.

The production of an undulatory movement has not been actually demonstrated in the cerebral substance, the spinal cord, or the nerves: it is simply a very probable hypothesis.

On the other hand it has been very plainly seen in muscle. "It has been observed in living muscle, that at stimulated points swellings or nodes are formed, which then run along the whole length of the muscle like a wave on the surface of water." *

By means of ingeniously constructed registering apparatus, Marey has been able to take a graphic tracing of the *muscular wave.* Aéby had already shown in 1862 that in living animals the swelling produced at the point stimulated, travelled to the ends of the muscle with a velocity of about one metre per second.

Every stimulus received by a muscle gives a shock to this organ which is transmitted by a muscular wave. If the stimuli follow each other quickly, it may happen that the first wave is still going on when the second begins. Then we see the two swellings run one after the other over the surface of the stimulated muscle. If the stimuli are repeated very quickly, the muscular waves are no longer seen, and one swelling occupies the whole muscle. This is then thickened and shortened uniformly: it is in a state of *contraction.*

Between the moment when the will orders a contraction, and the moment when the muscle contracts, there always elapses an appreciable interval of time. This time is occupied by various physiological actions, and in the first place by the transmission of the nervous vibration. The disturbance of the cerebral cells does not instantaneously reach the muscle. It has first to traverse the fibres of the white matter of the brain, then the spinal cord, and then the whole length of the nervous filament which passes to the muscular fibre. The length of this course may be estimated in centimetres, and we know from the experiments of Helmholtz that the nervous vibration is propagated with a velocity of about 35 metres per second. It is then easy to calculate from these data, how many hundredths of a second must, for example, elapse, from the moment when a man *wills* to flex his foot, and the moment when the foot begins to move.

* *Marey*, La Machine animale.

But if we make this calculation exactly and then compare the results with those given by direct observation, we discover that the contraction of the muscle is retarded. An appreciable interval separates the instant at which the stimulus of the will reaches the muscle, and the instant at which the latter responds by a contraction.

This period, during which the already stimulated muscle has not yet begun to contract, is known as the *period of latent contraction.*

The period of latent contraction is not always of the same duration. Many circumstances may cause a variation, but increased intensity of the stimulus received by the muscle is the condition which most efficiently shortens the *latent period.* To a feeble stimulus, the muscle responds slowly, lazily ; an energetic shock on the other hand is followed by a prompt contraction.

It was established by Helmholtz as a physiological law, that, *the length of the latent period is in inverse proportion to the intensity of the stimulus received by the muscle.*

When the will orders a muscle to contract, the latter obeys the more promptly, the more violent the nervous disturbance which transmits the order.

We shall see later what we shall deduce from these physiological data for the explanation of the great waste of nervous energy brought about by certain exercises which only represent a moderate expenditure of muscular energy, but which demand an instantaneous obedience of the muscles to the orders of the will : fencing for example.

CHAPTER II.

MOVEMENTS.

Associated Action of Different Regions during Work—How a Blow is given with the Fist—Coordination of Movements; Antagonistic Muscles; the Muscular Sense—Ataxic Patients—*Static* Contraction—Stiffness in Exercises—Muscular Education. Association of the great Organic Functions with Muscular Movement—*Effort*—The Porter and his Load—Effort during Slight Expenditure of Force; *too Hard a Nut*—Frequency of Effort in Exercise—Long-Distance and Sprint Running. Influence of Movements on the Circulation—The Quickening of the Pulse; its Mechanism—The Pulmonary Circulation and the Active Congestion of the Lungs—Congestion of the Brain during Movement—Dancing Dervishes—A Runaway Horse.

I.

THE slightest movement performed by the human machine needs the employment of a great number of wheels. When a muscle contracts, the neighbouring muscles always, and distant ones sometimes, act with it, and are associated in its work.

Let us analyse the phenomena of a very simple movement.

In order to be able to move the forearm, the arm must be fixed to give a point of application. The arm itself must be supported by the shoulder, and the shoulder by the vertebral column and the thorax. But the thorax and vertebral column being supported by the pelvis, and this by the lower extremities, the whole body is obliged to associate in the movement of the forearm. From head to foot, all the muscles participate in the most insignificant, and most localised work.

The slightest movement has a tendency to displace the centre of gravity of the body. While the extremities are at work, the vertebral column, a long bony rod which forms the axis of the body, oscillates like the beam of a balance, to right or to left, forwards or backwards, to compensate for the displacement occasioned by the burthen raised or the movement performed.

The lower limbs almost always associate in the movements of the upper limbs, and in many cases, a man really derives from his legs the force which seems to come from his arms.

"When I had my two legs," said a Zouave from whom they had been cut off, "I used to give a splendid blow with my fist!" And the Zouave was right. A well delivered blow with the fist is supported by the whole body. The effort which thrusts forward the closed hand begins in the leg, which is extended, and then involves the thigh which projects the trunk in the direction in which the blow is delivered; the muscles of the loins transmit the movement to the thorax, and those of the thorax pass it on to the shoulder, which in its turn thrusts forward the forearm and the fist, transmitting to them the force to which the whole body has contributed.

In this manner every muscular movement may have an influence at a point very far distant from that to which it seems to be localised. Hence an exercise sometimes produces very marked effects in a region of the body in which we should not have dreamed of looking for them

The muscles of a whole limb almost always act all together in the performance of a movement, although in each limb one half of the muscles generally has an action diametrically opposed to that of the other half. In the forearm, the muscles of the anterior surface have the function of flexing the fingers and closing the hand; they are flexors. Those of the posterior surface are extensors, and the action is to open the hand. For this reason these two sets of muscles are called *antagonists.*

In the performance of a movement, no muscle ever acts without a corresponding contraction of its antagonist, which submits it to a kind of balance and control. This opposition is necessary to moderate, direct, and make accurate the movement.

When two men are wheeling a barrow down a hill, and the one in front pulls forwards, and the one behind backwards, we may say that the action of the first is antagonistic to that of the second. Their efforts in different directions are combined in order that the barrow may advance neither too slowly nor too quickly, and may go at a uniform pace. In the same way two antagonistic muscles regulate each other; when they oppose each other in a proper measure, the movements are precise and well *co-ordinated.*

Co-ordination of movements is perfected by exercise, but it is often instinctive and perfect from the time of birth in the performance of certain natural actions. The chicken hardly out of the egg, reaches with the first stroke of its beak the grain of corn it sees, and the infant needs no practice to learn the degree of contraction of the lips and tongue necessary in the act of sucking.

For the movements of an exercise, however, it is sometimes necessary to go through a long apprenticeship. Much practice is necessary before a pianist is able to place his finger on the desired note with an ease equal to that which the chicken puts its beak to a grain of corn. Thanks to the *muscular sense* we can educate antagonistic muscles, and succeed, after more or less practice, in making them act with perfect harmony.

The muscular sense is the feeling we have of the force with which a muscle contracts and the direction in which it acts. It is the muscular sense which enables us to place the hand or the foot on the precise point which we wish to touch. By means of it we regulate the expenditure of muscular force in proportion to the resistance to be overcome. This sense guides us independently of vision, and enables us to reach, with our eyes closed, objects the position of which is exactly known to us: different parts of our body, for instance.

There is a disease characterised by the abolition of the muscular sense, and by defective co-ordination of movements; this is *locomotor ataxy.* The ataxic man does not know how to give to his muscles an impulse suitable to the movement required. If he wishes gently to take up an object, his hand passes by it, or strikes and upsets it. If he wishes to walk a few steps, his legs are violently projected forwards, to the side, or upwards. He has the aspect rather of an individual desirous of kicking someone with his foot, than of one who wishes to walk.

A nimble man, by the use of his muscular sense, can perform the most surprising feats. The skill of jugglers and balancers is due to the cultivation of this sense, and to the education of antagonistic muscles.

In all forms of bodily exercise, antagonistic muscles play a most important part, and it is impossible to understand certain phenomena of fatigue, without taking their action into account. Just as much as antagonistic muscles facilitate movement when their action is exact and moderate, so much can they hinder it when they act in an exaggerated or unsuitable manner.

Let us suppose that the flexors and extensors of the arm contract with an equal energy, the limb drawn by two equal forces in two opposite directions will remain motionless. We can easily understand that this immobility is not that of repose. It is *contracture* or *static* contraction, so called in contradistinction to the *dynamic* contraction which accompanies movements. It has been proved that static contraction produces greater fatigue, and causes a more immediate rise in the temperature of a muscle than dynamic contraction.*

In common language, static contraction is called *stiffness.* In bodily exercises, exaggerated and ill-planned contractions of antagonistic muscles produce stiffness of the movements. It is the fault of all beginners, and the sign of inexperience in skilled labour. "Don't keep your fingers so stiff," we say to a young pianist. "Your

* *Béclard.* Physiologie.

wrist is not pliable enough," says the fencing-master to his pupil. We demand ease of the horseman, and we forbid a rower to be stiff.

A man unskilled in the exercise he is doing, expends two or three times the necessary amount of force. Hence a difficulty in estimating the real quantity of work done; and the doctor, in prescribing exercise, must always take into consideration the muscular education of his patient.

It is necessary to have personal experience of bodily exercise to estimate the economy of labour which results from a well co-ordinated movement. Muscular expenditure is not diminished in skilled exercises alone; it becomes less also in exercises which seem to call for nothing but brute force: the act of raising a weight, for instance.

All movements need an apprenticeship, because, as we said in the beginning, there are no isolated movements. One limb assists another, and the attitude of the body helps or hinders the play of the legs and arms.

In order that all parts which associate in the performance of a movement, may have a really useful share in it, there must be a kind of discipline, assigning to each muscle its particular part. The Will, which commands, has under its orders a number of agents which cannot, at the first attempt, easily be made to act together. The man who exercises his muscles, is like the general who drills his troops, in order to have them under control on the day of battle.

Thus is explained the apparent increase of muscular power after certain exercises. There is, certainly, a real increase in the contractile force of a muscle which is at work every day, but this increase seems often so rapid, that we should be embarrassed for an explanation, if we did not consider the influence of education, or, as we might say, *drill*.

II.

When a man is raising a heavy load from the ground, we see his breathing stop, his face redden, and the veins of his forehead and neck swell. It looks as if, at the moment of greatest expenditure of bodily force, an invisible cord were tightened round his neck, stopping at once the entry of air into the lungs, and the circulation of the blood in the veins.

The phenomena which accompany a very energetic muscular action, are in fact very like those which would result from a constriction of the throat during the first stage of strangulation. Every time an *effort* is made, the air passages are closed and the veins in the thorax compressed.

The porter who wishes to raise a load on to his shoulders, first grasps it, and then, before raising it from the ground, he stops for a moment as if to prepare himself for the movement. This short period is occupied by important preliminaries.

Before performing the movement, he must take a deep breath. A great quantity of air is drawn into the lungs, and the glottis immediately closed to prevent its exit. The chest expands. The ribs are thus everted and raised, but at the same moment there is an energetic contraction of the abdominal muscles which tends to depress them. The air in the chest thus undergoes a vigorous compression, and the walls of the thorax, pushed upwards on the one hand, and pulled downwards on the other, are rendered motionless by the simultaneous action of the two opposite forces to which they are exposed.

The fixing of the thoracic walls is the object of this strife between the antagonistic forces of respiration, in which the inspiratory muscles are opposed to the expiratory, and which, in physiological language, is known as *effort*. The ribs, being motionless for the moment, can give a fixed and solid point of application to all the muscles attached to them, and in particular to the great muscular masses which move the arms, the vertebral column and the pelvis; these muscles then contract vigorously and the load is raised.

As soon as the muscular action is completed, the chest empties itself. The air which was retained is briskly expelled, with the production of a kind of murmuring sigh which indicates the end of the effort.

Effort is a physiological action which consists in the association of a great number of muscles and bones, that they may assist in the same movement, and which, moreover, brings into active association with the muscular work two great functions of the economy: respiration and circulation.

Effort is generally considered to be a phenomenon intimately connected with very great expenditure of force. It may, however, often come into play in cases in which the work done is very trifling. The essential condition for the production of effort is the need of giving to the contraction of a group of muscles all the force of which this group is capable.

Whenever a man wishes to put into a muscular action, however localised it may be, his whole strength, the action is inevitably accompanied by a series of physiological phenomena, of which the final result is the suspension of the respiratory movements.

Watch a man trying to crack a nut between his finger and thumb. If the fingers are very vigorous, and the shell offers little resistance, the muscular contractions remain localised to the forearm, and there is no derangement of the normal functions of other organs. The countenance remains calm, and the respiration is undisturbed; the nut is cracked *without effort*. But if the shell holds out, and the man has to use all his force, we see the muscular contraction extend to the arm, the shoulder, and finally the neck, chest, and abdomen. Respiration ceases, the face becomes congested, the veins of the forehead and neck fill and become prominent; and when the nut is at last cracked, there is a kind of sigh, similar to that of the porter who has raised a load from the ground.

It seems surprising at first, that an action in which the flexors of the fingers are the only muscles directly concerned, should necessitate the contraction of far distant muscles, and we fail to understand why, in order to shut the hand with all possible energy, a contraction of the abdominal muscles is necessary.

The body is made up of a number of moveable pieces, and a muscle cannot exercise all its contractile force unless one of its extremities be attached to a fixed point. Hence it is necessary, if we wish to move the forearm, that the arm should be fixed at the shoulder joint, that the shoulder should not move on the thorax, nor the latter on the pelvis. The lungs filled with air form a kind of resistant cushion, against which the abdominal muscles strongly press the ribs by pulling them downwards.

Thus, by a chain of successive muscular contractions, movements localised in the extremities of the limbs, can demand the assistance of the abdominal muscles and the ribs, and finally bring about a compression of the thoracic and abdominal viscera, in a word, all the results of effort.

Effort, so complex a phenomenon, associating the great organic functions with the most localised muscular action, results from the impossibility of fixing one of the bones of the extremities unless all the bones of the trunk are quite motionless. Its object is to make of the neck, thorax, and pelvis a rigid and resistant whole, to solder into one piece the jointed system which the trunk constitutes.

A profound disturbance always occurs in the system during effort, for this act always momentarily hinders respiration and circulation.

The lung serves to fix the ribs, and undergoes a compression proportionate to the intensity of the work. The first result of this energetic compression is the distension of the air-filled pulmonary vesicles, and hence there is a possibility of their rupture. But the lung itself transmits the compression to which it is subjected to the neighbouring organs, the great vessels, and the heart. The blood is forced back in the venae cavae, and regurgitates into the peripheral veins, which swell and become prominent in the neck and forehead. The capillaries are engorged with blood, and the circulation is momentarily arrested in the heart, the lungs, and the other organs.

The great arteries, and the heart itself, also are influenced by effort; the calibre of the aorta may be for the moment effaced, and the beat of the heart arrested for an instant by the pressure. The blood-pressure is greatly increased in the veins and arteries while the effort lasts. Indeed, we often see prolonged efforts give rise to a rupture of venous capillaries, and even to laceration of veins of a considerable size. In the most moderate efforts blood-stasis, a momentary passive congestion of internal organs, is unavoidable.

III.

The mechanism of effort has shown us how difficult it is for the great organic functions to isolate themselves from the work of the muscles, when the latter contract very energetically. But it is unnecessary that the work should be intense, and that an effort should occur, in order that the whole system should be influenced by muscular contraction. We are about to see that bringing muscles into action always produces important modifications in the processes of the great organic functions, and this however moderate the muscular action.

If we observe the circulation in the arteries of a muscle performing work, we perceive that the blood is flowing with a greater activity than during repose. This is the result, however small the work done, and however small the muscle concerned.

Thus, if a special registering instrument be fitted to the nutrient artery of the *masseter* muscle of a horse, and we note the rapidity of the blood current at different moments, we remark a very manifest acceleration of the current at the moment when the animal puts the muscle in action, as in chewing oats. There is a more considerable flow of blood to the organ in action, and the *debit* of its nutrient artery is increased.

But this is not all. The acceleration noted in the vascular region which supplies blood to the muscle is propagated gradually to the great vessels, then to the heart and to the entire circulatory system. After some minutes the blood is flowing in all the arteries, even in those most remote from the head, with the same speed as in those of the masseter muscle, and in the end the circumscribed movements of mastication will be found to have caused a more frequent pulse. We can understand that this effect will be more prompt and more intense when the movement, instead of being confined to a small group of contractile fibres, involves powerful muscular masses, as in violent exercises.

The increased frequency of the pulse during work results from a sort of aspiration of blood towards the muscles undergoing contraction. It is a vital law that every organ in activity draws towards it a greater quantity of nutrient fluid than it does when in a state of repose. This law has been verified even in regard to the secreting glands. We cannot enter into the intimate explanation of this phenomenon ; suffice it to say that it is invariable, and that every stimulus of a vital function causes a flow of blood towards the organ thrown into activity. *Ubi stimulus, ibi fluxus.* This is a formula which expresses the fact without explaining it.

Thus the excitement produced by the nervous flow to the contractile fibre draws to the muscle a greater quantity of blood, and, in order to supply this increase, the blood flows more quickly towards the excited organ. The increased frequency of the pulse is a physiological, not a mechanical, phenomenon, as at first sight we are inclined to think. It is not the pressure of the muscles swollen by contraction which quickens the circulation in the arteries : it is rather a kind of aspiration by the muscles, which have become more thirsty for blood.

This explanation is confirmed by the indications of a manometer connected with an artery. The instrument shows a fall of pressure in the vessel at the moment of work.* The pressure would rise, on the other hand, if the acceleration were due to a driving back of blood by the muscles.

Muscular contraction may, however, be called into play as a mechanical cause, capable of quickening the blood current in the veins and capillaries. The compression resulting from the swelling of muscles in action may thus become a factor in the acceleration of the blood current during work. In any case, however, this is merely an accessory factor.

Whatever the cause, the quickening of the blood current during exercise is a constant phenomenon. Constantly, therefore, at this time, the organs are traversed by a greater quantity of blood. There is an active congestion of all the organs during violent exercise: hence more active performance of function.

It will not be devoid of interest, after considering the phenomena, to study the consequences of the active congestion which accompanies every energetic movement. This active congestion is the really useful period of bodily exercises, that to which they owe their fortifying power. A man during this period of hyperactivity of all his organs benefits from a considerable increase of his nutritive forces. All the organs and all the tissues of the body are the seat of a more active circulation, and we know that the nutrition of an organ is in proportion to the quantity of blood which passes through it.

Under the influence of the greater quantity of blood which traverses the lung, this organ, fellow-worker with the heart, becomes more active, and introduces into the system a greater quantity of air. The vital combustions, thanks to this freer supply of oxygen, are more energetic and more complete. If we may make a simple comparison, exercise increases the intensity of the vital

* Chauveau, *Comptes rendus de l'Académie des Sciences*, 1857.

combustions, just as lowering the blower of a fire-place makes the combustion of the wood more active by increasing the draught.

The duration of this salutary period of exercise varies with different individuals. With some persons a considerable muscular expenditure is necessary to bring about this expansion of the vital forces due to active congestion: these are the strong natures, and those accustomed to exercise. With feeble natures, in persons accustomed to complete rest, and to muscular inaction, the least movement, the shortest walk, produces a similar result. The student calls a game of billiards exercise; for the pugilist who is training for a prize-fight, the use of dumb-bells is an exercise which employs without fatiguing him.

Perhaps the most interesting effect of this active congestion of the organs under the influence of bodily exercise is, that experienced by the brain. All thinkers have noticed that physical exercise is favourable to brain-work. The Peripatetics disputed while walking, and found their arguments more easily when the body was warmed by exercise. "Walking and movement," said J. J. Rousseau, "favour the action of the brain and the work of thinking."

Stimulation of the brain may be very great under the influence of active congestion brought about by muscular action. It is possible to be made drunk by movement, and in certain brains predisposed either by their native organisation, or by exalted ideas or passions, muscular exercise is often the prelude to actions resembling those of intoxication and even of madness. The war-dances of savages, the contortions of dancing dervishes, produce without the assistance of any alcoholic drink, a state of cerebral hyperexcitement capable of bringing about the most violent nervous phenomena.

It is related that the Gauls, in the midst of the excitement of battle, were sometimes seized with a sort of intoxication which made them furious and insensible to wounds.

Without going as far as intoxication, exercise in the end produces in every one a slight excitement, a kind of animation. The young girl dancing becomes animated, and would spend night and day forgetful of fatigue: a quarter of an hour's waltzing puts her into the same condition as does a glass of champagne. A vigorous horse becomes animated by a gentle gallop, and sometimes becomes so excited as to be attacked by a kind of madness, and runs away.

All these phenomena result from a moderate cerebral congestion. The apparent effects of exercise on the individual are, in short, similar to those produced by alcohol: the same flush, the same bright eyes, the same active demeanour.

Exercise has a stimulating action on all the organic functions, because it renders the circulation in all the organs more active. The blood makes all parts of the system share in the stimulation which the will has sent to the muscles to put them in action, and this stimulation is the more marked because the blood is warmed by the friction against the walls of the vessel through which it flows more rapidly, and warm blood is more stimulating.

Thus, when the limbs move, the internal organs cannot remain inert, and the whole organism performs its functions with more energy under the influence of muscular contraction.

CHAPTER III.

HEAT.

The Human Motor and Heat-Engines. The Mechanical Equivalent of Heat—Heat is a Cause of Movement, not its Effect —Heat Lost—How the Temperature of the Body is regulated —Effects of Heat on Muscle—Experiment of Marey on Caoutchouc—Observation of Daily Phenomena—Muscle Heated and Muscle Numbed by Cold—Gestures of Anger—Why we Make preliminary Passes in Fencing—The Hare which has just been put up—Effects of too high a Temperature—Death of Muscle at + 45° C.

I.

THE human body has been compared, inasmuch as it is a source of motion, to a machine driven by heat. We know that no machine creates force. The most perfect motors do nothing more than transform one force into another. The human motor transforms heat into movement.

In the steam engine it is easy to trace the connection between cause and effect. The movement of the wheels is due to a rod set in action by the piston ; the piston moves on account of the pressure of steam, and the latter owes its expansile force to the heat which it has absorbed. Finally the heat itself is due to the combustion of carbon. The combustion of carbon is found on analysis to be the cause of the movement of the locomotive.

In the body the motor power of the muscles comes neither from the nerves, the spinal cord, nor the brain. We know that these three organs only transmit to the muscles the stimulus of the will. The will itself is not the source of the motor force ; it orders the movement and sets the machine in action, just as the driver gives the first impulse to the locomotive by opening the steamvalve. But it would be as absurd to say that the will produces the muscular force, as to attribute to the driver the strength and swiftness of his machine.

The initial fact and the indispensable condition of movement in the human body, just as in all other heat-engines, is the production of heat. The body produces heat by the combustion of its own materials.

The combustion of our tissues is an expenditure necessitated by movement. How is this expenditure employed and how does the muscle make use of the heat produced? This problem is far from being solved, but we know that in the body, as in the machine, there is an intimate connection and a constant relation between the quantity of heat expended and the amount of work done. Muscular work is, like the work of all thermo-dynamic apparatus, subject to the principle of *the mechanical equivalent of heat.*

In mechanics, work is measured by a unit called the *kilogrammetre*, and heat by a unit called the *calory.* The kilogrammetre is the quantity of work necessary to raise a weight of one kilogramme through a height of one metre, and the calory is the quantity of heat necessary to raise the temperature of a kilogramme of water one degree centigrade.

Physicists tells us that the mechanical equivalent of heat is 425 kilogrammetres. That is to say, the quantity of heat necessary to raise the temperature of a kilogramme of water from 0° C. to 1° C. would be capable, when transformed into work, of raising a weight of 425 kilogrammes through a height of one metre.

Such is the theory; but in practice there is always much work lost, and the most perfect apparatus hardly makes use of nine or ten per cent. of the heat produced: the rest is lost in the machine, which becomes heated. In the human body, the heat lost, from the point of view of work, is considerable, and as the body absorbs that which is not used, its temperature is raised during muscular exercise.

Considering the enormous quantity of heat lost during muscular work, it is at first sight astonishing that the body in which so much heat is distributed, does not rise to a higher temperature. As a matter of fact, we find that the temperature of a man doing violent work is only 1° C. or 2° C. higher than that of a man at rest.

This constancy in the temperature of the human body is due to a regulating mechanism with which the system is provided and which works in the following manner.

When the body is warmed, the superficial blood-vessels dilate and receive a greater quantity of blood drawn from the internal organs. Thus we always see the skin of a hot man redden and swell. The blood which passes through the skin cools very quickly by radiation, and, since the circulation is very active in the body of a person doing work, the liquid which has given up its heat soon has its place taken by another wave of blood which becomes cool in its turn. In a few minutes all the blood in the system has been thus exposed at the surface of the body.

The surface of the skin considered as a means of refrigeration, does not only radiate heat, but also makes use of the evaporation of cutaneous perspiration. Every one knows the cooling power of an evaporating liquid. Everyone can also confirm the comfort derived from sweating when working at a high temperature.

Where there is excessive cooling, the mechanism is the opposite to that which we have just described. The capillaries contract under the influence of cold, and their calibre is lessened, driving the mass of blood forcibly into the internal organs. In the depth of the tissues the blood, protected from the external cold, can preserve its heat.

It is commonly said that work produces heat in the body; but the opposite is the truth: the heat is the cause and not the effect of the work. It is necessary to supply heat to a steam-engine in order to make it do work, and a considerable time elapses from the moment when the fire is lighted to that when the locomotive starts. In our system the affair is not such a long one, but the work is not absolutely instantaneous, and there is always an appreciable interval between the *willing* and the performance of a movement. This period is occupied by a series of operations in which combustions, the source of vital heat, hold their place.

Muscular contraction cannot occur without the production of heat. If we bury in a muscle a needle connected with a thermo-electric apparatus, and make the muscle contract, a rise of temperature is at once indicated.

Common phenomena confirm scientific experiments. Everyone knows that he can warm himself by movements, and cold stimulates everyone to quicken his pace and provide for the formation of heat.

We know the importance of heat in the production of movement, but we are ignorant how, and in what manner, heat acts on muscle and makes it contract. Does it act directly on the contractile fibres and make them shorten mechanically, as it does certain elastic substances? Some physiologists are inclined to think this.

"When we warm a muscle it changes its shape, and we see it shorten and swell. These effects disappear on cooling the muscle.

"Muscle-fibres are not alone in possessing this power of changing heat into work. Caoutchouc, for example, behaves in a similar manner; it is even possible with this substance to imitate up to a certain point muscular phenomena.

"If we take a piece of a thread of unvulcanised caoutchouc, and if by drawing it out between the fingers we stretch it to ten or fifteen times its original length, the appearance of the fibre changes and it becomes white. At the same time the thread becomes quite warm and strongly tends to contract, in such manner that if we release one of its extremities it immediately returns to its original length and falls to its previous temperature. Sensible heat has disappeared and has been converted into mechanical work. Indeed if we plunge the stretched thread into water and thus abstract its heat, it remains, so to speak, fixed in its extended condition and does not develop any mechanical work.

"But if we take the thread elongated in this manner, and restore its heat to it, it contracts with a considerable force.

"If we apply a weight to the cooled thread the latter has no tendency to raise it; but if we seize the thread in the fingers we feel it, as it is warmed by their heat, swell and shorten, raising the weight; there is a production of mechanical work.

"If we warm the thread in this way in several places we produce a series of swellings, each of which raises the weight for a certain distance. Finally, if we heat it throughout its length, the thread returns to its original dimensions, except for the slight elongation produced by the weight.

"There are close analogies between these phenomena and those observed in muscular tissue. These analogies have seemed remarkable to me; they appear to indicate new views as to the origin of muscular work." *

II.

The experiments of the laboratory do not always lead to conclusions applicable to common phenomena; however, everybody must have noticed the influence of temperature on bodily movements.

When it is very cold and the hand is numb, we cannot make use of its muscles, and if we plunge the arm in ice-cold water for some minutes, there ensues a temporary paralysis of the whole limb.

There is a greater aptitude for bodily exercises in summer than in winter. Professors of gymnastics, who are never at a loss for an explanation, say that the body is *more supple*. It is not on account of suppleness that the muscle works better when it is warm. There is no suppleness required to press a dynamometer in the hand; but we note a great difference in the power of the grasp, according as the muscles are cooled or heated.

Heat causes in muscular fibres the first stage of contraction, or at least an aptitude for coming into

* *Marey*. La Machine Animale.

action more quickly under the influence of the will. A heated muscle seems to have stored, in a sense, a latent force. It has been ascertained that the maximum aptitude for contraction is exhibited by human muscles at about 40° C. It follows that a man whose muscles are at this temperature, is able to act more quickly, and at once can make use of all his force.

A bodily exercise is performed with more vigour and ease when heat has raised the temperature of the muscles. This fact is so well known that there are characteristic phrases to express it in common speech. We say of a man beginning an exercise of strength or skill, whose movements have not yet acquired all their force and precision, that he has not yet *warmed to his work*.

We could quote a number of examples to show the necessity of preliminary work to warm the muscles before performing an exercise requiring a great expenditure of force.

It is interesting to see that nature has given to animals and to man the instinct of making these preparatory movements when there is a question of attack or defence.

Anger is, in principle, the prelude to an attack on an enemy, and animals or men, wishing to attack, make a series of gestures which are, in a sense, a preparation of their means of action. The dog draws back his lips to show the teeth which are going to bite, and man instinctively assumes a favourable position for the struggle. "He carries his head erect, with his chest well expanded, and the feet planted firmly on the ground. He holds his arms in various positions, with one or both elbows squared, or with the arms rigidly suspended by his sides. With Europeans the fists are commonly clenched."*

According to our idea, the evident end of anger is, as Darwin says, to prepare a man or an animal for strife; but the preparation does not only consist in making him

* *Darwin.* The Expression of the Emotions, p. 246.

take a favourable attitude for the strategy of attack and defence, the preparation above all is by causing him to make movements which raise the temperature of the body. It has always been noticed that the body of an angry man becomes warm, and the phrase "boiling with rage" has passed into common speech. When the anger is not sufficiently violent spontaneously to warm the muscles, the man and the animal make instinctively a series of movements which, while threatening the adversary, tend to increase the vital heat and to raise the body to the degree of temperature most favourable for action. Everyone has noticed that the gestures are more exuberant the less decided the man is to attack. If the anger is really very violent, gestures are useless; the man, in a paroxysm of fury, does not waste his time gesticulating, but throws himself at once on his enemy. His muscles have acquired, merely by the acceleration of the blood-current, the temperature necessary for action.

The gestures of anger are, in reality, violent movements which, in a short time, raise the temperature of the body to the degree at which the muscles act most vigorously. These gestures occur in all animals. They cannot be satisfactorily explained without admitting that they are a preparatory work, the object of which is to give the animal full power of action. The lion which lashes its sides with its tail, the bull tearing the ground with its horns, are doing the same thing as the racehorse in its *preliminary canter*. When a horse has a little gallop some minutes before the race, the temperature of its muscles is raised a degree; we are heating up a locomotive.

We discover this preparatory working of the muscles in all exercises needing vigour or skill. The pianist plays a few scales or a short prelude before attacking his great piece. In fencing, we make preliminary passes before beginning the assault. In boxing, which needs a great expenditure of force and skill, there is always some preliminary sparring. The object of all these movements is to raise the temperature of the muscles brought into action. A muscle which has been at work is a warm muscle, and a warm muscle is already in the first stage of contraction, and submits more easily to the action of the will, as the speed already possessed by a moving mass renders more effective a fresh impulse communicated to it.

The effort of a horse which starts a motionless vehicle is always more severe than that required to change its pace from a walk to a trot. The warm muscle is already in a state of semi-contraction, and the will has every facility for increasing and directing its action.

Many phenomena of common occurrences are explained by this action of heat upon muscle. We know that the temperature of the body is lowered during sleep ; in hibernating animals which sleep all the winter, the temperature falls from 37° C. to 20° C. Muscular contractility diminishes in the same proportion. By means of registering apparatus, Marey has obtained graphic tracings showing the form and intensity of the muscular contraction in the marmot. He has noted a considerable difference between the moment when the animal has just awakened, and when it is fully awake. The temperature and the muscular energy increase together.

Everyone can notice in himself a certain numbness of the muscles on getting out of bed. Animals surprised in their sleep do not at once recover their muscular energy, and have not at first the swiftness they gain after some seconds' flight. When a hare is put up and has two shots fired at it which do not touch it, the unskilful sportsman almost always thinks it is wounded. It seems unable to run, and its first steps are so slow that a dog could catch it; but after it has gone a few yards the illusions of the inexperienced shot are dispelled ; the animal becomes warm and goes like an arrow.

Heat is then an indispensable element in muscular contraction. But the temperature must not rise too high, for then, instead of increasing the activity of muscle, heat destroys it. In man and the mammalia, a muscle becomes incapable of contraction at 45° C. At this temperature vital combustions affect the muscular tissues too profoundly, and destroy their properties in a definite manner: the muscle dies.

Excessive muscular work can raise the system to a temperature at which the body can no longer live. This is one of the reasons why a *driven* animal dies. If the work becomes excessive, so much heat is produced that radiation from the surface of the body and evaporation of the liquids of the economy no longer suffice to keep the temperature at a level compatible with life. The overheated blood poisons the nerve-centres; the animal whose body is surcharged with heat owing to too prolonged exercise, dies in a condition similar to that of a man with sunstroke under a tropical sun.

CHAPTER IV.

COMBUSTION.

General Idea of Combustion—Chemical Sources of Heat—Ancient and Modern Theories—Part played by Oxygen—Oxidation; Hydration; Decomposition—Complexity of the Chemical Phenomena which Produce Heat—Combustible Materials; Food-Stuffs; Reserve-Materials; Tissue-Materials—Results of Combustion—Products of Dissimilation—Products of Incompleted Oxidation; Uric Acid—Elimination of Products of Dissimilation — Eliminating Organs — Auto-Intoxication — Dangers of *Human Miasma.*

I.

WORK and heat do not exist independently in the animal machine. Now work goes on incessantly in us. During repose, and even during sleep, the internal organs are never inactive. The heart beats and expends considerable force in propelling the blood through the vessels; the chest rises and falls in respiration; the stomach and intestines perform peristaltic movements to pass the food-stuffs onwards.

The work of the human body continues then night and day; it only ceases with death, and at this moment also is extinguished the fire of animal heat.

Life is impossible without heat.

The heat from which the human machine draws the force necessary for its existence is derived from combustion which goes on inside the organism. In chemistry, the term *combustion* is applied to the combination of two or more bodies with each other, accompanied by the production of light and heat.

It is evidently a considerable extension of the meaning of the word combustion, and a somewhat figurative use, to apply it to the phenomena which cause the heating of the body during work. The chemical combination going on in us is not accompanied by the production of light. The phenomena which produce vital heat resemble fermentation rather than combustion properly so called. For example, they rather resemble the changes which go on in a damp hay-stack, than the phenomena we observe in a burning fire.

The sources of vital heat are chemical combinations of infinite variety.

It has been long considered that all the combustions in the system are due to the action of oxygen upon the living tissue. At the present time we fully admit the capital importance of oxygen in the chemical combinations which are the source of work ; but we recognize that other bodies take a certain share in the vital actions capable of producing heat ; hydrogen for instance.

Further, many chemical reactions which produce heat are accomplished by the simple splitting up of a substance into two others which entered into its composition. In other cases the combination is limited to the hydration of a substance which absorbs some molecules of water, or to its dehydration by loss of these molecules.*

The problem of vital combustion has then become very complicated of late ; we may say that it is somewhat perplexed, and that it is difficult to give in a few words a clear and concise summary of it. It is a chapter of physiology which is being re-written, and we cannot at this moment formulate our conclusions.

All that we are able to say is, that the unceasing work of the internal organs, which constitutes life, is the transformation of one force, heat. This force is itself derived from the chemical reactions which set free the heat contained in a latent condition in the molecules of which the organs of the body are made up, and in the foods which serve to nourish the organs.

The chemical reactions which set free and render

* *Lambling.* Sources of Heat and Force.

sensible by the thermometer the latent heat-energy, consist in the expenditure of two classes of substances: the alimentary substances introduced into the blood by digestion, and the organic substances which form part of our bodies, and which are removed to give place to new substances obtained from the food.

Certain products of digestion which have only just entered the blood are made use of to undergo the chemical combinations which produce heat, and after their chemical constitution has been changed by this combustion, they are expelled from the body without ever having, in a stable manner, become part of our system. They only pass through the system, being changed in the process.

On the day following too hearty a meal, there may be seen at the bottom of the chamber-pot, a yellowish white, or a brick-red deposit. This is made up of very different chemical substances, certainly, from those which were absorbed the night before, but it results from the transformation of the alimentary substances into new products which have been rejected from the system because they were present in excess, and the organs of the body could make no profitable use of them. Here we have a case in which the food-stuffs have furnished the elements for vital combustions.

In other circumstances, however, the combustions take place at the expense of elements which form an integral part of the body. A man who performs violent muscular work after a two days' fast, cannot furnish the quantity of heat needed by this work, from the products of digestion. But the urine of this man, when the work is over, will deposit a sediment similar in appearance and constitution to that from the urine of the man who has dined too freely. In this case the chemical combinations, which have given rise to the heat, and at the same time to the product deposited by the urine, have not been made at the expense of substances introduced into the system from without, but at the expense of the organism itself, and of the tissues which form it.

Since the system is entirely built up by materials drawn from the daily food, it is not surprising that there are in it substances analogous in chemical composition to those in the food, and that the elements of the body can supplement, in case of fast, the elements usually supplied by the food.

Hence the chemical sources of heat, and consequently the forces from which work proceeds, may arise either from the food, or from the molecules composing the body.

The animal machine is so constructed as to be able to perform its functions for a long period without external assistance. We see the proof of this every day, in the diseases which keep the patient on a very restricted diet for some weeks. We have recently had a striking demonstration from the experiments to which two eccentric individuals* submitted themselves, one of whom was able to abstain from food for 50 days, and in spite of this to perform bodily exercise.

The body is then able to furnish the elements of the chemical combinations which produce heat and muscular work without the aid of food. But if these elements were furnished at the expense of organs which are the essential parts of the machinery we can understand that the latter would very quickly deteriorate and be worn out. There must then be in the body materials which act as a go-between for the food and the organs. These materials, known as *reserves*, are substances, the dissimilation of which cannot compromise the regular performance of the organic functions. The reserve materials are the result of a kind of tribute levied every day on the food, and stored up in various parts of the body as in a savings-bank, on which the system can draw when it has need.

The reserve materials are constituted anatomically for the most part of fat; but fat is not the only tissue of the body used for combustion. There are other substances, for instance a variety of sugar known as *inosit*, which is found in great abundance in muscular tissue, and the combustion of which is one of the sources of

* *Succi* and *Merlatti.*

the heat of work. There are undoubtedly, in muscular tissue, nitrogenous products which play the part of reserve materials, for, according to our own observations which are recorded in the second part of this book, persons who ordinarily do little work, and who in consequence are provided with an abundance of reserve materials, show in their urines after unusual exertion, a great quantity of nitrogenous excretion. Their urine is similar to that of persons whose diet is too rich in flesh and consequently in proteids.

But food and the reserve materials are not the only elements furnished to the chemical combinations which we call combustion. In certain cases, food being cut off, and the reserve materials being exhausted, vital heat is maintained and life persists. Still more even, violent muscular work may be done in such conditions, and consequently intense combustions be carried on. These combustions are then made at the expense of the essential tissues of life, of those which compose the intimate woof of the organs. In these cases the machine still performs its functions, but it is at the expense of the essential elements of its composition. It uses itself up.

Such are, from the physiological point of view, the three sources from which the vital work of the internal organs and the muscular work of external life, which is but the exaggeration of the other, draw the elements of which the chemical combinations give rise to the expenditure of heat.

II.

From the chemical stand-point, what are the substances used in these combustions? This is a question which in a few years has been answered in several different ways and to which a satisfactory and definite answer has not yet been given.

It would be uninteresting to follow in all its successive developments the theory of vital combustions, and it will be better for us to give a summary of the actual state of the science.

It is admitted by the most recent writers on the question, that the combustion of non-nitrogenous substances, such as fats and sugars, is the almost exclusive source of muscular work. The theory is now in great disfavour that the muscle burns up its own substance in contracting to perform work, and liberates a great quantity of nitrogenous products. Liebig's experiments showed an increase in the elimination of urea after work; more recent observations have seemed to upset those of Liebig, and it is believed that the elimination of urea is not increased, and may even be diminished by muscular work. It cannot, however, be denied that a part of the expense of the combustions of work falls on the muscle itself, for its chemical composition is profoundly modified by muscular work; but the modification is attributed to changes of the non-nitrogenous substances which enter into the composition of the muscle-plasma, to *glycogen*, for instance.

Glycogen is a hydrocarbon which can be transformed into sugar, and can play a similar part in the chemical actions of work to starches and fats. But we must allow that in certain cases the nitrogenous substances of muscle are made use of for the combustions of work. The proofs of this are as follows, The first is that muscle diminishes in size in certain forms of muscular exhaustion, which we shall study later on in the chapter on *Fatigue*. The other, which is more direct, is drawn from our own observations on the composition of urines after work, which show in an irrefutable manner an increase in the elimination of uric acid after muscular exercise. We must then admit that the nitrogenous as well as the non-nitrogenous tissues can be made use of in the combustions of work. And we shall show in the chapter on *Stiffness*, that the reserve materials destined for the supply of these combustions are not only fats, but must of necessity also be nitrogenous substances, because the nitrogenous waste-products in urine are especially abundant in individuals who are not accustomed to use their muscles, and who consequently have not used up their reserve materials.

Thus, the heat needed for work results from chemical changes which are accompanied by the evolution of heat, and which are undergone by certain nitrogenous or non-nitrogenous elements forming an integral part of the system or introduced as food. These chemical combinations are mostly, but not exclusively, *oxidations*, that is, combinations with oxygen. The oxygen is introduced into the system by respiration. It is fixed and retained there so as to form a provision which will be always ready for the chemical combinations which are rendered necessary by the different functions of life. Although oxidations are not the only chemical actions of work, they are the chief ones, and oxygen is almost always made use of in the chemical combinations which produce heat.

The oxidised compounds formed during combustion, can be placed in two categories: the products of complete and of incomplete oxidation. Carbonic acid and water are the final stages of all the complete oxidations of hydrocarbon substances, and urea is the last stage of complete oxidation of nitrogenous substances.

Besides these substances there are other products formed at the expense of the same tissues with which a smaller quantity of oxygen is combined, and which are consequently the result of a less advanced oxidation or of an incomplete combustion.

In a furnace, the oxygen of the air, which combines with the blocks of wood in order to burn them, gives rise to products of incomplete combustion which are smoke and soot. These products have not been carried to the furthest stage of oxidation or combustion, for we can submit them afresh to the action of the oxygen of the airi n smoke-consuming apparatus in order to burn them more completely.

Similarly uric acid, for example, is a product of incomplete combustion, and can undergo a further degree of oxidation. If we inject a quantity of this substance into the blood of a living animal it is further oxidised and transformed into urea.

Uric acid is only one of the numerous organic products which result from incomplete oxidation, and which we call waste-products of combustion.

The combustions do not cause the complete disappearance of the tissues on which they feed ; they change them as does the flame of a fire the coal and wood it consumes. The burning wood gives rise to products of decomposition, the cinders and soot which are found in a burnt-out fire-place. Similarly the system after work contains the products of combustion—or as they have also been called, products of *dissimilation*, because they are no longer similar to the organic tissues of which they at one time formed a part.

III.

The products of dissimilation, the history of which is still sufficiently obscure, have one character in common, they are all injurious to life, and are rejected from the body as soon as they are formed, just as the cinders and smoke are removed from the fire.

These waste-products are dangerous to the system, and their presence in the blood becomes incompatible with health when there is any excess of them. There is no danger when there is only a moderate quantity, for then the system can quickly relieve itself of them by means of the organs specially charged with their elimination.

The lungs, the kidneys, the skin, and the intestine have among their functions that of eliminating from the blood whatever harmful or useless substances are present in it, whether they have been formed there or introduced into the blood from without.

These four organs are specially charged with the removal from the system of products which are formed everywhere as a result of combustions. The lungs remove carbonic acid, the kidneys urea, the skin lactic acid, etc. All these are the waste products of vital combustions. To these three well-known substances it is necessary to add a great many more, of which we know very little. Fresh researches are daily throwing new light on the functions of excretion, and show the capital importance of the part they play in the system.

It is no part of the purpose of this book to make a complete study of the products of excretion, but it is indispensable for the exposition of our views on the results of work and of fatigue to insist on one point in their history, on the dangers to which the system is exposed when they are accidentally retained in the blood, or when their elimination is incomplete.

Long before chemical analysis had proved the existence of poisonous principles in the waste-products of dissimilation, many clinical facts had indicated that these principles must exist. We have long known that the slightest hitch in the functions of an excretory organ immediately produces a series of accidents due to the retention in the blood of the waste-products which this organ ought to eliminate.

The function, the suspension of which causes the most grave and immediate danger, is that of respiration. Should the lung become functionless for a few minutes, death occurs from asphyxia, which is a poisoning of the blood by carbonic acid. Carbonic acid is the best known and the most abundant of the products of combustion: it results from the combustion of the carbon contained in all the living tissues. The formation of this gas in the blood is continuous, and the system always contains large quantities of it, but the quantity compatible with life is never exceeded, because the lungs eliminate the surplus as fast as it is formed. If the respiratory function is suspended, the poisonous gas accumulates quickly to an extent incompatible with life.

Carbonic acid is not the only poisonous product eliminated by the respiratory apparatus. The air which is driven from the lung in expiration is saturated with aqueous vapour, and this vapour carries with it a product which has not been isolated, and which is formed in very small quantity, but it reveals itself by its unpleasant qualities and its pestilential smell. This product has been called *miasma*. If we go in the morning into a dormitory in which many persons have passed the night, we are struck by an unbearably fetid smell, which resembles no other. It is the smell of the miasma exhaled from the lungs of the persons who have slept there. The air is vitiated by it.

The skin eliminates the sweat, which contains 99 per cent. of water, holding in solution salts, chlorides, acids, such as lactic acid and a special nitrogenous acid called *sudoric acid*. Urea has also been found in it.

Besides the liquid part of the cutaneous excretion, there is a gaseous part, which is no less important. Various volatile acids and a considerable quantity of carbonic acid are exhaled by the skin. But the products of cutaneous excretion which interest us most, those which best establish the poisonous power of the waste-products of nutrition, are at present little known from the stand-point of chemical analysis, and only manifest their existence by the effect produced on the system when their elimination is prevented. Their poisonous properties are shown by the following experiment:—

Take a large dog, shave off all its hair, and cover its skin with a coat of impermeable varnish or with collodion, in such a manner that no liquid or gaseous product can be thrown off from the animal's skin. In this manner we imprison in the system of the dog all the products which are usually eliminated by the skin. At the end of eight hours, on an average, the animal dies.

Sokolow, the Russian physiologist, who performed the experiment we have quoted, attributes the death of the varnished animal to poisoning by the principles which are no longer eliminated.

The kidneys eliminate a great quantity of the products of organic decomposition. It would take too long to enumerate them all. The chief are the residues of the combustion of nitrogenous substances: urea, uric acid, and its salts, the urates. But urine, like all excretions, contains also a great number of unknown products. In any case no one will dispute the importance of a rapid removal of the products which are carried away by the urinary secretion.

When the functions of the kidney are abolished by disease altering the structure of that organ, urine has no longer the same chemical composition, and in the end does not carry off the substances which are usually eliminated in it. Their composition is changed and simplified ; they contain, so to speak, little but water. Urea and the other waste-products of vital combustions, being no longer eliminated in the ordinary manner, accumulate in the blood, and can be detected there by ehemical analysis. Urinary poisoning, or uræmia, soon follows, and quickly ends in death.

The remarkable experiments of Bouchard have established the poisonous properties of urine, and have shown that the injection of this liquid into the veins of a healthy animal can cause its death in a short time.*

The intestine is one of the eliminating organs which must reject the largest quantity of the waste-products of combustion. But being already mixed with a large quantity of food-residues, and also receiving the secretions of the liver, the pancreas, and many other glands, it is very difficult to discover in this mixture how much is derived from the products of dissimilation. A simple observation shows that the intestine receives its share of the eliminated waste-products of combustion. When there is increased combustion on account of excessive muscular activity, there are always more evacuations, and the stools are more liquid. The intestine seems to have been submitted to the action of certain laxative materials, and these materials, since they are not derived from any change of diet, can only come from the organism itself. The products of dissimilation, increased in quantity by exercise, are eliminated by the intestine, and stimulate its contraction, causing more frequent stools.

The functions of the intestine, like those of the lungs, the kidneys, and the skin, cannot be abolished without grave consequences. When the fæcal matters remain too long in the alimentary canal, owing to an obstructive

* *Bouchard*, les Auto-intoxications.

lesion, there ensues a series of accidents which may be called stercoral poisoning, and which are due as much to the reabsorption of the products of dissimilation, as to the putrid emanations from the alimentary residue.

The four organs, the excretory functions of which we have shortly studied, are not the only ones charged with the elimination of products of which the body desires to rid itself. All the glands can, at a given time, participate in this function, which might be called the cleansing of the body. The presence of poisonous substances in certain secretions has been discovered by accident. By injecting into the carotid artery of a small animal the saliva of a fasting man, grave consequences have sometimes been produced. This shows that the saliva, like the urine, can assist in the elimination of products of dissassimilation which have been demonstrated to be poisonous.

If we seek to summarise the conclusions drawn from the facts studied in this chapter, we can say that the work of the muscles, like that of the other organs, is accompanied by the production of heat, which results from chemical actions which we may compare with combustions. The living tissues, at the expense of which these combustions have occurred, have changed in their chemical composition, and become noxious to life, and must be rejected from the body under diverse forms and by special organs.

But the products of combustion are not injurious only to the organism in which they are accidentally retained. If absorbed by other individuals, they can produce in them the same bad effects.

We said a few words about the miasma exhaled by the lungs and the skin. These products are present in almost infinitesimal quantity, but possess most powerfully poisonous properties. If several persons are together in a confined place, the air of the place is quickly infected ; but the disagreeable odour is not all ; the air is vitiated and dangerous to breathe. Hence the evil results of deficient ventilation.

We could quote numerous facts showing the serious nature of the accidents resulting from the absorption of this product, the exact nature of which is unknown, but which is extremely poisonous—the human miasma.

Very serious symptoms, and even fatal results have often been observed in persons who have spent a long time in a confined space. These effects of "stuffy air" are not due to asphyxia, but to a direct poisoning by the human miasma.

Brown-Sequard and D'Arsonval, in a communication made to the Academy of Sciences, on January 16th, 1888, showed that human breath contains a most active poison, an alkaloid capable of killing in two hours an animal into which it is injected.

PART II.

FATIGUE.

MUSCULAR FATIGUE — BREATHLESSNESS — STIFFNESS — OVERWORK—EXHAUSTION—THEORY OF FATIGUE—REST.

CHAPTER I.

LOCAL FATIGUE.

Experimental Fatigue—Absolute and Relative Fatigue—Fatigue in Ordinary Conditions of Work; it is always Relative—Examples of Relative and of Absolute Fatigue—Causes of Sensation of Fatigue—Causes of Muscular Powerlessness—Influence of Waste-Products of Combustion; Transmission of Fatigue to Muscles which have not been Working—Use of Fatigue—Part played by the Brain in Fatigue. Unconscious Movements cause less Fatigue than Voluntary Movements; Practical consequences.

I.

If we isolate one of the muscles of a living animal and pass an electric current through it, we see that it contracts as long as the passage of the current lasts. But if the experiment is prolonged, the muscle after a time contracts more feebly; a little later there comes a stage when the muscle does not contract at all: it is *fatigued*.

Fatigue is at first only relative, and the muscle will contract afresh if stimulated by a current stronger than the first. But there comes a time when fatigue is absolute, that is to say the muscle has lost the property of contracting under the influence of the most powerful electric stimuli.

A human muscle never reaches, in consequence of work, the condition of absolute fatigue, of complete powerlessness, which we observe in animals under experiment. What prevents this is the painful sensation experienced by the man before the time when the muscle becomes absolutely incapable of action. Under the influence of the suffering which the contraction causes, the work is stopped and the muscle *rests.* Here is the capital difference between true absolute fatigue, such as can be produced by experiment on animals, and the fatigue observed clinically in a man at work.

That which dominates in the fatigue of a man performing any exercise is the *subjective* element, the painful sensation which prevents him from continuing his work until the muscle becomes absolutely exhausted. We can represent the effort made by a powerful man to carry his exercise to the last possible limits, as a combat between the will which commands and the sensibility which rebels.

The most energetic will is unable to use up the contractile power of a muscle as completely as do mechanical or physical agents. When a fatigued man ceases the effort which he has long bèen making, we say that his muscles are exhausted: this is not yet so. The proof of this is as follows:—

We know that one of the most tiring attitudes to assume is that which consists in holding the arm horizontally outstretched. The deltoid muscle in this case does most of the work. There are few men vigorous enough to be able to hold out an arm in this manner for more than five or six minutes. At the end of this time the deltoid can act no longer and the arm drops. But the muscle is not exhausted: its fibres still possess a great contractile force, and this is proved by the fact that certain agents, such as electricity, can bring into play this motor force over which the will has no longer any action. If, in a man who has been holding his arm outstretched, we wait till the sensation of fatigue becomes intolerable, and if, at the moment when the man declares he has used up all his power, and is about to let his arm fall, we apply a strong electric stimulus to the deltoid muscle, the fatigue seems to vanish, and the arm remains outstretched; the muscle had not yet lost its contractile power.

What is the cause of this local fatigue? A double answer is needed to this question; we must say why the work renders muscular contraction painful in a tired limb, and why also the muscle which has been long at work finally loses for a time the power of contraction.

Often repeated muscular contraction becomes painful mechanically, owing to the repeated shocks and disturbances occasioned in the muscle itself and in the neighbouring tissues. Every mechanical action submitting the muscular masses of the body to compressions, movements and shocks similar to those produced by work can bring about, just like work, a sensation of fatigue. What we call "massage" is a series of manipulations to which muscles are submitted. After the action exercised on the muscles by the hand of the masseur, sensations of local fatigue are experienced, similar to those produced by muscular work. We must then conclude that the sensation of pain in a region which has worked, is due to the same cause as that in a region which has undergone massage, that is to a mechanical action.

And this action is easily explained. The muscle is traversed by a number of sensory nerve-filaments. These little twigs are rubbed and twisted by the movement of the muscular fibres which swell and harden during the energetic contraction of work. The muscular fibres are themselves pulled about, and the tendons, the aponeuroses of insertion, and the synovial membranes undergo repeated friction. There results, then, from very violent muscular work a genuine traumatism in the whole region which is the seat of the work, and the consequences of this traumatism may be the same as those due to external causes, as for instance, contusions. Frequently, as we shall see in speaking of the *accidents of work*, ruptures, inflammations, and even abscesses may result from excessive work.

But apart from these causes of discomfort, the muscle at work undergoes others less known and more interesting. In the muscular fibre, modifications of nutrition take place, due to the combustions accompanying contraction. Every muscle in contracting becomes heated, and this increase of temperature is due to the chemical combinations of which we have spoken in the chapter on *Combustions.* The chemical actions which we call combustions, profoundly alter the structure of the tissues at the expense of which they occur, and from this change result new products which stay in the muscle for a certain time.

Now these products exercise on muscle a peculiar action which paralyses it and renders its contraction impossible. If we submit the muscles of a frog to the action of a powerful electric stimulus, and prolong this action until fatigue is complete, that is, till the limbs of the animal remain motionless under the most powerful stimulation, we shall have in the fatigued muscles the elements necessary for a most curious experiment. Their substance rubbed in a mortar, and made into a fine soup, contains a principle capable of producing in healthy muscle at rest the fatigue which had exhausted the first muscles. If we inject into a second frog this extract of fatigued muscles, we bring about in this animal all the phenomena of fatigue, and its limbs will fail to respond to electric stimuli.

Thus there are developed in the muscles, in the very act of work, certain products of dissimilation which have the power of doing away with the contractile force of the muscle-fibres. If these products are not formed in excessive quantity, they are rapidly carried off by the blood-current, and, if not renewed, the nutritive disturbances produced by work are promptly repaired. If, however, the work is continued too long, these products accumulate in the muscle in excessive quantity. They can then, for a time, abolish its contractility, and may further produce serious general consequences, of which we shall speak in the chapter on *Overwork.*

We must then conclude that the pain felt in a muscle which has been contracting for a long time, results from a number of small lesions, stretchings and rubbings, of the sensitive parts of the region which has been working, and that the absolute powerlessness which we notice is due to a nutritive disturbance, to the formation within the muscular tissue of products of dissimilation, the contact of which seems to paralyse the contractile element.

We must also say that the powerlessness of a fatigued muscle is caused in part indirectly by discomfort, for to make it contract necessitates a painful effort of the nervous centres.

The phenomena we observe in the laboratory on stimulating a fatigued muscle by means of electricity are a faithful imitation of those which take place in the system when the will endeavours to put in action a limb which has become powerless after excessive work. Just as the muscle of a frog which has been fatigued by excessive discharges needs for its further contraction an increase in the strength of the stimulating current, so in the living organism an increase of the voluntary stimulus is necessary to throw an exhausted arm into action, and to obtain from it energetic movements. Now the will manifests its effort by a disturbance of the grey matter of the brain, and when this disturbance is excessive it becomes painful.

Local fatigue is then at once a muscular, and a cerebral phenomenon.

The fatigued muscle is rendered painful by the friction to which it is subjected, and paralysed in its contractile powers by the contact of the chemical substances which result from the combustions of work. The brain feels the effects of fatigue by the more violent disturbance which the voluntary stimulus produces in its cells, a stimulus which must become more intense in proportion as the muscle responds less readily.

During muscular exercise, the sensation of fatigue is sometimes out of proportion to the lesion which the muscular fibres undergo, and to the modifications of nutrition produced in it by the work it has performed. In this case the brain has become exhausted before the muscle. The organ of will seems to have lost part of its stimulating power, and experiences an exaggerated sensation of fatigue. The man has no longer an exact idea of the energy which his muscles still possess. This is what we observe in all cases in which a depressing emotion has exercised a debilitating influence on the nerve centres.

In the retreat after a battle, the soldiers, as much demoralised as worn out, drag themselves painfully along. The state of depression into which the defeat has thrown them makes them incapable of resisting the uneasy sensations which at another time they would hardly have noticed. Their swollen feet, their wearied legs, their stiff backs prevent them from moving. Groups of stragglers loiter along: every one is dropping with fatigue. All at once there is a cry, "The enemy is upon us!" Immediately they all find their legs again. The stiff backs are straightened, the legs are stretched, the limping feet are vigorously planted on the ground, and those who could no longer even walk, are seen to run. Their muscles had not lost the power of action, but the will was no longer a sufficient stimulus to set them in action. A more powerful one was needed: Fear.

In some cases we can observe converse phenomena. A violent stimulation of the nervous centres may, after a fashion, galvanise the muscles, as would a very powerful electric stimulus. The animal can then force from its muscles all the contractile power they possess, and continue the work till the muscle is completely exhausted, till fatigue is *absolute*. It is thus when a pressing danger obliges a man or an animal to continue muscular effort in spite of the pain which it causes. A hunted animal runs till its legs can no longer carry it; when it drops, its muscles are *fatigued*, in the physiological sense of the word, and the most powerful stimuli cannot cause them to contract. But the work necessary to produce complete muscular powerlessness has at the same time produced in the muscles lesions so profound, and such grave troubles in the general system, that the animal hardly ever recovers from its fatigue.

II.

We learn, from the examples quoted above, the essential difference between *subjective* fatigue, that which is characterised by a sensation, and *objective* fatigue, which consists in a particular state of the muscles.

Objective, or absolute fatigue, is due to a profound alteration in the chemical composition of the muscles, an alteration which causes these organs to lose the power of performing their ordinary function.

Subjective fatigue is essentially relative and variable, as are all sensory impressions. It consists in a feeling of discomfort, or a slight painful sensation in muscle, which results from a very superficial modification of its structure.

In the ordinary phenomena of muscular exercise, fatigue is never absolute, and the cases in which a man really exhausts all the contractile force of his muscles are very rare. The sensation of fatigue prevents a man from having an exact idea of the energy which his muscular fibres still possess, and induces repose long before all the force of the motor organs has been expended. Similarly the sensation of hunger warns us that the body needs food long before the system is enfeebled for lack of nourishment.

We may say that the sensation of fatigue puts us on guard against a danger. It would in fact be dangerous to continue working until the muscles were completely exhausted, until the moment when they became incapable of contracting, for these organs would then have undergone such profound disturbances of nutrition as to endanger the entire organism, as occurs in the hunted animal.

Fatigue is then, in the ordinary actions of life, a kind of regulator, warning us that we are exceeding the limits of useful exercise, and that work will soon become dangerous.

Numerous physiological phenomena show us that the sensation of fatigue has its seat rather in the nerve-centres than in the muscles. Whenever muscular work is performed without the brain taking part in it, we notice that fatigue is much more slowly produced; while it is more intensely manifested the more vigorously the cerebral faculties are associated in the performance of the action.

Many movements are involuntary and unconscious; the movements of organic life, the heart-beat, the respiratory movements. None of these movements, which are performed without the intervention of the brain, and independently of the will, ever determine the sensation of fatigue.

At each contraction the heart exercises a force capable of raising through a height of one centimetre a weight of forty kilogrammes, and it contracts sixty times per minute. Which of our limbs could carry on such a labour for a quarter of an hour? We may say the same of the muscles which bring about the respiratory movements. They contract sixteen times per minute and never rest; they work incessantly from birth till death, and never become fatigued.

The muscles ordinarily under the control of the will have the same immunity from fatigue when their contraction is involuntary. In hysterical contracture, in catalepsy, in hypnotism, the patient, whose will is not in action, easily supports the most fatiguing positions without being fatigued. In chorea, or St. Vitus' dance, we see the patients making violent movements without intermission from morning till night. A man who endeavoured to perform the same movements voluntarily would have to stop to rest in a very short time. But these patients do not complain of the sensation of fatigue.

Thus the same muscular work which produces fatigue, when it is voluntary, no longer produces it when it is done without the intervention of the will, that is, when the brain does not associate in the performance of the muscular action.

The brain then, is most probably the seat of that sensation which causes cessation of work before the muscles are really fatigued. In voluntary movements, the more intimate the association of the brain with the muscular action, the more intense the sensation of fatigue. An exercise which is accompanied by a considerable tension of the will is more fatiguing than one performed independently of the will. Sometimes work which needs an insignificant expenditure of force, causes very prompt lassitude when it is executed with a sustained attention, that is to say when the will is not relaxed for an instant.

A man taking riding-lessons becomes much more tired in the narrow limits of the riding-school than he would by riding a long distance at a trot. In the first case the will must preside with a vigilant care over all the actions of the horseman's legs, and over the reins. In the second case, the body, accustomed to the horse's paces, automatically accommodates itself to the movements of trotting, and the brain takes no part in the exercise.

Few things vary as much as the susceptibility of different persons to fatigue. Very nervous and very irritable individuals feel sometimes too keenly the painful sensations which accompany muscular work, and they are then placed in this dilemma: whether to stop when fatigue is first felt, and do less exercise than they really require, or to resist fatigue and expose themselves to the nervous reaction which follows, in such persons, any considerable pain. Nervous hyperexcitability often results from the struggle of an enfeebled man against the discomfort which work causes him, and compels the doctor to forbid exercise to such a patient, to whom it would be most valuable if it could be endured.

In these cases we can always manage to make exercise supportable, but it is necessary carefully to consider the form under which it will have the best chance of being borne, that is to say the form which will cause least fatigue.

We can here only indicate broadly how to proceed in such cases, in which medication by exercise needs much tact, and a profound study of each exercise performed. Here we shall only formulate this law:

The muscular work being equal, the sensation of fatigue is the more intense, the more active the intervention of the cerebral faculties demanded by the exercise.

Consequently, in dealing with very nervous persons, it will be necessary to employ exercises which do not need a sustained attention, those of which the movements are easy, and as much as possible, automatic; walking, foı instance.

CHAPTER II.

BREATHLESSNESS.

A Hard Run—Exercises which cause Loss of Breath; **Trotting and Galloping**; Going Upstairs—Law of Breathlessness—Respiratory Need; Conditions under which it Increases and Diminishes—Carbonic Acid; its Production Increases with Muscular Activity; it Diminishes during Repose—The Sleep of the Marmot—Explanation of the Law of Breathlessness—Why we lose Breath in Running—Why the Horse *Gallops with its Lungs*—Why Exercises of the Legs cause more Loss of Breath than those of the Arms—The *Coefficient* of Breathlessness—The Horse which exceeds its Paces—Breathlessness is an Auto-Intoxication by Carbonic Acid—Analogy with Asphyxia—Impossibility of Fighting against Breathlessness.

HAVE you ever found yourself within sight of the station and been afraid of missing the train? You have a quarter of a mile to traverse, and you see from your watch that you have only two minutes. You will have to run, and for years you have been accustomed to the measured pace of the man who walks when he has plenty of time and takes a cab when he has not. But you want to catch that train, and plucking up courage you set off as hard as you can run.

Your legs are strong and it does not hurt them when you run. However, after a few seconds, a peculiar distress seizes you. Your breathing is embarrassed, a weight seems to press you down, and a bar to be fixed on your chest. Your respiratory movements become jerky and irregular. With each step distress increases and becomes more general. Your temples throb violently, an insupportable heat rises to your brain, an iron band is tied round your forehead. Then there is a singing in your ears, your sight is disturbed, and you have but a confused idea of the objects you pass, and of the people who turn to stare at your pale and dishevelled figure.

You reach your goal. As the train whistles you sink exhausted on the cushions of your compartment. There, in spite of the satisfaction of having caught your train, and the solace of being seated, your distress continues. Still for some minutes you are out of breath, and the hurried movements of your chest make you resemble a man seized with a violent attack of asthma.

This is what we call "*being winded.*"

We are seldom astonished by things which we see every day, and it seems natural to every one that a man should be out of breath when he has been running. But if we think about the matter, there is something surprising in the phenomenon of breathlessness while running: when we run the legs do the work and the lungs become fatigued.

I.

No methodical exposition and rational explanation of *breathlessness* have hitherto been given. This form of fatigue has not as yet been the subject of any monograph; it is not described in any great dictionary of medicine nor in any physiological text-book.

There is however, no phenomenon more common and more frequently observed than breathlessness; there is none more interesting from the point of view of the hygienic and therapeutical results of muscular exercise.

Breathlessness is a feeling of distress which is produced during violent exercise or intense muscular work, and it is characterised by an exaggeration of the respiratory need, and by profound disturbance in the functions of the respiratory organs. This state is merely a peculiar form of dyspnœa and presents the general phenomena due to deficient aeration of the blood. But it differs from the respiratory troubles which we notice in morbid conditions by certain special signs which we shall point out, and above all in the conditions in which it is produced and in the mechanism of its production.

If we try to determine in what conditions breathlessness is produced during work, we are struck first by the fact that certain exercises, certain movements, seem to have the privilege of influencing more promptly than others, the respiratory functions.

In certain muscular actions fatigue takes the form of breathlessness, and respiratory distress forces the individual to stop working long before the muscles are fatigued. A man running, or rapidly going up-stairs, is forced to stop, not to rest his legs, but to *take breath*.

In other exercises, on the other hand, the muscles are fatigued and refuse to go on working long before breathlessness occurs. Going along a hanging ladder by the hands only, dumb-bell exercise, holding out weights at arms' length, are movements which quickly fatigue the limbs without causing any marked disturbance in the respiratory functions. When we are obliged to stop these exercises it is not because we are short of breath, but because our muscular force is expended.

In animals it has been noticed that certain paces, certain forms of work, more particularly produce breathlessness, while others rather produce fatigue of the limbs.

Trainers say, "A horse trots with its legs and gallops with its lungs." This phrase expresses well, with its humorous figure, the importance of pace in the production of breathlessness. Why is a horse more out of breath after a gallop than after a trot? Our first idea is to attribute the more prompt breathlessness to greater swiftness. But we must not confound *pace* with *speed*. The pace of galloping is not incompatible with very little speed. We can slow down the gallop of a horse till it falls behind another horse which is trotting. There are animals so awkward that their gallop is as slow as a walk. Now, however slow a gallop may be, it will more quickly make a horse out of breath than an equally rapid trot.

Breathlessness is not then produced under the same conditions as local muscular fatigue, and certain exercises seem to have the privilege of influencing respiration.

When we try to find the explanation of this fact, we naturally ask at the outset whether the exercises which cause loss of breath have not a direct influence on the organs which execute the respiratory movements, whether they do not require, for example, that the muscles of the chest and back should be involved, the contraction of these muscles interfering with the action of the ribs. But this hypothesis is discredited at the first glance, for the exercises which in man cause most breathlessness are not those which demand work from the upper limbs, and consequently the direct concurrence of the thoracic muscles. Running, leaping, going up a steep ascent, are, of all known exercises, those which most quickly cause loss of breath, and they are executed by the legs, the muscles of which are not attached above the pelvis, and have consequently no direct action on the thorax.

We believe it to be impossible to explain the tendency of this or that muscular exercise to produce breathlessness, if we direct our attention solely to the peculiarities of movement and attitude which these exercises render necessary.

Certain authors, who have incidentally referred to breathlessness, seem to attribute this form of fatigue to the very mechanism of the exercises which cause it, and to the direct disturbance which these exercises produce in the respiratory movements.

"Breathlessness in running occurs because the runner, unable to make the deep and prolonged *inspirations* necessary for the continuance of his efforts, endeavours to make up for this by frequency of respiratory movements, so that he can fix as firmly as possible his vertebral column and his thorax." *

We quote this opinion to show how, as a rule, authors who have written about muscular exercise have made what seemed to them reasonable deductions, rather than direct observation of facts. In fact, Michel Lévy's view is based upon an error of observation which anyone can verify personally if he is not afraid to run for a minute or two. In a man running it is not *inspiration* which is difficult, it is *expiration*. In this exercise we experience

* *Michel Lévy*. Traité d'hygiène.

no difficulty in getting air into the chest: it is, on the contrary, the exit of air which is difficult and incomplete. According to observations which we have made on ourselves and on a friend who willingly lent himself to this study, inspiration is free, easy, deep, and three times as long as expiration. The latter, on the other hand, is short, insufficient, and leaves the impression of an unsatisfied want.

Moreover, the very peculiar rhythm of respiration in a man running is not due to the mechanism of the exercise, for we have the same rhythm in all exercises, of whatever nature, which produce breathlessness, and, moreover, it always persists a long time after the exercise has been discontinued. We cannot then say that this mode of respiration is due to muscular contractions, or to forced attitudes, for we still observe it when all the muscles are relaxed and the body is in the attitude of repose.

The derangement of respiration in all the exercises which produce breathlessness is not the prime cause of dyspnœa; on the contrary, it is the effect of it. The explanation of breathlessness, based on the mechanical hindrance to the respiratory movements, is far from being applicable to all the exercises which produce it, and to all the circumstances of breathlessness.

If we look for a condition common to all the muscular actions said to be capable of rapidly producing respiratory troubles, we are struck by the fact that all necessitate a very great expenditure of force in a very short period of time. This we believe to be the essential condition of breathlessness.

There are other conditions favouring the occurrence of respiratory distress during an exercise, such as a momentary suspension of respiration, as we see in the phenomenon of *effort*, or a forcing of the thoracic muscles to associate in an exercise in a way to prevent them from fulfilling their respiratory function. But these conditions have merely a passing influence, and contribute but little to the production of breathlessness. The causes capable of mechanically hindering respiration intervene as accessory factors, as a complication capable of accelerating the onset and of aggravating breathlessness; but they alone cannot induce a prolonged and persistent hindrance to respiration, nor unless they are associated with muscular actions needing a great deal of work.

To be convinced of this, it is only necessary to imitate experimentally what occurs in certain muscular actions which cause suspension of respiration.

If we take a deep breath, and after closing the glottis, vigorously compress the air in the chest by contracting the expiratory muscles, we are placed in all the physiological conditions of *effort*. The face injected with blood, the veins of the neck standing out, the ribs strongly raised, the thorax motionless in the position of forced inspiration, give a complete picture of the phenomena presented by a man who is raising a load from the ground on to his shoulders. But the load, and the expenditure of muscular force which it renders necessary, are wanting. Hence, in spite of the complete suspension of respiration, breathlessness is not produced by a great number of simulated efforts, while it is always produced by a very small number of real efforts, accompanied by intense muscular work.

That which causes breathlessness after effort is the quantity of work done and not the particular attitude which this work demands, and the momentary interruption of respiration which results from it. It is because they have not analysed these two elements in a complex action that many authors have attributed the breathlessness produced by certain exercises to the momentary suspension of respiration during effort. Even complete suspension of respiration cannot, acting alone, produce the phenomena we observe in persons who are out of breath. It produces respiratory distress, which lasts as long as the function is suspended; but as soon as the movements become free again the distress ceases, and respiration immediately assumes its regular rhythm.

Breathlessness, on the contrary, lasts for a long time after the exercise is over, and this proves that it has a more profound and more lasting cause than a momentary arrest of the respiratory functions.

If we pass in review all the exercises which seem especially to produce breathlessness, and submit them to a careful analysis, we find everywhere a confirmation of the law which connects the sensation of great respiratory distress with the expenditure of a large amount of force in a short time.

Let us analyse one of the simplest actions, that of going upstairs. No work more rapidly causes breathlessness than this, but none causes greater expenditure of force.

Let us suppose that a man is going at a moderate pace up two flights a minute, so as to take two minutes in going up four flights of a height of 20 metres in all. Let him weigh 75 kilogrammes, and he will in two minutes have raised 75 kilogrammes, 20 metres, and thus have executed work of $75 \times 20 = 1{,}500$ kilogram-metres.

If we reduce to another form the total quantity of work expended in going up the stairs, we are astonished to see that if we were lifting weights, it would be necessary in order to do the same amount of work, to take successively 30 weights of 50 kilogrammes each, and place them on a table one metre from the ground, and this within two minutes.

It is evident that work such as this is very violent exercise, but to go up four flights of stairs is so common, that we do not think of asking how much force it needs. Similarly with all the exercises by which the body is raised, such as climbing a hill. In all these cases the human body, a considerable weight, has in going up an inclined plane, been displaced more or less in height, and this displacement needs a great expenditure of force.

Similarly if we study what passes in a man running:

At every step there is an instant when both feet are off the ground, and the body is in a sense launched through space, without being sustained by the legs, by reason of the muscular impulse which lifted it from the ground. This impulse, which represents an enormous amount of work, is renewed three or four times a second.

While walking, on the contrary, the body is supported by the feet and never leaves the ground. These details show clearly the great difference of work represented by the pace of walking and that of running.

Let us note that in running, breathlessness is due less to the swiftness than to the mode of progression, to the manner in which the body is moved. Swiftness of movement does not suffice to produce breathlessness unless combined with intensity of muscular effort. So we must not use the swiftness of an exercise to form a judgment of the amount of breathlessness it ought to produce.

It is possible, as we have said, to slow the gallop of a horse so as to render it less rapid than a long-stepping trot, but all the same we find that the animal becomes much more breathless galloping than trotting. This is because the gallop of the horse is a much *higher* pace than the trot, as the experiments of Marey have shown. The galloping horse raises its body to a greater height from the ground than a trotting horse, and consequently performs a greater quantity of mechanical work. It is because of this difference in the quantity of force expended that a trot of equal swiftness always makes the animal less breathless than a gallop.

It would be easy to multiply examples. Those we have given suffice to demonstrate that the true condition of breathlessness, that in which respiratory distress is produced for a considerable time, is the great expenditure of force rendered necessary by an exercise in a given time. Other things being equal, we can say :—

In every muscular exercise, the intensity of breathlessness is in direct ratio to the quantity of force expended in a given time.

Breathlessness is a general effect, a *resultant.* It is the effect of the total quantity of work performed by the muscles which concur in an exercise.

Muscular fatigue, on the other hand, is a local effect. It is in direct proportion to the share in the work taken by each muscle used in the exercise.

An amount of work too small to induce breathlessness can produce fatigue if the effort is performed by a small number of muscles, or by very weak muscular groups. If, on the contrary, the exercise is divided among a great number of muscles, or performed by very powerful muscular masses, the part of the work performed by each contractile fasciculus will be too small to induce local fatigue, while the sum represented by the work of each may be sufficient to induce breathlessness.

Breathlessness is a general form of fatigue. When we wish to obtain from muscular exercise its *general effects*, we must seek exercises which cause breathlessness, and not confine ourselves to those which cause fatigue. The effects of the latter are especially local.

Finally, in the *dosage* of muscular exercise, we can consider breathlessness as a kind of physiological measure indicating more surely than muscular fatigue the intensity of the work to which the organism has been submitted. When breathlessness has not been produced, we can say that the exercise has been moderate, or at least that it has been taken—if one may so express it—*in fractional doses.* Whenever, on the contrary, respiratory distress is promptly produced, we can affirm that a great quantity of work has been done in a short time, and consequently that the exercise has been taken *in large doses.*

Certain exercises which, at first sight, appear moderate, will be considered properly to be violent exercises, if we submit them to the above criterion.

Thus it is that a girl dancing on the tight-rope is really performing a more violent exercise than an oarsman rowing, or a gymnast on the trapeze.

Thus, to sum up, if certain exercises cause breathlessness more than others, this result is not due to special movements or to particular attitudes which they occasion. The quick advent of breathlessness is not due to the contraction of certain muscles, to the displacement of certain bony levers, to the mechanical disturbance which certain organs undergo during exercise: it is due to the excessive expenditure of force which the exercise necessitates.

It was important clearly to establish the conditions under which breathlessness is produced, for from these conditions we are about to deduce the real cause of breathlessness.

II.

When a breathless man seeks to study himself, and to analyse the tumultuous sensations he experiences, he finds himself much embarrassed exactly to characterise his distress, and accurately to localise it in this or that part of his body. One impression, however, dominates all the others, and sums them up aptly enough: it is the feeling of an increased respiratory need, which he is unable to satisfy.

This increase of the respiratory need is the fundamental character of breathlessness.

In what does respiratory need consist, in what conditions is it produced, why does increase of muscular work induce an increase of this need? These are the questions we have to answer in order to understand the connection between breathlessness and the muscular exercise which causes it.

The respiratory need is a kind of regulator of the respiratory function. It is a sensation which forces the individual to increase, more or less, the frequency and amplitude of the thoracic movements, according to the greater or less need of the system for the aeration of the blood, that is to say, for giving to venous the qualities of arterial blood, by replacing the excess of carbonic acid, contained in the former, by oxygen derived from the atmospheric air.

Neither hunger, nor thirst, nor any other natural appetite produces a disturbance in the system as rapidly as the respiratory need when it is not satisfied. No other appetite is bound up so intimately with the safety of the organism.

Respiration, in fact, has to defend us from a very pressing danger, by eliminating carbonic acid from the blood, a poison, the accumulation of which in the body can cause death in a few minutes.

Carbonic acid is a product of dissimilation, resulting from vital combustions. It is incessantly formed in the organism, as long as animal heat is being produced, that is, as long as life lasts. If the system usually suffers no ill effects from this poison, it is because it is constantly eliminated by the lungs.

The system can bear, without detriment, a definite dose of carbonic acid. When that dose is exceeded, distress is immediately produced. This is called respiratory need, dyspnœa, and is a warning to us that the toxic substance is accumulating in the blood.

The presence of an excess of carbonic acid in the blood is the cause of the sensation which instinctively urges us, sometimes even against our will, to render more active the play of the respiratory apparatus.

All the circumstances which cause more or less variation in the quantity of carbonic acid in the blood cause also more or less variation in the intensity of the respiratory need, and in the frequency of the respiratory movements—the sign by which the need is externally made manifest.

Whenever the organism produces less carbonic acid than usual, the respiratory need diminishes, and the respiratory movements become slower. We observe this during sleep. A sleeping man produces less carbonic acid than one awake; his respiration is also less frequent. More especially in the sleep of hibernating animals we can observe the very intimate correlation between the diminution of carbonic acid in the economy, and the lessening of the respiratory need.

According to the curious experiments of Regnault, the production of carbonic acid in a hibernating marmot is one-thirtieth of that which occurs when the animal is awake. Also he observed a surprising diminution in the respiratory need of the hibernating animal. On waking, the production of carbonic acid quickly increases, and at the same time the exigencies of respiration resume all their intensity.

A hibernating marmot was placed under a very small bell-glass, the edge of which was cemented to the table on which the apparatus was placed. In this manner the access of the external air to the jar was prevented, and the respiration of the animal was confined to the very small quantity of air contained in its prison. As long as its sleep lasted, its respiration was sufficient, and the animal was able to live for several days on this almost infinitesimal quantity of oxygen, without giving any sign of distress. One day the marmot was awakened by a violent blow on the bell-glass. The animal was hardly awakened before it manifested by its agitation, and by the disordered movements of its thorax, a great respiratory need, and died of asphyxia in a few minutes. The quantity of air which sufficed to support its life before it was awakened was no longer enough when aroused from hibernation. The awakening had suddenly increased the activity of the organism, increased the production of carbonic acid, and the saturation of the blood with this gas had increased the needs of respiration so much that the small quantity of air in the bell could no longer satisfy them.

If the respiratory need diminishes when the proportion of carbonic acid in the blood is less than usual, it increases, on the other hand, whenever this gas becomes more plentiful. If the quantity of carbonic acid becomes very large, the respiratory need assumes the character of intense dyspnœa, of severe suffering, and provokes more and more energetic and frequent respiratory movements.

If we inject carbonic acid into the veins of a dog, its respiration is quickened, becomes oppressed, anxious; the animal manifests greater and greater respiratory distress. If we continue the injection the symptoms become continually more grave until the animal finally dies with all the phenomena of asphyxia. No experiment can invalidate this. It definitely proves that the respiratory need increases when there is an excess of carbonic acid in the blood, and not only—as some have urged—when there is too small a quantity of oxygen.

In fact, in the example we have given, the air passages of the dog were free, there was nothing to prevent a normal quantity of the oxygen of the air from reaching its lungs; but dyspnoea ensued and the animal died of asphyxia.

The respiratory need is then proportional to the quantity of carbonic acid in the blood.

Many conditions in man can bring about an accumulation of carbonic acid in the economy. It can be introduced from without through the air-passages, and we then see accidents similar to those which we have just described in the experiment on the dog. In this manner the emanations from a brewing vat produce death by asphyxia.

Similar accidents occur when the carbonic acid, instead of being introduced into the system from without, is simply retained there by some hindrance to the eliminating power of the lungs. Thus when a child dies of croup, it is asphyxiated by the carbonic acid which is no longer eliminated in sufficient quantity through the obstructed air-passages.

Finally, there is a third cause for the accumulation of carbonic acid in the blood: the accumulation may come about through excessive production, and this is what occurs in violent exercise.

It is a truth demonstrated by physiology that the production of carbonic acid by an animal increases with increased muscular activity. The work of Sanson has shown that in large animals, such as the horse and the ox, the quantity of carbonic acid given out by the lungs is doubled or even trebled when the animal is performing violent exercise, such as running.*

This increase in the production of carbonic acid during work has been ascertained in all animals, even in insects.

A bee-hive contains twenty-seven times as much carbonic acid when the swarm is working as it does when the latter is at rest.

* *Sanson.* La Respiration des grands animaux.

Finally, in man, in a given time, there is discharged by respiration :

0·35	grammes	of	carbonic	acid	during sleep ;
0·60	„	„	„	„	while sitting ;
1·65	„	„	„	„	while running.

Besides the increase in the carbonic acid exhaled by the lungs, there has also been determined an increase in the quantity of this gas eliminated by the skin during work. Further, in spite of the increased elimination, there remains an excess in the system for a certain time after the exercise is over. If we kill an animal after forced exercise, we find much more carbonic acid in the muscles than in the normal condition, and the arterial blood is blackish, and resembles venous blood in its chemical composition.

Thus, when a man performs muscular work, an excess of carbonic acid is produced throughout his system. A man who performs a very violent exercise is threatened with asphyxia just as much as an animal into the veins of which we inject carbonic acid. In both cases the cause of the respiratory disturbance is the same : there is a poisoning of the blood by the same toxic substance ; only, in the man rendered breathless by muscular work, the poison has not been introduced from without, it has been formed within the system itself. It is a product of dissimilation which has accumulated in the economy in too large a dose.

The presence of an excess of carbonic acid in the blood produces the sensation of dyspnœa. Dyspnœa, or increased respiratory need, produces, in a reflex manner, increased respiratory effort. There is a strife between the poisonous substance and the eliminating organs whose function it is to expel it from the system. For a longer or shorter time, according to the respiratory fitness of the individual, the increased action of the lung compensates for the increased production of carbonic acid, and the distress is bearable. But if the work increases, the production ends by exceeding the eliminating power of the organs ; the pulmonary air-cells are no longer able to discharge all the carbonic acid brought to them by the blood, and this gas accumulates. If at this moment the work is stopped, the production of the poisonous gas becomes normal in quantity, the excess present in the system is eliminated, and the distress ceases. If, on the other hand, the violent exercise is continued without a break, carbonic acid at last accumulates in very large quantities, and may finally produce serious accidents, even death from asphyxia.

So intimate is the correlation between the quantity of work performed by the muscles, the quantity of carbonic acid produced in the system, and the intensity of the respiratory distress experienced. Muscular work increases the quantity of carbonic acid in the blood, and the excess of this gas leads to an increase of the respiratory need.

This is the explanation of the law which is deduced from the observation of phenomena, and which we here enunciate :

The intensity of breathlessness during exercise is in direct proportion to the expenditure of force demanded by the exercise in a given time.

The cause of breathlessness is a kind of poisoning of the system with one of its own products of dissimilation, an *auto-intoxication* by carbonic acid. The excessive increase of the respiratory need, and the exaggeration of the respiratory movements which we observe in a man rendered breathless by muscular exercise, are due to the imminence of the danger of intoxication, and to the effort made by the organism for the speedy elimination of the poison.

III.

If we review all the circumstances in which breathlessness is produced, we shall see that our theory gives a satisfactory explanation.

For the production of breathlessness it is necessary that much work should be done in a short time, that the exercise should be taken, so to speak, in a large dose, so that the increase of carbonic acid may be rapid enough to bring about an excessive accumulation of this gas, and the saturation of the blood with it.

If the exercise, for instance, merely doubles the production of carbonic acid, breathlessness will not occur, for the elimination of this gas, according to the researches of Sanson, may be trebled during work. The respiration will be rendered *more active*, but it will not be *insufficient*. If, on the other hand, the muscular work, in a given time, produces a greater quantity of carbonic acid than the lungs are able to eliminate in the same period, this gas will accumulate in the system; the respiratory distress will increase every moment, and will finally interrupt the work.

Thus are explained the phenomena by which we are struck while practising bodily exercise, and which show how muscular fatigue is produced under different conditions to breathlessness.

The quantity of carbonic acid produced by a group of muscles in a given time is in proportion to the amount of work they do. Further, the work which a group of muscles is able to do without fatigue is in direct ratio to the power, that is to the number and size, of the muscles forming this group. If then an exercise is localised in a very small group of muscles, fatigue will ensue before a large quantity of work has been done, and before a large dose of carbonic acid has been poured into the blood. The eliminating power of the lungs will exceed the power for work of the active muscles: muscular fatigue will precede breathlessness. If, on the other hand, the muscles put in action are very numerous and very powerful, they will be able, before being fatigued, to perform a large quantity of work, and consequently, to produce a very large dose of carbonic acid. Their power for work will exceed the eliminating power of the lungs. Breathlessness will this time precede fatigue.

This is why exercises performed with the upper limbs, the muscles of which are relatively feeble, mostly culminate in fatigue without producing breathlessness. These muscles do relatively little work at a time ; they are fatigued before they have produced the dose of carbonic acid necessary to embarrass the lungs.

The lower limbs, on the contrary, with their powerful muscular masses, can perform in a few seconds a great deal of work, and throw into the blood a great quantity of carbonic acid. So when we demand from them all the work of which they are capable, they produce in a very short time more carbonic acid than the lungs can eliminate. Breathlessness interrupts the exercise while the muscles are still full of vigour.

Breathlessness occurs whenever muscular work produces, in a given time, more carbonic acid in the blood than the lungs can eliminate in the same time.

The quantity of work necessary to produce breathlessness should not then be the same in all persons, for not everyone can eliminate by the lungs the same quantity of carbonic acid in the same time. We may say that there exists for each individual a *coefficient* of breathlessness which varies with his respiratory fitness. The moment when breathlessness will occur will be retarded by the vigour of the subject, the size of his lungs, the perfect integrity of his heart, and above all by his acquired aptitude in the use of his respiratory organs.

But, however great the respiratory power of the individual, if we suppose an exercise as violent as possible, and one which brings into action all the muscles of the body at once, breathlessness will be produced almost instantaneously, because the muscular system, as a whole, can produce in a given time more carbonic acid than the lungs can eliminate.

It is for this reason that it is important in an exercise of great swiftness, such as running, not to make at the outset all the efforts of which we are capable, but to economise. In order to avoid becoming breathless during the exercise, we must regulate the work of the muscles by the eliminating power of the lungs, in such a manner that the quantity of carbonic acid produced in a given time shall not be greater than that which the respiratory organs can dispose of in the same time.

The habit of practising an exercise or of performing a work brings a man or an animal instinctively to regulate the intensity of his muscular effort by his respiratory power, in such a manner that there may be an equilibrium between the amount of carbonic acid produced by the muscles and the amount eliminated by the lungs. Thus it is that every man, every animal, comes to adopt in the exercise of running, a pace—or rather a rate—from which he cannot depart under pain of breathlessness.

In horse racing, certain animals are charged with *making the running*. They force themselves to the front at the start, endeavouring to lead their adversaries into an extremely rapid gallop. The aim of this manœuvre is to force the other horses to exceed their paces, while a confederate holds himself in check in order to take the lead when the others begin to be exhausted. A horse which exceeds its paces is, from the physiological point of view, an animal which produces more carbonic acid than it is able to eliminate. This causes a rapid intoxication, which paralyses its action. To win the race, a horse is almost always obliged to provide at a given moment all the swiftness of which its legs are capable, and consequently, to exceed its paces. But the art of the jockey is not to let it exceed its paces till the last possible moment, so that it may not be exposed to this inevitable intoxication till close to the goal.

Nevertheless, if a violent exercise is performed continuously for a certain time, breathlessness is always produced in the end, although the individual does not exceed his paces. Let us suppose a case in which the muscular work produces a quantity of carbonic acid just equal to that which can be eliminated by the lungs. At first there will be no breathlessness, as there is an equilibrium between production and elimination. But if the work goes on, respiration in the end becomes embarrassed. Running at a moderate pace, for instance, which we can do for five minutes without losing breath, will produce breathlessness in a quarter of an hour, although the pace remains the same.

It is because, the quantity of work remaining the same, the respiratory power is diminished by the very continuance of the exercise. In the very act of working disturbances are produced in the functions of the respiratory apparatus. The circulation of the blood through the lungs is increased, and there results at first an *active* congestion. Later however, we have *passive* congestion as a result of fatigue, of the *forcing* of the right side of the heart, the contraction of which is not sufficiently powerful to drive the blood through the pulmonary vessels. Further, the nerve-centres, strongly stimulated by the carbonic acid brought to them by the blood, react on the movements of the lung in a reflex manner, and respiration becomes short, precipitate, and irregular.

The congestion of the lungs, the derangement of the respiratory movements, the excitement, and then the enfeeblement of the heart-beat, are so many secondary factors of breathlessness, which we shall study in the next chapter. The part they play in the production of dyspnœa in the course of exercise is important, for they create obstacles to the free working of the lungs at the moment when there is need that these organs should work with their fullest power.

CHAPTER III.

BREATHLESSNESS—(*continued*).

Mechanism of Breathlessness—Reflex Disturbances of the Respiratory Movements—Physical Sensations and Moral Impressions — *Stammering* Respiration — Why we become less Breathless at a Fencing-School than in a Duel—Reflexes due to Carbonic Acid—Reflexes are at first Useful ; they become Dangerous when Exaggerated—Dangers of Instinctive Movements—Part played by the Heart in Breathlessness—Active Congestions—Fatigue of the Heart-Muscle and Passive Congestion of the Lungs—The Influence of the Heart is Secondary —Cessation of Breathlessness notwithstanding the Persistence of Circulatory Disturbances after Exercise—Personal Observation ; the Ascent of *Canigou—Effort;* its part in Breathlessness—Prompt Advent of Breathlessness in *Wrestling—Sprint* Running and Long-Distance Running—Our observations on the Rhythm of Respiration during Breathlessness—Inequality of Expiration and Inspiration during Breathlessness ; Causes of this Inequality—Serious Phenomena of Breathlessness—Action of Carbonic Acid on the Muscular Fibres of the Heart.

THE essential condition of respiration is the presence in the lungs of atmospheric air and of venous blood, in order that the inspired air may give up its oxygen to the blood, and that the blood may rid itself, in exchange, of its carbonic acid. It is evident that any obstacle to the circulation of blood in the pulmonary capillaries or to the free entrance of air into the pulmonary air-cells, will render the respiratory act incomplete.

Now violent exercise causes a disturbance in the respiratory movements which renders them less efficient in drawing air into the chest, at the same time as it produces in the vascular system disturbances capable of hindering the pulmonary circulation.

Each of these two effects deserves attentive study.

I.

Exercise may have a direct action on the respiratory movements, for many muscular actions are performed with the aid of the muscles of the thorax or the back. These muscles, being used in the work, are momentarily distracted from their function as respiratory muscles. They can even stop respiration when they take their fixed point at the ribs for the purpose of moving the upper limbs. Effort, which we discussed at length in the chapter on *Movements*, is the type of the actions which stop respiration by fixing the thorax.

This action has important consequences on the circulation of the blood, and it is in this way that it especially affects the respiratory function. But it also momentarily hinders the interchange of gases, and this usually at a time when it is most needed. Stoppage of respiration during repose has no grave consequences, because it is always followed by a compensatory effect, by a series of longer and deeper respirations, which promptly eliminate the carbonic acid, of which the quantity retained in the body cannot be excessive while the muscles are at rest. But if the effort has taken place during work, it happens that the working of the lungs is hindered just at the moment when their action ought to be increased ; the suspension of respiration shuts the passage by which carbonic acid ought to be eliminated, at the very time when the muscles are producing three or four times as much of this gas as usual.

Respiration, which hardly answered the needs of the system while the lungs were freely performing their work, becomes suddenly insufficient when the thoracic movements are so hindered. Thus the repeated stoppage of respiration during work may become a very efficient cause of dyspnœa, while in a state of repose it produced but a passing disturbance.

But effort, and the other muscular actions capable of suspending or hindering the play of the ribs, are not the most frequent causes of the respiratory troubles which we observe during exercise. Respiration is often profoundly modified in its rhythm, its amplitude, and its frequency, without it being possible for us to consider these disturbances as a result of the direct action of the exercise performed. Very often we see that exercises, whose performance does not involve the use of the thoracic muscles, nevertheless profoundly affect the thoracic movements.

It is then by a reflex action that we must account for this indirect effect of exercise.

Reflex actions, capable of modifying the rhythm of respiration, have very various origins, and the lungs are very frequently exposed to their effects, being the most impressionable of all organs. In order fully to understand the reflex effects to which the lungs are subject, we must recall the fact that powerful impressions in general, whether physical or moral, tend to produce involuntary movements, and that these movements may take place just as much in the muscles of organic as in those of animal life.

When we pass near a room in which a person is taking a cold shower-bath for the first time, we hear sighs and suppressed groans. These inarticulate sounds, which resemble cries of distress, are simply reflex actions. The sensation of cold which the water causes when applied to the chest-walls is transmitted to the nerve-centres as a stimulus which produces abrupt expiratory and inspiratory efforts. The air is violently drawn into the chest, or driven out from it in an irregular manner, and causes in its passage vibrations of the vocal cords without the influence of the will. If the impression produced by the cold water is too strong, the reflex action may culminate in a complete stoppage of respiration: it becomes impossible for the air to enter the chest, or, having entered, to get out again. Hence there is a kind of distress, a momentary suffocation which makes hydrotherapeutics very painful at first to impressionable patients.

Every violent physical sensation, wherever situated, will re-act upon the lung ; every powerful moral emotion, whatever its cause, will also make its influence felt on the respiratory function. Joy, sorrow, fear, can produce reflex effects on the respiratory movements which we call a laugh, a sob, a sigh, a cry.

Every time that the rhythm of respiration is disturbed, breathlessness is produced, even in the condition of muscular repose. Moreover, very often, causes of a moral order come to increase the tendency to breathlessness while performing an exercise. An exercise which is performed with tranquil breathing if the mind is free from care, promptly produces respiratory disturbances if the mind is brooding and pre-occupied.

Those who have acted as seconds in a duel to men accustomed to the use of the sword, know that they become breathless in the duel much more quickly than they do in a fencing school. Yet their movements are more prudent, more limited ; they make no violent attack, and they watch more than move ; they expend less force, but—their rapiers have sharp points.

Depressing emotions make their effects felt on the respiration of animals as well as of man. A sensitive horse which is badly used when at work, or even roughly spoken to, quickly becomes breathless.

For the same reason, wild animals can be caught, when hunted, by domestic animals, in spite of their being more accustomed to fatigue ; the dog is incomparably less swift than the hare, but is able to catch it : the fright of the hunted animal disturbs its breathing and robs it of much of its strength

Moral impressions, like physical sensations, can only lessen the respiratory power by reflex effects which disturb the regular working of the pulmonary air-current. Under the influence of fear we see the movements of the chest, now quickened beyond measure, now slackened, and momentarily stopped, now following at irregular intervals. The defect of co-ordination, the disorder of the respiratory movements which we observe under the influence of fright, much resembles the incoherence in the movements of the lips which prevents a man, deeply moved, from clearly articulating his words. It is thus that depressing emotions can bring on a kind of *stammering* respiration.

The disorder of the respiratory movements destroys the regularity of the gas interchange which takes place in the lungs between the venous blood and the atmospheric air, and thus profoundly hinders the function of aeration of the blood. When the respiration is irregular, the carbonic acid produced by work cannot be eliminated as fast as it is formed, and oxygen cannot be introduced in proportion to the needs of the system; hence the respiratory need is unsatisfied and breathlessness comes on.

Moral impressions, then, add their influence to that of work in the production of breathlessness, not by increasing the production of carbonic acid, but by checking its regular elimination. The more impressionable the subject, the more easily do emotions influence his respiratory actions. Hence the superiority in certain bodily exercises of men who are calm and masters of themselves. The fear of being beaten, the annoyance of seeing himself passed for a moment, may diminish the respiratory power of an athlete, otherwise very vigorous, but too impressionable, and make him lose the prize for running or rowing.

There is a striking resemblance between the respiratory disturbances due to a violent moral impression, and those which result from a powerful physical sensation. The analogy is just as striking if we compare the modifications produced by a very strong emotion in the working of the lungs, and those produced by too violent an exercise. If we find ourselves before a man panting from terror, we might fancy he was out of breath from fast running. In both cases there is the same picture: breathing irregular, speech interrupted, complexion livid.

In a man *overcome* by a powerful physical impression, such as a cold shower-bath, in a man *carried away* by fear, and in a man *breathless* from running, there is a common element capable of disturbing respiration; there is a kind of shock undergone by the region of the nerve-centres which presides over the respiratory movements. The cold shower-bath influences the breathing by the powerful sensation which the nerves of the skin transmit to the brain. Fear acts by producing a commotion in the nerve-centres, the mechanism of which we do not understand, but the effects of which are analogous to those of a physical impression. As for muscular work, it makes its effect felt on the respiratory centre because it profoundly modifies the composition of the blood ; there accumulates in this liquid an excess of carbonic acid, and this substance has the property of acting on the medulla oblongata, from which the respiratory nerves arise, as a stimulus which produces, in a reflex manner, profound modifications in the respiratory movements.

The stimulation of the medulla oblongata by the carbonic acid in the blood is not perceived as clearly as an external impression, but it results in a crude sensation, the respiratory need, which immediately causes reflex movements in the respiratory muscles. These movements, which are quite automatic, aim at eliminating from the system with greater energy the carbonic acid which is tending to accumulate too much in the system.

II.

It is a physiological law that, under the influence of an impression announcing a danger, the organs react, and endeavour to remove the injurious agent. A grain of dust introduced into the eye produces a reflex winking, by which the eyelids seek, as it were, to sweep it away ; if a foreign body has entered the air-passages, it excites coughing ; in the nostrils it is driven out by a sneeze.

All these are reflex actions, and it is by a similar reflex action that carbonic acid in excess causes an acceleration of the respiratory movements for its elimination.

The instinct in virtue of which the respiratory movements are modified during violent exercise is then so intimately bound up with the preservation of the individual, that it seems astonishing at first sight that it can produce ill effects, and hinder the accomplishment of the functions over which it presides.

It is because instinct is a blind force which measures the intensity of its action by the strength of the stimulus received, without considering the result produced. We daily see the most serious accidents arise from an exaggerated or inopportune exertion of the automatic power of the organs. It is thus that the peristaltic contractions of the intestine, which are useful for driving out a foreign body, or the undigested residue of food, can occasion by their exaggeration grave maladies, such as *intestinal invagination.* Similarly the contraction of the orbicular muscle of the eyelids can aggravate an affection of the eye accompanied by *photophobia.* The lowering of the eyelids, when the eye fears the light, is an instinctive, and at first useful movement. But if the photophobia is extreme, an exaggerated effort at occlusion results from the excessive irritability of the eye, a *spasm* which may go so far as to turn in the edges of the eyelids, when the eyelashes will produce a painful friction of the cornea.

Similarly, on the part of the pulmonary organs, a moderate increase of the respiratory stimulus renders their function more effective and favours aeration of the blood ; the movements of the thorax become more extensive and more frequent ; they introduce more air into the lungs, and eliminate more carbonic acid from them. But if the respiratory nerve-centres are over-stimulated, if the respiratory need is exaggerated, the movements become excessively frequent, and here is one of the prime causes in rendering their action inefficient. In fact very clear experiments show that when the respiratory movements exceed a certain number per minute, the quantity of carbonic acid eliminated diminishes in proportion as the frequency of respiration increases.

If the respiration is only moderately quickened, the number of the movements more than compensates for the diminished amplitude of each, and a man breathing thirty times a minute will in the end eliminate more carbonic acid than one breathing 16 per minute. But if the respiration is immoderately quickened, the carbonic acid has no longer time to traverse the pulmonary air-cells, and the expiratory movement expels the air which has hardly entered.

Thus the reflex action, at first useful because it rendered respiration more active and increased its efficiency, becomes in the end a hindrance to the regular accomplishment of this function, and constitutes a danger to the system.

By practice we are able to exercise a certain domination over actions not ordinarily under the control of the will. By means of sustained and persevering efforts a man can strive victoriously against the respiratory reflexes which urge him to quicken his respiratory movements beyond measure. This is the secret of the resistance to breathlessness which professional runners acquire. They learn to regulate the working of their lungs and to prevent them from yielding to the species of madness under the empire of which the panting breast but half finishes the respiratory movements.

Certain diseases offer us a curious demonstration of the rule we are able to acquire over movements which are usually involuntary, to hold them in check and to regulate them. Asthmatic patients who have long suffered from dyspnœa have learned to resist the impulse which urges every oppressed man to quicken his respiratory movements. They slow the rhythm of respiration and prolong it as much as possible. In this manner they are able to better their condition, although the disease is unaltered. Persons who have been emphysematous for some years, *know* how to breathe and get much more good out of their bad lungs than they could at the outset of their disease. By slowing their respiration they render it more efficient.

Muscular exercise which quickens the respiratory movements up to the advent of breathlessness, often produces, when pushed too far, excessive slowing, and even momentary cessation of these movements.

These two opposed effects are alike due to reflex actions which the stimulation of the nerve-centres by carbonic acid produces. In fact moderate stimulation of the medulla oblongata, such as that caused by a small dose of carbonic acid, produces quickening of the respiration; a very strong stimulation on the other hand, such as is produced by a powerful dose of this gas, makes the respiration slow. We see these different effects manifested when the nerves of the lungs are stimulated in any way whatever. If in an animal we give a feeble electric stimulus to the *pneumo-gastric*, which innervates the lung, we cause quickening of respiration; but if we stimulate it very strongly, we cause slowing, and even complete arrest of the respiratory movements.

In the most advanced stages of breathlessness, when forced exercise has caused the accumulation in the blood of excessive doses of carbonic acid, we see no longer quickened respiration, but respiration half-finished interrupted by periods of stoppage, and finally complete arrest of the movement of the lungs.

III.

The heart and the lungs have a very intimate functional connection, and it is rare that the working of one of these organs is disturbed without the other being also affected.

Now one of the first effects of exercise is to increase the frequency of the heart-beat, and consequently to quicken the blood-current.

The quickening of the blood-current during exercise is the result of two causes, one of which acts on the systemic and the other on the pulmonary circulation.

The peripheral circulation is quickened, as we have explained in the first part of this volume, on account of the increased flow of blood to the working muscle. A more rapid current is drawn towards the muscle-fibre, and in the end all the blood participates in this increased activity; the pulse is more frequent and more blood is sent into the arteries. The whole vascular system is thus traversed by a greater quantity of blood.

The lungs, like the other organs, become the seat of a more active circulation, owing simply to the increased frequency of the pulse.

But there is another cause of increased flow through the pulmonary capillaries; this is the increased need felt by the organism for the aeration of the blood in which the carbonic acid has increased in quantity during work. Through a reflex mechanism which has been already described, blood overcharged with carbonic acid is driven more energetically towards the organ which will free it from this gas.

From these two causes there results an unusually large flow of blood, an *active congestion* of the lungs. What are the consequences of this?

The space occupied by the blood which swells up the pulmonary capillaries is no longer available for the air in the air-cells. The respiratory field is thus rendered smaller. The lung then makes an effort of expansion, in virtue of which certain air-cells not usually in action, but collapsed and closed, swell up with air, and supplement the deficiency of the ordinary respiratory field. This accessory respiration occurs especially in the apices of the lungs. In this manner there is established, for a certain time, an equilibrium between the amount of blood which passes through the lungs and the amount of air which enters them; respiration has become fuller and deeper; it is more active, but not insufficient. Breathlessness has not yet come on.

But an important factor of respiratory distress soon comes into play; this is the fall of blood pressure in the arteries. The heart, in spite of the increased frequency of its beat, does not give to the blood so powerful an impulse as in ordinary circumstances, and the blood-pressure falls.* It is a well-established fact that the heart contracts with less force during muscular work than in a condition of repose. In compensation, the frequency of its beat may be more than doubled, so that the increased number of the movements makes up

* *Marey.* La Circulation du Sang.

for their diminished energy, and the work done is, on the whole, increased.

The blood, driven forward less vigorously by the cardiac piston, circulates less easily through the small capillaries of the lungs; its current is slowed, there is a kind of stagnation, of blood-stasis, and the small pulmonary vessels become over-distended. There is established a *passive congestion* of the lungs. These, engorged with blood, now offer too confined a space to the inspired air, and moreover, offer a serious hindrance to the blood circulation. The venous blood can no longer reach the air-cells in order to get rid of its carbonic acid, and there is a reflux to the heart.

Passive congestion of the lungs is one of the most formidable factors of respiratory distress during exercise. Now all the causes which diminish the force with which the blood is driven through the capillaries will favour the occurrence of pulmonary congestion; hence we notice a very marked liability to breathlessness in persons whose heart is hindered by disease of the valvular orifices, or by diminished power in the heart muscle, in all cases, in fact, in which there is a tendency to enfeeblement of the cardiac contractions.

Breathlessness is very quickly produced in persons who are much enfeebled, whose muscular system has lost all vigour, for instance, in persons who have just recovered from a long illness. The heart, being a muscle, participates in the general want of tone, and its contractions become feeble at the slightest effort. Now, as soon as the heart-beat becomes feeble, the lungs are congested and breathlessness comes on.

Such is the part played by the heart in the production of breathlessness. Notwithstanding the importance of circulatory disturbances during exercise, such disturbances are not the prime cause of the dyspnœa. They act by mechanically aggravating the respiratory distress through making the functions of the lungs more difficult of execution, but acting alone they do not necessarily produce breathlessness.

A series of personal observations enables us to affirm that after exercise the dyspnœa disappears very rapidly, while the circulatory disturbances continue for a relatively long time. The figures which we are about to give prove that these two phenomena are to some extent independent of each other.

Last July, making the ascent of Mt. Canigou, we assured ourselves, by making observations on ourselves, and on two guides, that after violent exercise the heart remained disturbed long after the lungs. We have noted side by side the respiration and the pulse at three different stages of the ascent, (1) during complete repose, (2) while going up the last slopes, which are nearly perpendicular, (3) after we had been five minutes on the top.

	Pulse.	Respiration.
Complete repose. . .	62.	14.
Most rapid ascent . .	123.	30.
Five minutes after reaching the top . . .	117.	14.

Thus the disturbances of the heart during exercise are not the prime cause of breathlessness, for in this observation made on four healthy persons, at the time when the pulse rate was still almost double the normal, the lungs had returned to their ordinary rhythm and all respiratory distress was over.

If we follow out our examination of the disturbances produced in the circulation by excessive muscular exercise, we shall find a last and very serious cause of dyspnœa through diminished action of the heart; this is the influence of the blood surcharged with carbonic acid, on the heart-muscle itself.

We know that carbonic acid has a weakening influence on muscular fibre; if we inject carbonic acid into a muscle, we paralyse it. If the blood in the cavities of the heart is changed in its composition and contains an excessive quantity of this acid, it exercises on the walls of the heart an action which makes them lose their energy. Inertia of the heart-muscle will add to the other causes of the slowing of the blood-current, and a definite stoppage of circulation will soon occur.

In fact the stoppage of the heart is the last of the series of phenomena of asphyxia, of which breathlessness pushed to its furthest limits is merely a particular form.

IV.

To sum up, most of the causes capable of rendering the work of the lungs less efficient, end in passive congestion of the lungs, by slowing the current in the capillaries. Under the influence of this blood-stasis, the vessels become engorged, the air-cells are encroached upon, and the respiratory field is diminished.

Passive congestion of the lungs is only produced in an advanced stage of breathlessness, and when it occurs, it produces very interesting changes in the rhythm of respiration, which seem up to the present time to have escaped notice.

When a man has carried an exercise to the last degree which his respiratory power enables him to reach, his respiration, which at first was simply quickened, comes to present a very characteristic type, of which we will give an exact description and try to find a physiological explanation.

In a state of repose, the two times of respiration are exactly equal ; but when we observe a runner at the moment when he is about to stop for want of breath, we notice that his respiratory rhythm has completely changed. Inspiration is much longer than expiration. If he forces himself to slow his respiration, he can considerably prolong the period of inspiration, but finds it quite impossible to prolong that of expiration. An involuntary inspiration draws more air into the chest before the latter has had time to empty itself. A man who notices his own sensations during an exercise which causes breathlessness, will have a feeling that he cannot entirely empty his lungs. When he has driven out a small quantity of air he has an unconquerable need for a fresh inspiration. If he tries to resist this need, he finds it as difficult as it is to check a hiccough: it is an irresistible movement.

We will describe a very simple experiment which has enabled us to establish the very peculiar character of the respiration of a breathless man.

Running at a regular pace along a road, and carefully making steps of equal length and rhythm, we began an inspiration and counted the number of steps while it lasted, up to the moment when the need for expiration became very imperious. Then making as slow an expiration as possible we again counted our steps until irresistibly forced to make a new inspiration. The steps were practically equal, and their duration may serve as a unit of time. Now we made thirteen steps during the period of inspiration, and only five during the period of expiration.

Such is, according to our observations, the character of respiration during running. Inspiration is easy, deep, and unhindered: expiration on the contrary, is short, insufficient, interrupted by an involuntary inspiratory movement, and leaves the sensation of an unsatisfied need.

This change in the rhythm of respiration is not due to the mechanism itself of running, nor to the attitude of the body during this exercise, for when we have stopped running we continue for some minutes to make expirations which are shorter than the inspirations which precede them. Moreover we have satisfied ourselves, by varying the experiments, that all exercises which cause breathlessness, whatsoever form they take, produce this defective balance between the two times of respiration. In fencing, in rowing quickly, in dumb-bell exercise, we become breathless just as in running, and we observe the same inequality in the two periods of respiration.

It is curious to note that the respiration of persons suffering from asthma has a type the exact opposite of that we have just described. During the crisis inspiration is very short, and expiration lasts twice as long.

We do not believe that anyone has hitherto pointed out the change of which we are speaking, and which we may consider as typical of the dyspnœa due to muscular exercise.

The following is our explanation.

The first result of violent exercise is the quickening of the blood-current, and consequently, as we explained in Chapter III., active congestion of the lungs. In these exercises the lungs are very quickly engorged with blood, and there is great need for their disembarrassment by increasing the activity of the blood-current. The movement of inspiration increases the velocity of the current by a force of aspiration which tends to empty the overfilled capillaries. This aspiration lasts as long as the enlargement of the thorax continues ; hence this movement is an assistance to the breathless man ; on the other hand, as the thorax is diminishing in size during the expiratory movement, the blood-current becomes slower and the lungs more engorged. Hence the discomfort, and the irresistible impulse to a prompt repetition of the inspiratory movement.

We may say that the lungs of the breathless man are placed between two different needs. On the one hand they have to drive out carbonic acid and the other products of dissimilation, and for this a long expiration would be necessary ; but on the other hand, they have to free themselves from vascular engorgement, and therefore expiration is cut short to return to inspiration which helps the circulation through the lungs.

In order to observe the breathless type of respiration, the exercise must be pushed very far, for the characteristic change we have described only precedes by very little the moment when work becomes impossible. At the time when it occurs the production of carbonic acid is no longer in equilibrium with the eliminating power of the lungs, and the respiratory distress tends to become a serious danger.

V.

There is a phenomenon in muscular exercise the frequent occurrence of which very quickly causes breathlessness : this is *effort.*

Effort brings about a momentary stoppage of respiration, and in this already we have a hindrance to the functions of the lungs. But there is further an action on the heart and great vessels, through the necessity put on the thoracic organs to serve as points of support for the ribs. To the ribs in fact are attached the powerful muscles which fix the thorax during the execution of movements demanding a great expenditure of force. The lungs, inflated by a forced inspiration, act as a kind of cushion on which the ribs press, and this pressure is transmitted to the great thoracic vessels and to the heart itself.

It is easy to understand the fatigue of the heart-muscle and of the contractile walls of the blood vessels which must result from this mechanical action which quickly and excessively increases the tension in the vascular system.

Every exercise which demands a series of efforts, repeated at short intervals, very quickly induces fatigue of the heart, and diminution of the contractile force of the blood-vessels. There results a transient condition of asystole, and the subject is for some minutes in the condition of a person suffering from cardiac disease. Breathlessness is thus produced by a kind of over-driving of the heart, and by the passive congestion of the lungs which this immediately produces.

On performing an exercise needing very prolonged efforts, breathlessness comes on with astonishing quickness.

Two wrestlers who strain, each trying to throw the other, remain for a few seconds completely motionless owing to the resultant of their several efforts which balance each other, then suddenly one of them gives way and yields to the pressure of the other. It has hardly taken half-a-minute, but the two champions are pale, breathless, and unable to speak. For some seconds it seems as if the air can no longer enter their chests. Under the great pressure occasioned by their athletic effort the larger vessels have been distended until they have momentarily lost power of recoil, the heart has been compressed till it is on the point of ceasing to beat, and the lungs, engorged with blood which is no longer driven forward, remain for a moment under the power of passive congestion, which renders them unable to work.

Effort plays an important part in all movements which are executed with a person's whole force. We must often attribute effort rather to the energy which a man throws into an exercise than to the mechanism of the exercise. Thus long-distance running does not need the production of effort, while this action occurs during sprint running. Hence the latter can only be continued for a very short time without producing breathlessness.

CHAPTER IV.

BREATHLESSNESS—(*concluded*).

Three Stages of Breathlessness—First or Salutary Stage; Respiration more Active but not Insufficient—Second Stage—Symptoms of slight Carbonic Acid Intoxication; Leaden Complexion; Breathless Respiration; General Discomforts—Third or Asphyxial Stage—Cerebral Disturbances; Symptoms of severe Carbonic Acid Intoxication; Vertigo; Unconscious Movements; Syncope; Stoppage of the Heart—Observations—Dangers of Running as a Sport—Too vigorous an Assault-at-Arms—Animals succumbing to Breathlessness; the Horse ridden to Death—Death of a Carrier Pigeon—A Hunted Beast which Breaks Cover.

WE now know the influence of muscular exercise on the chemical and mechanical phenomena of respiration, and we have studied the effects of work on the circulation of the blood and the movements of the heart. We have thus brought together all the materials which are necessary for establishing the physiology of the very complex general state called breathlessness, and we may sum up its principal features.

The prime cause of breathlessness during exercise, is the excessive production of carbonic acid.

The accessory causes are: (1) the disturbances of the respiratory movements produced by muscular exercise, (2) the disturbances in the circulation of the blood, and the congestion of the lungs which these cause.

We have seen how an excess of carbonic acid is produced by the combustions which occur during muscular work. We have seen how everything concurs in favouring its accumulation. We have before us an organism striving against a cause of disorganisation. It remains for us to examine the various incidents in this combat, the manner in which the organism defends itself, the conditions in which it has the upper hand, and the conditions in which it may succumb.

I.

We may group in three stages the symptoms presented by a man whose respiration is under the influence of violent exercise.

In the *first stage*, the respiratory movements are increased in frequency and in extent. The production of carbonic acid is increased, but the respiratory energy being greater, there is an equilibrium between the needs of the organism which demands a more active elimination of this gas, and the working of the lungs which is powerful enough to satisfy these needs. During a time, which varies much with the individual, with his constitution, with his resistance to fatigue, and above all with his power of directing his respiration, gained from his *respiratory education*, these are only symptoms of greater vital activity, and there are as yet no signs of functional disturbance, no sensation which rises to the degree of discomfort. The man has a general sensation of warmth, some throbbing of the temples, and has an animated appearance, flushed, his eyes sparkling, and a general aspect of cheerfulness due to the greater activity of the circulation and the resulting active congestions. In a word it is the stage in which exercise causes a greater intensity of life, without reaching the degree of discomfort or of danger.

Here we have the really salutary dose of exercise, the limits within which we must keep in order that work may cause us no inconvenience. But nothing varies more with the individual than the duration of this inoffensive period, which is, in a sense, the preface of breathlessness. In some persons it is as long as an hour; in others the stage in which discomfort begins is reached in a few seconds.

If violent exercise is prolonged, the equilibrium is soon broken between the production of carbonic acid, which becomes more and more abundant, and the eliminating power of the lungs which is insufficient to free the organism from it. Respiratory distress occurs.

In the *second period*, the effects of insufficient respiration begin to show themselves, a vague discomfort is experienced, which is most accentuated in the præcordial region, but which is rapidly generalised throughout the body and notably affects the head. In the chest there is a feeling as if it were oppressed by a weight, or bound down by a girdle, of insufficient air. In the head there are clouds obscuring sight, sparks before the eyes, then murmurs and ringing in the ears, and finally a certain bluntness of sensation, a certain confusion in impressions and in ideas. All these disturbances are due to the action upon the nerve-centres of an excess of carbonic acid. They indicate the beginning of intoxication.

In the face remarkable changes are to be noticed, which are the consequences of the respiratory distress and of the efforts made to draw a greater quantity of air into the chest. The nostrils are dilated, the mouth and eyes widely opened. They all seem to be widely opened to favour the entrance of the air which the lungs so greatly need.

In certain animals the movements associated with respiratory effort are especially noticeable in the nostrils. A horse returning to its stable after a race is typically breathless, and we can study in it the to-and-fro movement of the nostrils which accompanies the movement of the flanks.

The alternating movements of elevation and depression of the alæ nasi have for their object the presentment of a large passage to the air drawn into the chest. They tend to occur in every animal with increased respiratory need. When we look at a small child suffering from acute bronchitis or pneumonia, we see a very characteristic working of the nostrils, which at once makes the doctor think of a disease of the respiratory organs.

The colour of a breathless man shows very striking modifications. At the beginning of exercise we have said that there is animation, more colour in the face, due to active congestion. But in the second period the picture has changed. To the lively red colour has succeeded a pale and wan tint. There is something peculiar about this pallor; it is not uniform. Certain parts of the face, such as the lips and the cheeks, have a violet-blackish appearance; the rest of the face is white and colourless. From the two colours, one darker and the other lighter, there results a grey, leaden, livid appearance.

The following is the explanation of the different colour of different parts of the face. The violet tint is due to the retention of blood in the capillaries which are losing their elasticity, and in which the circulation is failing. This blood, overcharged with carbonic acid, has lost its bright red colour, hence in the lips and other more transparent parts of the face, we see no longer the ordinary red colour; they have the blackish colour characteristic of venous blood.

As for the pallor, this is due to a transient anæmia, to the emptying of the arterioles. The heart, the energy of which diminishes in proportion to the increase of the breathlessness, does not send forward a sufficient quantity of blood, and it is easy to understand that a part receiving less blood is less deeply coloured than usual.

The leaden hue of the face in a breathless man indicates an already profound disturbance of the system. In no case should exercise be continued after it comes on, for it indicates the beginning of asphyxia.

It is at this stage of breathlessness that we observe the very characteristic change in the rhythm of respiration which we described in the last chapter. The ordinary rhythm is lost and the two periods of respiration become unequal. The first period increases, and the second diminishes; inspiration becomes three times as long as expiration. This change in the rhythm of respiration is an indication of blood-stasis in the capillaries of the lungs. As soon as it occurs we can see that the organism, its force exhausted, can no longer fight to good purpose against the poisonous substance which permeates it. The congested lungs eliminate less carbonic acid than is formed by the muscles at work. Intoxication is imminent.

If exercise is continued, the gravity of the condition rapidly increases. We may call the *asphyxial stage* the third phase of breathlessness into which the organism passes under the influence of forced exercise.

This *third stage* is as follows. To the respiratory distress succeeds a sensation of anguish generalised throughout the organism. The head feels as if bound by an iron band. Vertigo is very distressing. All sensations become more vague; the brain is overcome by a kind of drunkenness. The subject begins to become unconscious of what is passing, his muscles continue to work mechanically for a time, then they stop, and the man falls in a faint.

At this time respiration is of a different type to that of the last stage; the two periods are both short, jerky, occasionally interrupted; with them are mingled swallowing movements and hiccough. The heart-beat is feeble and intermittent. The pulse is small, irregular, and imperceptible. When exercise is continued to these extreme limits it is almost always stopped by grave syncope, and unless prompt help be given the syncope may be fatal.

II.

The description of breathlessness which we have given is no picture of the imagination. We have studied some of the phenomena on our own person and on that of a friend who has willingly helped us in our researches.*

As to the more serious phenomena, they are often observed in England, the country of sport. It is by no means rare to see a severe fainting fit interrupt a runner in his course. Often a match between two pedestrians ends before either has reached the goal. One of the champions, breathless to the last degree, falls unconscious, and is only restored to life by the cordials and rubbings of his attendants. Often the unfortunate breathless man comes to himself, and after eliminating some puffs of the carbonic acid which is stifling him, wishes to continue the contest, but his muscles are impregnated with this gas, a poison which deprives them of all energy. The heart itself, bathed in blood overcharged with this poisonous product, loses power: the heart-muscle is paralysed and the circulation

* This friend was M. A. du Mazaubrun of Limoges; we take this opportunity of thanking him for his intelligent assistance.

stopped. The case is then unusually grave, and the most energetic measures have sometimes to be employed to restore to life the man who has overstepped the limits of prudence.

One of our friends who was somewhat enfeebled by excessive intellectual labours wished to resume bodily exercises which he had long discontinued, and returned to the fencing-school. He was an excellent fencer, and when he had the foil in his hand he forgot his exhaustion and only thought of regaining his quickness of attack, and his energy of thrust. After ten minutes he became very breathless, but he would not stop. All at once he fell down insensible, his face pale, his forehead covered with a cold sweat; his breathing and pulse had stopped. We at once went to his assistance, and thanks to the horizontal position in which we kept him, and to vigorous flicking of the chest and temples with a wet towel, his heart began to beat again and consciousness returned.

It was a syncope produced by breathlessness, the occurrence of which was favoured by the feebleness of the patient.

Syncope is a frequent termination of breathlessness, just as of asphyxia, of which breathlessness is in reality only a peculiar form.

Such are the symptoms and course of respiratory fatigue, and such are the dangers to which a person fighting against breathlessness is exposed.

Breathlessness is a *ne plus ultra* imposed upon us by the instinct of self-preservation. The severe suffering which accompanies it is a true cry of distress on the part of the organism to which the consciousness cannot shut its ears with impunity.

Animals which are overdriven usually succumb to breathlessness. The horse, which as Buffon said, "dies for better obedience," gives us the most frequent opportunity of studying the mode of death of which we are speaking. It is common enough to see a horse fall dead beneath its rider. When respiration is failing, and it wishes to pause to recover breath, it is answered with whip and spur, and continues to gallop. But the moment comes when the dose of carbonic acid which has accumulated in the organism, owing to the insensate speed demanded of it, becomes fatal, and the animal drops down dead from asphyxia.

Most of the animals which die suddenly during too violent work succumb to breathlessness. It is a common accident with all animals from which great swiftness is demanded, and the very birds, so well made for speed, may become its victims.

We saw a curious instance of death from breathlessness in a carrier-pigeon.

Carrier-pigeons undergo a special training, which consists in setting them free at points continually more and more remote from their home. The bird is driven by its instinct to return to its usual home, and whether it be from haste to reach the pigeon-house, or whether it be from a spirit of emulation, it seems to fly home as swiftly as it possibly can.

A friend of ours had a pigeon, which was the swiftest in the district, and which had never been beaten in a race. One day its master, who lived at Limoges, had sent it to Bayonne, where it was to be set free, and we were awaiting its return, well knowing that it would soon traverse the 375 miles. This time its speed exceeded our expectation, and seven hours after the time at which it was set free the valiant little bird appeared; we gave a cry of admiration, but the poor pigeon paid for its glorious prowess with its life. Just when it was about to settle on the pigeon-house we saw it flap its wings, turn, and fall helpless on the roof, where it was dashed to pieces.

The poor pigeon had exceeded the measure of its strength: it died of breathlessness from having flown too quickly.*

* We sometimes see fatigued quails fall on ships. We have even seen them fall on houses or in the streets. In these cases the bird is suffering from muscular fatigue, which is a much less serious condition than breathlessness. Quails which are thus caught, owing to their inability to fly, do not die, and may be kept alive for years.

We must remark that not every animal which dies from fatigue dies of breathlessness. Hunted animals usually die in quite another manner, which we shall study under the name of overwork. However, in hunting it sometimes happens that an animal is forced to run without stopping until it dies. This is the case with an animal which breaks cover, and trusts to its speed to elude the hounds. If the beast is too young, it may be taken before it has gained the wood in which it hoped to find new shelter. Then it is breathlessness which gives it up to the hunter. But it is rare for this to happen, and more commonly the hunted animal stops from time to time, to *double* if it be a deer or a hare, or to *stand at bay* if it be a wild boar.

Even these very short rests are enough for the animal to render its respiration regular, and to eliminate the excess of carbonic acid with which it is being poisoned. After a minute or two it is ready to start afresh, and the chase may in this manner last a whole day. In this case, if the animal is in the end hunted to death, death is not due simply to insufficiency of respiration; it results from a profound decomposition of the tissues, which we shall study in the chapter on *Overwork*.

CHAPTER V.

STIFFNESS.

Return to the Gymnasium ; A Sleepless Night—Febrile Stiffness —Three Degrees of Stiffness of Fatigue—Causes of Stiffness ; Immunity due to Habituation—Explanation of Symptoms — Imperfection of Theories — Local Symptoms ; They are due to Trauma — General Symptoms ; They are due to Auto-Intoxication — Deposit of Urates — Influence of Muscular Exercise on their Formation ; Diversity of opinion of Authors —Personal Observations—Conditions which cause Variations in the Formation of Deposits after Work—Slow appearance of the Deposits after Exercise—Influence of the Intensity of the Work on their Formation — Hitherto misunderstood influence of Training—Constant Correlation observed between the Production of Stiffness and the Formation of Deposits—This Correlation is found in all circumstances which render the Individual more liable to Fatigue—Influence of Moral Causes on Consecutive Fatigue and on the Deposits.

If a person has for some months taken no active exercise, and then returns to the gymnasium, he usually finds at the outset that he retains all his old vigour. He performs all the most difficult movements with as much ease as when they were assiduously practised. He gives himself up to the pleasure of long-discontinued performances, he is prodigal with the work of his muscles, and finally, after a long practice, he goes away astonished at feeling no fatigue after an hour so well spent.

In the evening, however, a little weariness and sleepiness make him think that the violent exercise he has taken makes him need more sleep than usual, and he hastens to seek in sleep the reparation of the force he has expended.

But sleep does not come. It is made impossible by excessive agitation, by insupportable heat throughout the body, by pains in the head, even by delirium. If towards daybreak he goes to sleep for a short time, he awakes shaken, bathed in sweat; his limbs are so stiff that he cannot move them; his head is heavy, his tongue coated, his appetite lost.

During the day the fever declines; but there remains a general condition of discomfort, of inability to work, a sensation of extreme lassitude.

Usually after twenty-four hours the general disturbances have disappeared, but there remain local sufferings, and for five or six days to come all the muscles which have taken part in this forced exercise remain stiff, painful and powerless.

This is the ordinary picture of the *Stiffness of fatigue.*

I.

Stiffness does not always present the same train of symptoms, for there are several degrees of it.

If the exercise we have not practised for some time be executed with a certain moderation, and especially if it be confined to localised muscular groups, its effect usually remains local, and is limited to muscular pains which for some days hinder the movement of the limbs employed in the exercise. This is stiffness of the first degree.

If the muscular efforts have been intense and prolonged, without too much exceeding the power of resistance of the system, general disturbances are added to the local pains, and produce an indefinable sensation of lassitude, of unfitness for work, which extends even to muscles which have taken no part in the exercise. But the pulse remains quiet, nor is there any characteristic symptom of fever. Slight depression, increased sensibility to cold, are the only witnesses to a passing disturbance of health.—This is the stiffness of the second degree; it is that which is most commonly observed, and that which we shall more particularly study.

Finally, when the exercise has been excessively violent, or when it has been performed by one whose system possesses little power of resistance, the ensuing disturbance takes the form of an attack of fever. This is febrile stiffness, such as we described at first.

The fever of stiffness, a typical form of consecutive fatigue, does not usually begin till some hours after the exercise which has caused it.

It may be ushered in by a rigor, and have the whole appearance of a severe febrile affection. The severity of the symptoms may sometimes lead the physician to a false diagnosis, and make him suspect the onset of an eruptive fever, a malarial fever, or some other affection which begins with severe fever. Moreover in some cases it may last longer than usual—for three, four, or more days.

The intensity of the stiffness is not always in proportion to the *immediate* fatigue, to that which is felt during the exercise, and which forces the muscles to rest. Exercise is sometimes followed by stiffness without having been accompanied by any muscular fatigue during its performance. Sometimes, on the other hand, an exercise is pushed to the utmost limits of a man's powers, without the slightest disturbance following.

This is because stiffness depends rather upon the conditions of the worker, than on those in which he performs the work. A moderate exercise, such as walking, may result in febrile stiffness in a man accustomed to complete inactivity, while running or fencing will produce in a well-trained man not even a local consecutive disturbance.

Before examining the reasons for this immunity produced by habit, it is necessary to establish the cause and the mechanism of stiffness.

And first we must divide in two classes the phenomena observed in persons suffering from stiffness. We must study separately the local symptoms and the general symptoms of this form of fatigue.

The local symptoms have been more studied than the others, but, according to Richet,* they have not yet been

* *Richet.* Les Muscles et les Nerfs.

satisfactorily explained. Under the influence of the organic combustions which accompany muscular work, an excess of lactic acid is produced in muscle. According to the recognised theory, this substance, impregnating and saturating the muscular fibre, causes it for the time to lose its contractile power.

"But firstly," says Richet, "recent experiments have shown that little lactic acid is produced during contraction. Secondly, the alkaline blood passing constantly through the muscle would instantaneously neutralise the lactic acid formed. Finally, how do you explain that several days after the fatigue, this or that muscle remains painful? Assuredly there no longer remains a trace of the lactic acid produced by the contractions of seventy-six hours before."*

We believe that the persistent local pains of stiffness are to be explained by a series of small material lesions.

If we submit any region of the body to violent compressions, to prolonged manipulations like those which would result from an excessively violent massage, we produce in the muscular masses thus treated, persistent painful phenomena, perfectly analogous to the muscular pains of stiffness.

On the other hand we often see excessive work produce in muscles, tendons, and synovial membranes, a series of lesions exactly similar to those which would be produced by external violence. Inflammation of muscles running

* Lactic acid, however, plays an important part in the local phenomena of stiffness. But its action is transient. To the presence of lactic acid we must attribute the stiffness which is almost instantaneously produced in an overworked limb when the circulation in it begins to slacken during repose. This stiffness, which makes it so painful to resume work, is dissipated by a few energetic efforts, which re-establish the circulation in the muscles. The stiffness which comes on with repose is not so much due to the cooling of the muscle as to the slowing of the circulation. When the muscle ceases to contract, the blood does not so freely bathe the muscle fibre. When work is resumed, the blood-current, more active again, carries away the lactic acid with which the fibre is impregnated, and further, thanks to its alkalinity, it neutralises this acid.

on to suppuration, inflammation of synovial sheaths with painful crepitation of tendons, may result from overwork of motor organs, just as from external violence. This is because the mechanism of the accidents is in both cases the same.

The muscular pain felt in a muscle which has done too much work is only the first degree of a series of small lesions similar to those which are observed after any injury. We need be no more astonished at the prolonged painfulness of the muscular fibre bruised by unusual work, than by the persistence of blisters on the skin irritated by a body which the hand is not used to hold. A series of small lesions of the motor organs may result from violent exercise. We can make no better comparison than to the different injuries which may be produced in a machine by excessive work. Just as in the machine, the bands may become loose, the bearings roughened and the oil dried up.

But the general phenomena of consecutive fatigue cannot be explained mechanically. They are of an essentially vital order, and have no analogies in any machine constructed by the hand of man.

Febrile stiffness has the general appearance of a mild infectious disease. It resembles most nearly intermittent fever, if we suppose the latter to be limited to one attack. Mild septic intoxications have also a very marked resemblance to the fever of fatigue. It is the same with the onset of the eruptive fevers, and with all febrile states characterised by the presence within the economy of an injurious substance, against which the vital organs re-act.

Does not the resemblance of the symptoms point to a similar cause, and can we not refer stiffness to an infectious process or a poisonous material? We know that the combustions of muscular work produce changes in the living tissues which profoundly alter their structure, and we know further that the products resulting from these phenomena of combustion, or *dissimilation* are dangerous to life, and must be speedily eliminated from the system, under pain of severe disorders, and symptoms of poisoning. The study of *breathlessness* has shown us that this form of fatigue is an auto-intoxication by carbonic acid, a product of dissimilation. Might not the consecutive fatigue called stiffness be caused by a transient intoxication of the system by the products of its own activity?

Let us examine how far the physiology of muscular work can help us to solve this question.

We know that local muscular fatigue, and the loss of irritability resulting from excessive work, are due to a chemical change in the structure of the organ, and to the formation of certain new organic products. The composition and exact nature of these substances, resulting from the dissimilation of the anatomical elements are still in dispute, but their physiological effects are known. We know that these waste products are the cause of the loss of irritability of the fatigued muscle, and that their contact with the motor fibres prevents the latter from responding to electrical stimuli, or to the will.

We know further that these substances, with which the fatigued muscle is impregnated, have the curious property of making their fatiguing power felt by the muscular elements of another organism. In fact, by injecting into the muscles of a healthy frog a soup made from a finely-powdered fatigued muscle, the muscles of the frog lose their irritability and become unable to contract.

Among the products of dissimilation of muscle are there not some substances which have a poisonous action on the whole organism, and produce the general discomforts and febrile disturbances of stiffness?

But stiffness only occurs after exercise in certain special circumstances: in case the person is out cf practice in the exercise he is performing. We must find then products of dissimilation which are not constantly formed during work, but the appearance of which depends on the want of practice in the work, or the want of *training*.

Now we have been able to make a series of observations proving that certain organic waste-products are invariably formed after an exercise when the person performing it is not in training, and that these waste-products are not found when the person habitually practises this exercise. We have many times been able to assure ourselves that there is a constant coincidence between the formation of these waste-products and the production of stiffness, and we have ventured to establish between these two phenomena a relation of cause and effect.

II.

It is among the waste-products eliminated in the urine after muscular work, that it is necessary, in our opinion, to seek the substances capable of causing the general disturbances of stiffness.

Which is the exact substance, among those which we find in the urine, which has the property of producing these disturbances? We do not know the exact substance, but we can affirm that it is contained in the *deposits of urates.*

These deposits are known to all observers as being formed in the urine after violent exercise. Everyone will have observed the turbid appearance presented by his urine when it has stood some hours after a very long walk, or a first day's hunting, when he is not yet accustomed to fatigue. These deposits, which indicate the saturation of the urine by sparingly soluble substances, are only formed after some hours, when the liquid has become cold. The urine has then usually a whitish yellow colour which makes it resemble pus; sometimes the tint is reddish, recalling the colour of brick-dust. But if we warm in a test tube a small quantity of this turbid urine, it at once becomes clear, owing to solution of the precipitate, which is more soluble in hot than in cold water. On cooling, the turbidity reappears.

This simple test is sufficient to prove that the deposits in the urine after muscular work consist *for the most part* of urates. We shall see, after a methodical analysis, that they consist of alkaline and ammoniacal urates. For this reason we give them with Neubauer * the name of *deposits of urates.*

All authors agree in recognizing that the appearance of the urine can be modified by muscular work, but they are far from agreeing about the conditions under which this modification is produced.

According to Béclard,† muscular exercise *diminishes* the amount of uric acid and urates in the urine.

According to Lécorché,‡ exercise *increases* the amount of uric acid and urates in the urine.

After these two absolutely contradictory statements we will quote two others which seem contradictory.

Bouchard § declares that moderate exercise causes the *disappearance* from the urine of deposits which it ordinarily contains, and violent exercise causes the appearance of some not ordinarily formed.

Guyon || says that slight exercise *increases* the amount of uric acid and urates, and an active life causes their diminution.

If the authors we have quoted have the same opinion on this question, we must agree that they express it in very different fashions, and that it is difficult, after reviewing their conclusions, to get any clear idea of the effect of work on the formation of deposits of urates.

If we endeavour to form a personal opinion on this question, with the help of careful observation, we see that there are many causes of error which can render the observations incorrect, for many circumstances besides exercise cause the appearance of deposits in the urine. We must first ascertain that the person on whom we experiment has not ordinarily deposits in his urine, such as occur in most men who lead a very sedentary life. Next we must be sure that he is exposed to none of the numerous causes which can accidentally provoke

* *Neubauer.* l'Urine.
† *Béclard.* Physiologie.
‡ *Lécorché.* La Goutte.
§ *Bouchard.* Le Ralentissement de la Nutrition.
|| *Guyon.* Maladies des voies urinaires.

the appearance of these deposits. We know that prolonged vigils, severe mental work, excesses in eating, often produce this phenomenon. Finally we must know that he suffers from no constitutional or transitory pathological condition capable of producing turbidity in the urine; gout and fever, for example. In short we must know well his habits, his antecedents, his actual condition of health, and his mode of life.

Under these circumstances, the best person the observer can choose for his studies, is himself when in a condition of perfect health. It is then on ourselves that we have made the observations we are about to describe. But we have carefully repeated them, as a check, on several persons with whose constitutions and mode of life we were thoroughly familiar, and who, for the most part, performed in our company various bodily exercises.

The results of our observations may be summed up as follows:—

When a healthy man of a temperate habit, active and regular, performs a bodily exercise, the appearance of his urine varies much according to three different circumstances: (1) the time when it is examined, (2) the greater or less violence of the exercise, (3) the greater or less "habituation" to the exercise.

With regard to the time when the liquid is examined, it is hardly necessary to mention a circumstance which is as important as it is well known: the urines which will deposit urates become turbid only when they have cooled, and are always clear at the time they are passed. By the side of this well known fact there is another which we believe we are the first to point out: namely that muscular exercise does not make its influence on the urine apparent *till the end of a certain number of hours.*

It is important to be well aware of this. Supposing we perform a muscular exercise in the conditions which are necessary to produce in the urine the subsequent changes of which we have spoken. Suppose too that we have been careful to empty the bladder immediately before the exercise, so that no liquid formed before the work, is left. If we then begin fencing or rowing, the bladder gradually fills with urine secreted during and after the exercise. If we then collect in different vessels the urine passed at different intervals, every hour for instance, we shall have a series of samples of urine secreted since the exercise began, some during it, and some after it.

If we then place these different samples in their chronological order and keep them till the next day, this is what we notice:

The urine passed immediately after the exercise is perfectly clear, and so is that passed one, or two hours afterwards. It is only in the vessel containing the urine secreted during the third hour after the cessation of the work, that the first cloudiness, due to deposit of urates, is usually manifested. This phenomenon has never varied in experiments made on six or seven persons of different ages or temperaments, but all in good health and under normal circumstances having clear urine: and the deposits due to muscular work have not appeared in the urine till three hours after the cessation of the exercise. On the other hand, in some persons, the urine has been clear for a longer period; we have seen cases in which no deposit occurred in the urine for six or seven hours after the exercise.

At the risk of repeating ourselves we wish to make it clearly understood that this delay, averaging three or four hours, does not apply to the time elapsing between the passing of the urine and the formation of the precipitate, but to the time which separates the end of the exercise from the time when the urine is secreted. Moreover, the urine which will form deposits is passed, as usual, quite clear, and becomes turbid more or less quickly according to the rapidity with which it cools.

Here then we have a first fact: *the urinary deposits which are observed in man after work must only be looked for in urine passed at least three hours after exercise.*

This may be one cause of errors of observations. If we examine only the urine passed an hour after work, we shall never find deposits of urates, and we might conclude that exercise never caused their production, though they would show themselves very abundantly in the urine of the third or fourth hour, which we have not examined.

But we can draw another conclusion from our observations : namely that the organic substances forming these precipitates are slowly eliminated, and stay long in the economy before passing through the renal filter. Now we know that the kidney does not elaborate the substances which are found in the urine, but that it eliminates them as they are brought to it by the blood. The excrementitious materials, which are the waste products of muscular work, are then ready formed in the system before passing through the excretory organ. They can make their injurious influence felt for a long time, for they stay several hours in the economy.

We must add that this production of deposits of urates which begins three hours after the work, continues sometimes for twenty-four hours, that is as long as the general disorders of fatigue.

The time when the precipitate is observed being thus established, it is easy to study the influences on its production, firstly of the conditions under which the work is done, and secondly of the physiological condition of the worker.

If the work is not very severe and of short duration there will be no precipitate. The precipitate is very abundant on the other hand when the exercise is very violent and very prolonged. In the same individual the urinary deposits are more abundant, and appear during a longer period, the more intense and more sustained the muscular work necessitated by the exercise. According to the greater or less violence of the exercise, the precipitate will vary from a faint cloud in only one of the specimens, to the thickest deposits rendering turbid and muddy all the urine passed during twenty-four hours.

But the condition of the individual has much more influence than the severity of the exercise in increasing or diminishing the quantity of deposit formed after the work. The nearer he approaches to the condition of *training*, the less abundant the deposits in the urine, the amount of work remaining the same. In proportion as from practice he acquires more power of resisting fatigue, his urine loses the tendency to deposit urates.

There is nothing more interesting than to follow the inverse progression of these two phenomena: power of resisting fatigue, and the formation of urinary deposits. If the same individual does every day the same exercise, demanding the same expenditure of force; if he undertakes for instance, to row a certain distance in an hour every day, his exercise, which causes great stiffness during the first few days, hardly produces any disturbance after a week's practice. His urine which at first gave abundant deposits, shows later only a faint cloud.

As the deposit becomes smaller, the sensation of consecutive fatigue tends to diminish, and when the urine keeps perfectly clear after the exercise, he will suffer from no kind of discomfort: there will be no stiffness. There is then a close relation, an invariable coincidence between the formation of deposits of urates and the production of stiffness.

This remarkable correlation is found in all circumstances which can alter the effects of work. If we pass from an exercise with which we are familiar, to another exercise calling into action a different muscular group, we experience afresh the discomfort of stiffness, and our urine again shows a deposit. Thus, a man used to forced marches, experiences no consecutive fatigue on the day following a long journey made on foot. He will, however, suffer from stiffness, if, without being used to it, he spends a short time in fencing. If we examine his urine, we shall discover that though it remained perfectly clear after twelve hours' walking, it is very turbid after twenty minutes' fencing. This will always be the result when we undertake a new kind of work, which brings into play muscles not hitherto exercised.

The close correlation between stiffness of fatigue and the formation of excrementitious products which make the urine turbid, may be ascertained even in accidental circumstances which make the resistance of the individual variable, and render him for a time more vulnerable to fatigue. Under the influence of slight indisposition, of an insignificant disturbance of health, it often happens, as all amateurs of sport know, that the aptitude for work is for the time diminished. On these days the gymnast has not his accustomed vigour, and the exercise is followed by a long-forgotten sensation of discomfort. A man well broken in to his work shows, under these circumstances, the same phenomena of fatigue as a novice, and his urine, which for a long time has always remained clear after exercise, begins again to deposit urates.

We have many times observed these facts on ourselves, and have been able also to record them on other persons, as the following observation shows.

A friend of ours, a good oarsman, in perfect training, offered himself for our studies on the changes in the urine produced by work ; but he was so inured to muscular exercise that we could never find the slightest deposit in his urine. One morning we were rowing with him in the same boat, and we were surprised to see that he was wanting in his accustomed vigour ; he needed all his force of will to go on rowing to the end of his ordinary course. Two nights without sleep had brought about this temporary enfeeblement. On this occasion the exercise left him throughout the entire day with a sensation of discomfort and stiffness, such as he had never experienced, and his urine, which for a long time had been very clear after work, showed very abundant deposits of urates.

Whenever the organism is in a condition of "diminished resistance," there is a tendency to the formation of deposits of urates, and a tendency also to a manifestation of the symptoms of stiffness.

It may happen that the deficient resistance of the organism is produced by a cause of the moral order, by mental abstraction, by depressing emotion. We have been able to ascertain that, in this condition of physical and moral depression, a well-trained man loses for a time his immunity from fatigue, and shows, after muscular exercise, all the symptoms of stiffness; but, at the same time, his urine is not clear as usual after work, but deposits urates. We have observed this phenomenon in a man who was a great fencer, inured to all forms of exercise. He fenced every day, with no symptoms of stiffness, and no deposit in his urine. One day, after a short fencing bout, when his mind was preoccupied with thoughts of a serious duel he had to fight on the following day, he suffered from a very severe attack of stiffness, and we found an abundant precipitate in his urine.

Such are the facts of experiment and observation showing the constant correlation between the formation of deposits of urates and the production of the stiffness of fatigue. Every circumstance which makes a man more vulnerable to fatigue, causes at the same time a tendency to the formation of deposits in his urine.

Between these two phenomena, excretion of turbid urine, and discomfort following exercise, there is so constant a correlation, that it is impossible not to see in them a relation of cause and effect.

CHAPTER VI.

STIFFNESS (*continued*).

Objection to Our Theory—Are Urinary Deposits due to the Perspiration produced by Exercise?—Observations opposed to the opinion of Authors on this Subject—An Experiment in Fatigue:—Rowing from Limoges to Paimbœuf—Agreement of Observations with Chemical Analysis—Exercise produces a Uricæmic condition—Analogy of Stiffness of Fatigue with certain Febrile conditions—Stiffness of Fatigue and an Attack of Gout—Cause of Immunity from Stiffness when in Training—Function of Reserve Materials—Products of Dissimilation—Part played by Uric Acid in Stiffness—Stiffness is an Auto-Intoxication.

I.

AN objection first presents itself against the conclusion we have just formulated.

Some authors consider urine which forms deposits after muscular exercise not as a liquid containing more excrementitious materials than in the ordinary condition, but as a more concentrated liquid, that is to say, one containing less water for the same quantity of solids in solution. Urinary deposits are not more abundant in urine after exercise, but the water which holds them in solution is less. Hence more saturation of the liquid and tendency to precipitation.* If the theory of these authors were true, these urinary deposits would not indicate any change in the chemical composition of the liquid; they would merely mean that a part of the water ordinarily eliminated by the kidney has been discharged by other channels, and notably by the skin. Excessive

* Dictionnaire de médicine et de chirurgie pratique. Art. "Urine."

perspiration would then be the true cause of the formation of the deposits.

Two strong arguments can be opposed to this theory. In the first place the urine is often just as abundant on the days when there are deposits, as on the days when there are none. We have established this by fifty observations on different persons. It often happened during these observations that, perspiration having been but slight, and urine more abundant than usual, the deposits were none the less formed, in a person unaccustomed to work. On the other hand, we have been able to ascertain that, in perfectly trained men, profuse sweats often occur during exercise without any subsequent turbidity of the urine.

A long observation of fatigue, made on a friend and on ourselves, has enabled us to confirm through nine successive days the result of the studies we had already made, and certainly to give them more weight.

In the beginning of August 1886, we set out in a boat intending to row in as short a time as possible from Limoges to Paimbœuf. In nine days we covered the distance of 341 miles with double sculls, having further an excessive supplementary work in dragging our boat up the high and nearly dry weirs, which to the number of 83 interrupt the course of the Vienne.

This great expenditure of muscular force never made us stiff, for we had both been hardened by two months' training. After working twelve or fourteen hours in the sun on the hottest days of the year, we suffered in many ways, but never from stiffness; we never found ourselves on rising in the morning less disposed for work than the night before, although, while working, fatigue was carried to its utmost limits, and when we left the oars our strength was exhausted. The exercise had been pushed to the degree of overwork, for, in spite of a very substantial diet washed down with some wine and a great deal of coffee, we each of us lost ten pounds in weight in the nine days. But we were never attacked by stiffness, and our urines, examined day by day, never presented the least deposit of urates.

If however these deposits were the result of excessive perspiration, no opportunity could have been more favourable to their formation than the second day of our voyage, of which I will give you an exact account.

On the 10th of August, after rowing 31 miles under a burning sun, which had covered our necks, faces, and hands with blisters, having saturated our thick sweaters with perspiration, we put up for the night in the little town of Availles, of which the innkeeper was at the same time the baker. We had to sleep in enormous feather-beds in which we sank up to the chin, in a night following one of the dog-days. Finally our host, as if wishing to give us all the elements necessary for a physiological experiment, had given us a room directly over the chimney of his fire which burned throughout the night.

It is impossible to imagine a more complete collection of conditions calculated to provoke sweating; forced work for ten hours under an August sun; a night spent in a feather bed in a room heated like an oven. The following day, an injury to the boat, which had to be repaired, compelled us to stay half a day in the village, and we had ample leisure to examine the urine we passed during several hours. But in spite of the profuse sweats which had saturated our clothing by day, and inundated our beds by night, there was no deposit in either of our urines.

Thus it is not enough to sweat much during and after work in order to form deposits in the urine. Excessive perspiration will produce in persons in training, as in anyone else, a diminution in the quantity of urine passed, but does not necessarily determine the appearance of deposits of urates.

A last proof, which is of course the most convincing, establishes the real increase in the uric acid and urates in urine presenting a deposit of urates after exercise; this is chemical analysis.

Here is the result of the examination of a sample of urine passed after a long fencing bout by a person not in training, who had abstained from all active muscular exercise for two months.*

In a litre of urine the quantity of uric acid eliminated was 1·43 grammes.

In the same person who had performed the same work after a course of training, in whose urine there was no deposit, a litre of this liquid contained 0·6 gramme, a quantity which does not exceed the normal.

We see then that after the performance of the same muscular work, the untrained man eliminates rather more than double the quantity of uric acid, while in the trained man there is no increase in this product.

The facts which we bring to the study of the changes produced in urine by muscular work are evidently very incomplete, for they point out one fact only; the formation of a deposit of urates; but this fact alone is interesting to determine, and the more so because hitherto no one had pointed out its close correlation with the general disturbance of stiffness.

We are able, after the preceding study, to establish one fact; that the proportion of uric acid eliminated is much increased when the urine becomes cloudy after exercise. Now the urine merely serves for the discharge from the system of products already existing in the blood. The excess of uric acid which we have found in the urine after muscular exercise, must then have existed in the blood before it passed into the urine. We know further that the elimination of urates does not begin till three hours after exercise and continues for some time, for twenty-four, or even thirty-six hours. Throughout this period the system has been exposed to the influence of an excess of uric acid.

Violent exercise then leaves, in persons who are not trained, an excess of uric acid in the blood, a true uricæmic condition, similar to that which is, for instance, observed in gouty subjects just before an attack of gout.

* This analysis was made by M. Papon, experimental chemist, whom we wish here to thank for the assistance he has so willingly given us.

II.

Is it to this excess of uric acid that we must attribute the disorders felt after violent exercise?

Evidently among the waste products eliminated in the urinary deposits there must be many other substances which could make their influence on the system felt during their prolonged stay in the blood before being eliminated. It is certain that the extractives such as kreatinin, xanthin, and other products of incomplete combustion, have an important part in the production of the febrile disturbances of consecutive fatigue. But the physiological relations of these substances are as yet so little known, that it is advisable to speak of their probable influence with the greatest possible reserve.

We have on the other hand often the opportunity of observing circumstances in which the urine contains an excess of urates, and of ascertaining that the disturbances from which in this case the system suffers have sometimes a strong resemblance to those of consecutive muscular fatigue.

Attacks of intermittent fever, and of rheumatic fever without any local affections, are two disorders which much resemble the fever of stiffness. Now these two disorders are accompanied, like stiffness, by an abundant excretion of urates.

A cold shower-bath taken by a person unused to it generally produces a tolerably severe subsequent disturbance, with a general feeling of tenderness in the limbs, and slight febrile reaction; we have been able to assure ourselves by observations on the urines of persons suffering from these symptoms, which are so similar to those of stiffness, that there is an abundant deposit of urates.

It might be objected that since in the examples quoted there is a febrile reaction, we should attribute to the fever the production of the urates equally in the stiffness of fatigue and in the attacks of intermittent or rheumatic fever. But fever only exceptionally occurs after violent exercise, while we can frequently observe an abundant deposit of urates in circumstances in which muscular work has left the pulse and the temperature quite normal. We believe the urates and other waste-products of combustion which accompany them, to be the causes and not the effects of the fever. The febrile condition in stiffness results from an effort on the part of the system towards the elimination of these waste-products, when they have accumulated in too great quantities.

It is impossible to avoid seeing a certain analogy between the process of the fever of stiffness and that of an attack of gout. In these cases there is uricæmia, that is to say, an excess of urates in the blood. Only, in the gouty attack the blood discharges itself into the articulations, and there rejects the excess of urates, while in the stiffness of fatigue it discharges itself by means of the kidneys, and the noxious substances are eliminated in the urine.

This analogy in the causes is confirmed by observation. In persons predisposed to gout, violent exercise taken without preliminary training, is often the exciting cause of an attack. It is because the attack of gout, like that of stiffness, is due to an accumulation of uric acid compounds in the blood, to a condition of uricæmia. Too violent muscular exercise temporarily places the organism in all the conditions necessary for the explosion of the accidents of the uric acid diathesis. We have often observed that the most violent exercise is without danger for the gouty person when he is in a condition of perfect training. One of our intimate friends, the very active president of a fencing-club, has for a long time been subject to gout. The most prolonged bouts have never produced in him the least attack of gout as long as he remained in training; but on the other hand he has several times suffered from well marked arthritis on resuming fencing after too long an absence from the school.

If the condition of training frees a gouty person from the dangers which fatigue ordinarily has for him, it is because in the man in training work does not produce deposits of urates, nor the transient condition of uricæmia which causes them.

But a last question remains to be solved in order to give a satisfactory explanation of the production of stiffness. Why is it that the nitrogenous waste-products which form the deposit of urates, are not formed, the work being equal, in the man in training, just as in the man who performs an exercise for the first time?

There can be but one answer to this question, namely, that in the man who does not exercise his muscles, there exist materials capable of giving rise to these products of incomplete combustion, whereas in the man in training the muscular work has used up these materials, and caused them to disappear. The daily practice of the violent exercise has gradually brought about the disappearance of the *reserve materials* which were accumulated in the muscles. Work has burned up and dissipated the materials hoarded by inaction.

The reserve materials are only destined to stay a short time in the system; they are provisions of fuel for combustion, and not intended to enter into the intimate woof of the body, and to become an integral part of it. Hence these materials are more easily affected by the process of dissimilation. They resist less the combustions of work; they burn more readily, and are discharged from the organs before undergoing the last stages of oxidation, and remain in the condition of products of incomplete combustion. These waste products, to follow the expression of Bouchard,* are *true organic cinders.*

The further we examine the facts, the more is this opinion confirmed.

Amateur gymnasts know well, that, in resuming an exercise which has not been practised for a long time, it is impossible to avoid stiffness; but all those who have had occasion to go through this little trial, know that there are two ways of paying tribute. One is, every day

* *Bouchard, loc. cit.*

to do a small amount of work gradually increased, and thus after a sufficient time to resume the usual quantity of exercise. They feel only slight discomfort after the exercise, and their urine shows only a slight cloud. They come in time to the most violent gymnastic exercises without ever passing through the condition of complete stiffness. This is because they have only produced every day a minimal quantity of the waste products of combustion. These waste products were insufficient to cause any serious disturbance in the system, and not abundant enough to make the urine very turbid. Others prefer to free themselves more quickly and do on the first day all the work they can, exercising their muscles without any stint. There results on the following day severe stiffness and urine loaded with urates. But on the third day, usually, they have recovered all their fitness for exercise, and are quite free from consecutive fatigue. From this time also their urine is free from deposit, and keeps perfectly clear after exercise.

These two different methods lead in the end to the same result; the using up of the reserve materials.

If we seek to establish as clearly as possible the conclusions to be drawn from the facts we have observed, and recorded here, to contribute to the study of consecutive fatigue, we shall be led to formulate two opinions, of which one is an established fact, and the other a very probable hypothesis.

1. We can state as an established fact, the increase in the products of incomplete combustion which form the deposits of urates in all cases in which muscular work is followed by the general disturbances of stiffness, whether febrile or not.

2. We propose as a probable hypothesis which establishes a relation of cause and effect between these phenomena closely united by a constant coexistence; production of nitrogenous waste-products which form deposits of urates, and appearance of the general disturbances of consecutive fatigue. This hypothesis seems to us founded on sufficient deduction to allow us to attribute the *stiff-*

ness of fatigue to a kind of auto-intoxication of the system by the products of dissimilation.

There will thus be a certain analogy between the process of stiffness and that of breathlessness. These two forms of fatigue will be due to the accumulation in the blood of certain products of dissimilation.

The respiratory distress which we call breathlessness is due to the saturation of the blood with a product of dissimilation which is eliminated by the lungs. The general discomfort which we call consecutive fatigue or stiffness of fatigue, must be attributed to the presence in the economy of certain products of dissimilation which are eliminated by the kidney.

We know the product which causes breathlessness; it is carbonic acid.

It is much more difficult, in the present state of our knowledge, to point out the product or products which are the true cause of stiffness. But we can affirm that these products are found among the substances which go to form deposits of urates, and that, among these, uric acid and the urates play an important part in the phenomena of general consecutive fatigue.

CHAPTER VII.

OVERWORK.

Overwork is Exaggerated Fatigue—Different forms of Overwork—*Acute* Overwork; Death from Breathlessness—*Sub-acute* Overwork—The Stag hunted to Death—Forced Game; Rapid Cadaveric Rigidity; Prompt Putrefaction—Mechanism of Death by sub-acute Overwork—Auto-Intoxication by products of Dissimilation—Extractives—Lactic Acid—Discoveries of Gautier; Poisons of Living Organisms; Leucomaïnes—Rarity of sub-acute Overwork in Man—The Soldier of Marathon—Observations on rapid Cadaveric Rigidity in Men dying in a condition of Overwork—Curious positions of the bodies; Horror-Stricken Expressions in Persons who have been Assassinated—Effects of Overwork on the Flesh of Animals—Dangers of Eating Overworked Flesh—Culinary Qualities given to Flesh in certain cases by Overwork—Suffering a cause of Overwork—Cruelty of a Butcher—*Chronic* Overwork the form most frequently observed in Man.

I.

OVERWORK is nothing but fatigue pushed to an extremity.

We have seen that excessive work has as its consequence the formation in the system of certain products of dissimilation, and that the general disorders of fatigue are caused by a kind of intoxication of the body by these waste-products, the injurious influence of which is felt until they are eliminated from the body by the excretory organs. In the condition of overwork the organism is no longer able to strive against the too abundant waste-products, which the eliminating organs are incapable of removing. There is a disproportion between the eliminating power of the organism and the great quantity of the products of combustion with which it is encumbered.

Between fatigue and overwork there is simply a difference of dose in the substances which poison the organism; the substances are the same and have the same origin; they are always the waste-products of combustion produced by work.

A man who stops out of breath after running for five minutes is simply a man whose system is under the influence of transient intoxication with carbonic acid resulting from exercise. A horse urged into a very rapid gallop, and forced to run till it drops, dies *over-worked.* The accidents which kill it are due to the carbonic acid gas with which its system is saturated; in the case of the man, the poisonous gas has been eliminated in time; in the case of the horse it has accumulated in quantity sufficient to cause death.

Carbonic acid is, of all the products of combustion, that which is formed most rapidly and in largest quantity during work. It is the most dangerous to the organism; it is the one which causes the man and animal the most pressing dangers. When the organism has the under hand in the contest for its elimination, the fight is always very short, and rapidly fatal. This is what we observe in a horse excited to gallop with insufficient time to breathe, we make it exceed its paces, that is to say, we demand from it a speed out of proportion to the power of its lungs. The animal which exceeds its paces, makes more carbonic acid than its lungs can eliminate. In a short time there accumulates in the blood a sufficient quantity to produce the first symptoms of poisoning. If we allowed it to stop, only for a minute, it could, in this short rest, discharge the excess of gas which distresses it, and continue its course without danger. But if we do not give it a moment's breathing space, it retains this excess of carbonic acid, of which the quantity increases every moment, the nerve centres are supplied with blood incapable of maintaining life, the heart-muscle is impregnated with a substance which paralyses it, the circulation stops and the animal dies. Death from breathlessness may be considered as the type of *acute* overwork. This form of overwork is really asphyxia from auto-intoxication.

What we have called *sub-acute* overwork has a less rapid course. The type of this is furnished by the hunted animal. In this sport the animal must not be killed, but *taken*, that is to say, pursued to the extremity, till the complete exhaustion of its powers renders it unable to escape the hounds.

We will study what happens to a stag worn with fatigue and the death-whoop of which will soon be sounded.

The animal has been doubling, that is, instead of going straight forward, it has stopped, and tried to conceal itself after returning for some distance, after making *doubles* to throw the dogs off the scent. Its course is thus interrupted by numerous stoppages long enough to allow it to take breath and eliminate carbonic acid. In this manner the chase may continue for a long time, five or six hours, sometimes longer, which would not be possible if it ran without stopping, for fright would make it exceed its paces, and, though much swifter than the hounds, it would become breathless, and quickly be caught. All huntsmen know that if the beast leaves the forest to take a long run in the open, the chase will soon come to an end ; unless indeed, the animal be one of great strength, an old wolf for example, which laughs at the dogs, knows the strength of its own legs, and does not do its hunters the honour of exceeding its paces in the effort to escape.

The stag avoids then, by doubling, being overcome by breathlessness ; but the excessive work which it performs in order to escape from its enemies gives rise to various products of dissimilation, which after a time become largely accumulated in the system, for they cannot, like carbonic acid, be eliminated in a few minutes. The greater part of these products are in fact eliminated by the urine, and we have already said that waste-products eliminated in the urine are very slowly discharged. It will then be impossible for the deer to free itself during the chase from these products of combustion with which its muscles are loaded, and its blood poisoned. When their accumulation becomes excessive, two orders of phenomena occur. In the first place, movements are difficult owing to the disturbances occasioned in the motor organs by the waste-products with which they are loaded, and which we may compare to the cinders which choke a fire, or to the soot which fills up the passage of a chimney. In the second place, these waste-products pass into the vessels and are taken up by the blood current, causing speedy infection of the system.

After some hours of a rapid run, the deer begins to slacken its pace, its legs become stiff, and the hounds gain on it. It is *on its last legs* say the huntsmen. From our point of view it is poisoned by organic waste-products, the formation of which has been excessive, and which have accumulated in great quantity. Its limbs are stiff because the muscle-plasma begins to coagulate under the influence of an acid elaborated by the combustions, sarcolactic acid, and because its muscles as a whole have undergone a true chemical decomposition under the influence of the heat of work. The motor organs of the animal fail it, it can no longer run, and lets itself be taken alive by the hounds. But this is not the only cause of its death; for if, by a last double, the deer succeeds in throwing the hounds off the scent, it generally dies from the consequences of overwork.

An animal thoroughly overdriven does not need to be killed either by the hounds or by the huntsman; it perishes, and often on the day following the hunt we find in the brushwood the corpse of the animal which had escaped the hounds, and which has died of fatigue. A friend of mine had set free in his woods a few deer, and hunted them sometimes without intending to take them, but simply to exercise his hounds, stopping the chase whenever he saw the animal was nearly exhausted. It happened that several deer died of the effects of this hunting, which was nothing but a game, a kind of sham fight, in which the animal was untouched. It is not merely the inability to run, the local fatigue of the limbs which makes up the condition of the overdriven animal; it is a general condition of decomposition of the living tissues capable of having fatal effects. The overdriven animal is one poisoned by a kind of putrefaction of its yet living flesh.

If we examine the body of an animal hunted to death we find certain phenomena which are exceedingly interesting to study. In the limbs there occurs almost instantaneously a stiffness known as cadaveric rigidity. This phenomenon is observed in all animals after death, man included; but it does not usually appear till some hours after death, while in the hunted animal it occurs immediately life is extinct, sometimes even during the last moments of the death-struggle. There is nothing more curious, or more capable of moving a man to pity, if a hunter is capable of feeling pity, than to see an unfortunate hunted animal dragging along its limbs which it is unable to bend, and which are as stiff as a log of wood.

Cadaveric phenomena then begin a few moments before death in animals suffering from sub-acute overwork.

Among the phenomena which follow death, there is one which comes on much earlier than under ordinary circumstances; this is putrefaction. The game hunted to death cannot be kept, it must be eaten at once, for it is already high a few hours after death. The body of a hunted animal putrefies and decomposes with the same rapidity as that of a man carried off by an infectious disease, and whose burial has to be quickly performed. Ordinarily we can keep for a long time the body of an animal if we have removed the viscera directly after killing it. The necessity for this precaution is explained by the constant presence of microbes in the alimentary canal, which after death penetrate all the tissues, which are no longer protected from this action by vital processes. In the hunted game, evisceration is quite useless, and does not retard putrefaction. This is because the origin of this putrefaction is not an agent introduced from without, but is due to products which are formed in the organism during work, and above all in the parts which have done most work, the muscles.

The rapid corruption undergone by the body of the overworked animal is caused by chemical changes occurring in the muscles. These muscles are nothing else than the meat or flesh of the animal: they make up more than half the body-weight, and it is not surprising that a change in the composition of so great a mass can have very marked effects on the whole organism.

Muscles which have worked to excess, have undergone a change in their chemical composition. Alkaline in a state of repose, they have become acid: they contain lactic acid which was not present before work; they contain less oxygen and more carbonic acid than when at rest. Numerous nitrogenous materials resulting from the combustion of muscular tissues are considerably increased.

These substances, of which the last stage of combustion is urea, form a series of bodies only differing in containing more or less oxygen, and being consequently at a different degree of oxidation or combustion. All authors enumerate amongst them kreatin, hypoxanthin, inosit, etc., and finally the best known one, and the most interesting because of the part it plays in the production of gout, uric acid.

These substances generally crystallise with difficulty, and have the common character of dissolving in alcohol when a fatigued muscle is macerated in this liquid. They are generally called *extractives*.

Extractives are found in muscle in a condition of rest, but in much greater quantity in a condition of overwork. Liebig was able to extract ten times as much kreatin from the muscles of a hunted fox as from those of an animal killed after confinement in a cage in the laboratory.

What is the part played by these extractives in the production of overwork? Have they the principal share in the production of the phenomena observed in overworked animals? These are questions to which we can give a satisfactory answer. Gautier (Académie de Médecine, 15th January, 1886), has shown that, amongst the products of muscular work, there are formed alkaloids of a toxic power not inferior to that of the poisons already discovered in putrefied flesh, and known as ptomaïnes. It is impossible, in the present state of science, to give the names and the chemical characters of the organic substances which are the true causes of the phenomena of overwork, but everything leads to the belief that these alkaloids, called by Gautier leucomaïnes, are the cause of most of the accidents, still but ill understood, from which overworked animals and men suffer.

In man it is rare to observe cases of sub-acute overwork, especially in our stage of civilization. Antiquity records a celebrated example of it, that of the soldier of Marathon who, wishing to be the first to bring news of the victory, ran to Athens without stopping and fell dead on arrival.

We can assure ourselves that fatigue carried to its utmost limits brings about, in man as in other animals, the speedy advent of rigidity of the whole muscular system. Combatants, dead after a long and bloody contest, whose bodies were in the condition of sub-acute overwork, have been seen to preserve strange positions. Their corpses have remained in the positions corresponding to the movements of attack and defence. Cadaveric rigidity coming on in the very moment of death, had surprised the dying men in their last attitudes, and the muscles, instantaneously stiffening, had preserved them.

Under the influence of sub-acute overwork cadaveric rigidity invades as rapidly the muscles of the face as those of the rest of the body, and, for the same reason, may keep these muscles in the contraction in which they were in the last moments of life, and consequently preserve the expression of the last emotions experienced. In persons who have been assassinated, and who, endeavouring to defend themselves, have been engaged for some minutes in a supreme struggle, there has sometimes been seen an expression of terror lasting for some hours after death. Their despairing efforts to escape their murderers had occasioned rapid overwork: rigidity of the facial muscles, coming on very quickly, had as it were, stereotyped the last expression.

If it seems surprising that cadaveric rigidity should occur in the very moment of death, we might quote a fact recorded by Richet, who saw the muscles stiffen before the heart had ceased beating.*

The bad effects of overwork on the flesh of animals has been frequently pointed out by veterinary surgeons, and by persons whose business is with the preservation of meat. The flesh of animals killed during great fatigue becomes quickly flabby and damp; it has a sour smell, like that of dirty linen, according to the expression of Raillet and Vilain; it is impossible to keep it long. It is dangerous to use the flesh of animals suffering from overwork unless it be eaten very fresh. Epidemics of typhus have been recorded, due to the eating of animals exhausted by following armies on the march. These facts are well-known in meat-preserving factories, and in these industries, precautions are taken to prevent the ill-effects of fatigue on animals to be slaughtered. In the *saladeros* of South America, great care is taken not to kill the nearly wild oxen which have been driven a long distance from the Pampas to the slaughter house. Each establishment is provided with a great court in which the animals rest before being killed. Their flesh would not keep if the overworked oxen were killed before two or three days' repose had enabled them to eliminate the waste-products of fatigue accumulated in their blood and muscles.

In opposition to these phenomena, in which overwork gives to flesh harmful properties, we could quote others in which fatigue is, on the contrary, desired, as a means of developing peculiar culinary qualities in the flesh of animals to be killed. We have heard gourmets complain that formerly they used to get much better beef

* *Richet.* Les Muscles et les Nerfs.

than at the present time. Before the days of railroads, the animals used to come on foot by short stages, sometimes as much as a hundred leagues, before reaching the slaughter house. It was said that the fatigue of the journey made the meat more tender, and gave to it a taste of "hazel nut." Similarly, in South Italy, it is usual, before killing the oxen, which run almost wild, and the flesh of which is tough and waxy, to chase them for some time on horseback, making them gallop as fast as possible. Their flesh acquires, it is said, after these mad gallops, a more savoury taste.

These facts are not in contradiction to those given above. They all alike show that fatigue causes an accumulation within the muscles of new products, the presence of which profoundly changes the qualities of the flesh. If these products are not present in too great quantity, and more especially if the animal is eaten soon after it is killed, so as to avoid the putrefactive fermentation which would quickly come on, the fatigued flesh is not offensive. The extractives even cause a kind of seasoning of the meat, and give it a suspicion of a high taste, a flavour agreeable to the palate. Connoisseurs prefer this savour to that of ordinary meat, just as they like to eat their game high.

It is always through overwork that we can explain the peculiar taste of the flesh of animals which have suffered before death. A butcher near Limoges had the reputation of selling much better pork than others in the district. The brute never killed the animals without torturing them. He pierced their eyes and bled them slowly to death with small stabs. In certain districts in the South of France, geese are only killed after being plucked alive, that their flesh may be made more tender by suffering.

These abominable practices deserve nothing but censure from humane persons, but we must recognize, from the scientific stand-point, that the idea under which they are performed is not without foundation. The flesh of an animal which has suffered extreme pain may have a peculiar flavour like that of an overworked animal, for the pain induces overwork. The unfortunate animal which is being tortured, exhausts itself in desperate efforts to escape the pain, and expends in a few minutes as much nervous energy as it would in a very long period of muscular exercise.

It has long been noticed that animals which have undergone vivisection, for the sake of physiological research, and which only die after suffering for some time, and striving in vain to escape from the constant pain, have after death all the appearances of overworked animals; hair bristling, bathed in sweat, rapid cadaveric rigidity, and flesh subject to early putrefaction.

Here are phenomena which are at first sight very distinct, and which we should not perhaps have expected to find in the same group. They have, as we hope we have shown, a common bond, the formation within the organism of certain products of dissimilation which result from the performance of an excessive quantity of muscular work. These products are found alike in the body of the man muscularly overworked, and in that of the animal which for a long time has striven against pain, for in both cases there is the same excess of fatigue.

Chronic overwork is due, like sub-acute overwork, to the impregnation of the system with the waste-products of work; but the course is not so rapid, and the termination usually less fatal, because the dose of the poisonous substances is less considerable, the exercise producing them being less violent.

This condition is observed in persons whose bodies are subjected to work too long sustained, or to fatigue too often repeated, and not followed by sufficiently long periods of repose.

Let us suppose that a man performs a fatiguing work which does not absolutely pass beyond the measure of his powers. The work is borne, and produces in his system the ordinary disturbances of consecutive fatigue and of stiffness. If he performs the same work on the following day, the waste-products of the day before have not been all eliminated when other waste-products are formed and add to the last, increasing the dose.

Let us suppose that on the following days the work is again repeated; the quantity of injurious substances accumulated in the blood will increase more and more, and will reach after a time a proportion great enough to have serious consequences. Then the fatigue will assume the character of an illness, and the condition of overwork will be established.

The condition of chronic overwork terminates in diseases of long duration, or at least ill-defined morbid states which do not, strictly speaking, constitute diseases, but which cause a profound change in the organism, which makes it liable to the most serious consequences from slight disturbances of health accidentally produced. The organism infected by the products of dissimilation becomes an admirable field for the hatching of the most pernicious germs.

The more or less lasting disturbances of health which are a consequence of excessive work will be studied in the following chapter.

CHAPTER VIII.

OVERWORK (*continued*).

The Disorders of Overwork—*Pseudo-Typhoid* Fevers—*Auto-Infection* and *Auto-Typhisation*—Opinion of Professor Peter—Microbes and Leucomaïnes—Frequency of Fevers of Overwork—Greater predisposition of Adolescents—Two personal Observations—Abuse of Fencing and too much of the Trapeze—Overwork in the Army—Too Energetic a Colonel—Forced Manœuvres — Overwork a cause aggravating Disease — Infective forms assumed by the mildest Disorders in Overworked systems—So-called *Sunstroke* of Soldiers on the March—The large influence of Overwork in the production of these Disorders—Rarity of Sunstroke in Horse-Soldiers ; its frequency in Foot-Soldiers—Spares persons habituated to Fatigue—Rarity of Sunstroke in Harvestmen.

IT often happens that the medical man is confronted by a continued fever for which he can find no external cause. No contagion, no epidemic to invoke : the case is an isolated one. He is tempted to diagnose typhoid fever, but none of the usual ætiological elements of this fever are discoverable ; a careful inquiry shows that there could have been no infection from air, from water, from milk, from a privy : no cause of illness is found in the persons or things surrounding the patient. If then he carefully examines the circumstances which have preceded the illness, he will almost always find that his patient has undergone an abuse of exercise or some excess of work.

There exists, in fact, a fever of overwork which has the closest analogy with typhoid diseases, and amidst the confusion which reigns between the true typhoid fever and the serious accidents of fatigue, it is difficult very precisely to determine the pathognomonic characters belonging to the one and to the other.

The fever of overwork is merely an exaggeration of stiffness. The causes and the processes are the same. These two disorders are due to an auto-infection, to a poisoning of .the body by the body; and the infective agents are, in both cases, products of dissimilation due to work; but in simple stiffness, the disorder is checked in time, and it has been possible, thanks to rest, to eliminate the substances which are doing the mischief, whereas in the fever of overwork these substances have been renewed by new work before they have been completely expelled, and have thus accumulated in the blood in excessive quantity.

Overwork does not always lead to a febrile condition of a typhoid character. It often happens that the disorder is limited to a condition of general prostration, to a languor of all the functions. In this case there is no explosion, and the disturbances of the system are checked in the prodromal stage, in the condition when disease is imminent. It is a menace which aborts, because the abuses which have called it forth are remedied in time. The disorder which was smouldering did not burst into flame, because the organism was placed in better hygienic conditions—and the only efficient hygienic condition against overwork, is repose. It is thus that we must explain many morbid conditions known as *abortive typhoid fever*, in which symptoms of great severity sometimes develop and disappear in a few days.

Overwork is usually quoted among the predisposing causes of typhoid fever; but overwork is much more than a predisposing cause of typhoid fever; it is capable, in absence of all other causes, of producing epidemics of continued fever absolutely resembling typhoid fever.

Sevrael eminent members of the Academy of Medicine, in a most interesting discussion (*Comptes rendus*, March, 1886), on the subject of the poisons discovered by Gautier as the products of living organisms, have drawn attention to the importance of auto-intoxication in disease. They showed that the blood can suffer from the toxic influence of certain chemical poisons called leucomaïnes which are elaborated in the organism itself, and accumulate in it in certain cases, whether it be owing to defective elimination or to excessive production. Professor Peter calls this mode of infection *auto-typhisation*, because it gives rise to affections quite similar to those of the typhoid disorders.

Excessive work, an active cause of the accumulation of organic poisonous substances, often terminates in auto-typhisation.

We have been able personally to observe several cases of these pseudo-typhoid fevers, in persons whose mode of life was well-known to us. We could easily proceed from the effect to the cause, and recognise, after careful inquiry, the exclusive share which excessive muscular work had in the production of the disorder.

We were specially struck by two of the cases. One man was overworked by fencing, spending six hours daily with the foil in his hand. Another had overdone his gymnastics and exercised four hours daily on a horizontal bar at his own house. Both were adolescents, and at this age, the anatomical elements of the body, less stable than in the adult, more easily undergo dissimilation. The work had acted on their tissues, and the superabundant waste-products resulting from too intense combustions had poisoned their systems.

Constantly in practice the physician meets with cases which puzzle him, and which would be inexplicable if overwork were not invoked as the cause of the phenomena. A barrack is old; the walls and floors doubtless contain microbes, for an epidemic occurs, and typhoid fever decimates the men. We whitewash and we disinfect, the epidemic goes on increasing. There comes a new colonel: the disease disappeors as if by enchantment. This is because there is a less energetic man in command. No more thirty mile marches, no more displays of skill in gymnastics and vaulting for the admiration of the civil population. The soldier, doing now nothing beyond strictly regimental work, no longer suffers from overwork; diminution of fatigue has sufficed to extinguish the epidemic.

Typhoid fevers, so frequent in the army, are almost always fevers of overwork. They are specially observed in troops going through supplementary manœuvres and making forced marches. They are especially severe on the men who have most work to do, in the artillery, for instance, as happened at Angoulême and at Clermont. Finally they attack by preference young soldiers, who are not yet accustomed to fatigue. Further, and this is a characteristic feature, they rarely spread to the civil population in the houses adjoining the barracks, who are not subjected to the same causes of overwork.

Many things prove the important part played by muscular fatigue in the production of illness. Many things point, by the side of external influences, to the power of morbific agents which arise within the organism. Microbes, parasitic organisms, play their part in the production of infectious disorders, but besides them we have to reckon as causes of serious disorders certain chemical poisons which are developed during the vital actions accompanying violent exercise.

These poisons, which have not long been known, and which resemble the alkaloids of putrefaction, are capable of exercising a pernicious influence on the organism within which they are formed, and by which they have not been eliminated with sufficient speed. They cause the development of certain forms of typhoid affections. They also cause a remarkable aggravation of the simplest lesions, of the most benign affections, when these occur in an overworked man.

After great physical fatigue, an attack of pneumonia or erysipelas assumes an infective character, and insignificant wounds are liable to be complicated by the accidents of *septicæmia*. It is no longer a germ introduced from without which has vitiated the blood; it is the organism which has poisoned itself with products of its own manufacture. The illness, which was at first benign tends to become aggravated and to take on an infective form, because it takes root in a field vitiated by leucomaïnes and other poisons formed by the exaggerated activity of the organs.

Typhoid fever is, according to all observers, the result of the absorption of a human miasma. It always occurs where men are much crowded together. A celebrated authority, Griesinger,* has pointed out the remarkable ætiological contrast between intermittent malarial fever, which occurs away from towns, in uncultivated districts and in countries in which men are few and vegetation abundant, and typhoid fever, which occurs in towns and in places encumbered with human beings.

Overwork increases the dangers of overcrowding by a very simple mechanism, by increasing the quantity of the miasma discharged by men living in a confined space.

A dormitory occupied by forty men, who have just made a forced march, is much more charged with miasma than one in which an equal number of men, who have not performed any muscular work, are sleeping. It is enough, if we would be certain of this, to go into a barrack room on the morning after a long march. There is a very peculiar and repulsive odour which is almost unbearable. Notwithstanding all the jokes made at the expense of the foot-soldier, it is not the feet of fatigued men from which this pestilential odour arises, but from their lungs and from the whole surface of their skin.

There have been many opportunities of observing facts which agree with this opinion of the poisoning of man by man, and of seeing that these intoxications by the human miasma are the more serious, the greater the fatigue endured by the persons producing the toxic substance has been.

We read in the history of the Indian Mutiny the following fact :—

A regiment of Sepoys, after being defeated by the English, took to flight, and the 800 men who survived were hunted down like wild beasts during three days.

* *Griesinger*, Maladies Infectieuses.

Being utterly fatigued, the unfortunate men took refuge in a small island, where they allowed themselves to be taken without resistance, like hunted animals. After their capture, 180 of them were confined in a small room to wait until they were shot. The following morning, when they were to be led out to execution, three-fourths of them were dead. The confinement of these overworked men in too small a space had caused the accumulation in the air of the dungeon of a great quantity of miasma, the absorption of which had caused the death of 135 of the prisoners. The 45 remaining suffered from febrile disorders of a typhoid character, and most of them died after thirty or forty days' illness.

It is, moreover, to overwork that we must attribute the greater number of certain disorders which are generally referred to the heat of the sun, and wrongly called *Sunstroke.*

In a military column marching on a very hot day, men are often seen suddenly to fall unconscious, and sometimes to die on the spot. These serious attacks are usually attributed to the heat of the sun. We believe that two factors are needed to produce the sunstroke from which a young soldier suffers when marching under an August sun. The sun is certainly one of the factors, but work is the other, and much the most important of the two.

Let us recall how the body relieves itself of the excess of heat developed in it by muscular work. We know that the vaso-motor apparatus sends more blood to the skin in proportion as the blood is heated by work; the body thus cools by radiation with a rapidity in proportion to the difference between the temperature of the surface of the body and that of the surrounding medium, this medium being supposed the cooler of the two, as is always the case in temperate climates. If the surrounding air is much cooler than the body, the blood in passing through the skin becomes almost instantaneously cooled. If, on the contrary, the external temperature is higher than that of the body, the cutaneous surface should gain instead of losing heat by radiation.

In spite of this result, so unfavourable to the cooling of the blood, the body, in a state of rest, can easily defend itself from invasion by external heat, thanks to the cooling produced by the evaporation of sweat from the skin, and the transpiration of vapour by the lungs ; it is for this reason that it is possible, without any serious consequences, to spend some minutes in an oven, the temperature of which greatly exceeds that of the air in the hottest summer. But if to the action of the high temperature there is added that of muscular work, the organism has not only to fight against the heat of the surrounding medium, it has also to defend itself against the increased heat developed in its own organs. It is deprived, in this unequal contest, of the assistance of the vaso-motor apparatus, the action of which has become useless. The blood, constantly carried to the skin, can no longer lose heat by radiation in a medium already hotter than itself, and returns to the internal organs, carrying with it almost all the heat produced by work.

There is a very clear distinction between our way of understanding sunstroke and that in which it is ordinarily explained. We do not believe that the sun kills a man by giving him more heat, but simply by preventing him from getting rid of the internal heat, which is being produced in excess. The practical importance of this distinction is at once evident. A man who succumbs during a forced march, under a hot sun, is not killed by the sun, but by the forced march. He does not die of sunstroke, but of overwork, and consequently if he were not overworked, the sun alone could not kill him. The sun is not the essential cause of the accident, it is merely an accessory condition.

In our temperate climates we never see cases of fatal sunstroke in men exposed to the heat of the sun, unless these men have been doing some fatiguing work. A man under the powerful sun of July may perhaps have a *sunstroke,* if his skin is delicate ; he may have a congestion of the brain if his head-covering is not sufficient ; he may suffer from very various disorders due to the excessive heat : a fainting fit, an attack of indigestion, etc., but never from any fatal illness, unless there be complication with some other disease, or some constitutional vice, which will have no connection with sunstroke properly so called.

Cavalry officers know that their men are rarely attacked by sunstroke, while the horses which carry them often succumb to it. It is among the infantry that sunstroke is almost exclusively observed, especially in forced marches and when the men are heavily laden. The infantry officer, who carries no baggage, is much more rarely attacked than his men, and among the latter the so-called sunstroke always fixes on those who are least accustomed to fatigue. In the cases of sunstroke reported every year in connection with the great manœuvres, the soldiers who succumb are always reserve men who have passed without preparation from muscular inaction to excessive work, and are placed, in consequence, in the conditions most favourable for the production of overwork.

The same observations have been many times made as regards animals. It is a matter of common notoriety that horses are so much the more liable to sunstroke, the fatter they are, and the less trained by daily work.

Men inured to fatigue, those who daily do hard work, rarely suffer in the way we have just described. We never see in the country a peasant die of sunstroke. And yet no regiment performing manœuvres ever supports the heat of the sun longer and with as much disregard of precaution as do the reapers.

To sum up, the heat of the sun cannot alone cause death, except in tropical climates. The cases of so-called sunstroke seen in our temperate countries are indeed due to an increase in the temperature of the blood, for a temperature of 112° F. has been noticed in dying persons; but this excessive temperature is not the result of the heat of the sun, it is a consequence of excessive vital combustion.

What kills a man in so-called sunstroke is overwork, from which he suffers in ill-understood hygienic conditions, but it is not the sun.

CHAPTER IX.

OVERWORK (*concluded*).

A Phthisical Hercules—The Overtrained Horse—Chronic Overwork—Exhaustion through using up of the Organic Tissues—Difference between the Physiological Processes of Acute and of Chronic Overwork—*Auto-Intoxication* and *Autophagy*—Dangers of excessive Expenditure—Defective Balance between Expenditure and Income—Impoverishment of the System by excessive work—Atrophy and Degeneration of Muscles—The Calves of Runners—Overwork of the Heart-Muscle—The *Over-Driven Heart*—Nervous Forms of Overwork—Anæmia of the Nerve-Centres and Exhaustion of the Nervous Substance—*Epilepsy of Walkers*—Observations on Peasants—Insanity from Overwork; Influence of Harvest-Time on its Frequency—Frequency of Neuroses in Overworked Peasants.

ONE day, passing before a booth of acrobats, we were struck by the sickly appearance of a man who was haranguing the crowd, and all the while juggling with cannon-balls and dumb-bells. He was a great, raw-boned fellow, with a starved appearance, drawn features, long and slender limbs, but none the less seeming to have great muscular strength, to judge from the ease with which he handled his weights.

The booth was a wretched one, and the spectators far from choice, but the desire of seeing at work this Hercules of phthisical build overcame our self-respect, and going up the inclined plank which took the place of a staircase, we entered the establishment.

Then we could see the man more closely and assure ourselves that his limbs, in spite of the strength shown by his performances, were thin and fleshless. His thin thighs, which worked wonders in French boxing, no longer filled his tights, which fell in numerous folds. Finally a weak and hoarse voice, with a few fits of coughing, made us believe that this strong man had an extremely delicate chest.

When the performance was over, we found it easy to become initiated into the mode of life of this man who seemed to us an interesting case for study. Hurrying from fair to fair he worked excessively hard, giving ten performances a day, in each of which he had to throw one or two opponents, not to speak of single-stick, French boxing, and juggling with weights and dumb-bells. His muscles were rarely idle, but they did not increase in size, far from it. It is true that his diet was not fattening, and he only dined well when the takings were good. The strong man, becoming more confiding, spoke to us about his health, and we could easily understand that he was phthisical. In fact, shortly afterwards we heard that he had fallen a victim to pulmonary phthisis.

Such is often the end of strong men, who, beginning by mastering fatigue, after going through a training which enables them to work to excess without feeling the discomfort of fatigue, exceed the limit of their strength, and do not repair their loss by substantial diet.

Trainers have a very striking expression when they wish to describe a horse which has been overtrained; they say that the horse has become *stale*, this means that the excessive work it has undergone has consumed not only the reserve materials, fats and other substances not directly concerned in movement, but the combustions have attacked the horse itself considered as a machine, and its muscular tissues, the essential motor organs.

Similarly our Hercules at the fair had been *used up* by excessive muscular work. He offered a type of a kind of overwork very different from that we have previously described, and which we shall call *organic exhaustion*.

I.

The form of overwork which we call organic exhaustion is a condition of chronic fatigue in which the organism, instead of absorbing the noxious products as in acute fatigue or febrile overwork, is despoiled of its useful materials and of the tissues most necessary for life.

This condition represents usually the chronic form of fatigue, but it can come on very quickly when there is inanition as well as work. There results a defective balance between income and expenditure.

If a man performs violent exercise and his nutriment is proportioned to the work, the system can repair its losses; and the work having a tendency to distribute the assimilated materials to the organs which participate in the action, the muscles benefit from the excessive nutriment, and the machine becomes stronger. But if insufficient food is taken, or, what comes to the same thing, if the nutriment introduced into the stomach is not assimilated, there is a disproportion between the expenditure of heat demanded by the animal machine, and the quantity of fuel supplied to it from without. Now movement cannot occur without heat, and heat cannot be produced without combustible materials. Thus, in default of sufficient food, when the reserve materials have been consumed the essential organs of life have to serve as fuel. A man who eats little and works much may be compared to those unfortunates who, having exhausted all their fuel, make up for it by burning the remains of their furniture.

It is not always a profession demanding great muscular force which leads to organic exhaustion. It is rather an occupation needing a great many hours of work. The combustions are not in this case very violent, and there is time for the elimination of the waste-products formed by them: the products of dissimilation do not accumulate in the system, there is no auto-intoxication, but many organic substances are burned, and the body suffers.

It may happen that a man becomes exhausted without experiencing the slightest discomfort from fatigue, and may go on with his work, steadily losing weight. But when the system is deprived of some of its essential materials, he falls into a condition of "diminished resistance" and can no longer defend himself against the numerous injurious influences which may act upon him from without. Exhaustion is the most important predisposing cause of all diseases.

It is convenient, we think, to make a capital distinction between overwork by intoxication and overwork by exhaustion. In the first case there is an infective condition, which may be influenced by various affections acting from without, but capable in itself of producing serious illness, and even death. In the second case there is a condition of lowered vital resistance, giving to the organism greater receptivity for diseases, but not capable of being in itself an illness.

Take an *exhausted* man, put him in better hygienic conditions, shield him from all germs of contagion, he will certainly restore in time the tissues he has lost. But give to a young soldier overworked by forced marches, or to an animal which has been hunted, all the best conditions of repose, food, and hygiene, it may happen that neither will escape a serious illness, and both may die.

Organic exhaustion is the condition in which a man who has suffered excessive losses finds himself. He presents an analogy with all morbid conditions characterised by a considerable diminution of the organic elements of the living body. Now every important subtraction of materials which form an integral part of the organism induces a general condition of weakness and adynamia.

It is well known that exhaustion results from too copious sweating caused by excessive heat or by any other agent. This phenomenon causes sufficient loss of power for great importance to be attached to its prevention in exhausting diseases, phthisis for example.

Diarrhœa is a still more active cause of exhaustion than sweating, and it will carry off nursing infants in a few days if not successfully checked at the onset. The cholerine of adults, by the rapid and abundant loss it occasions, also causes profound prostration in a few hours. Every one knows the profound and long-lasting exhaustion caused by great loss of blood.

All fluxes, all losses from exaggerated secretion, cause a diminution of the strength and resisting power of the patient, and render him more liable to suffer from all causes of disease to which he may be exposed.

Considering these facts we may enunciate this axiom :

Whenever a man is in normal condition a considerable loss of weight is a proof of diminished power of resistance.

The organism needs, to be truly strong and resisting, a certain mass of elements ; if we take them away on one side we must restore them on the other, and what we remove as fat from a man or a horse during training, we must restore in the form of muscle, under pain of throwing him into an enfeebled condition which lessens his power of resistance.

Why does the organism deprived of a part of its elements fall into a condition of diminished resistance ? It is difficult to give a satisfactory answer to this question. We may say that the elements of the body draw a mutual support from each other, and that in the struggle for existence each contributes its part for the common defence.

The essential elements of the blood are the corpuscles. When these elements are diminished in number, there is a condition of lessened resistance throughout the system. So much importance is attached to the number of these corpuscles when we wish to judge of the gravity of the condition of the patient, that apparatus have been designed for their enumeration. There is no absurdity in attributing to elements forming muscular fibre, or to nerve-elements, the same importance as to the blood corpuscles in estimating the power of resistance of the organism.

However incomplete the theory, let us keep fast hold of the facts, and endeavour to throw light on them. Let us above all endeavour to render clear the practical importance of an exact knowledge of the state of exhaustion, and of the conditions in which it is produced.

II.

Exhaustion due to muscular work generally makes itself felt throughout the whole system, and all the functions, all the organs, seem to experience its influence. The most striking symptom of this phase of overwork is a condition of general languor of the functions and prostration of the powers, a condition of adynamia. We may notice in an exhausted man, anæmia, neuropathy, digestive disturbances, muscular weakness, etc.

Sometimes the disturbances seem to be localised in certain organs, or in certain organic systems, according to the form of the work which has caused exhaustion, and according to the accessory conditions under which the work has been done by different individuals.

The fact which most strikes one who observes a man exhausted by muscular work, is the diminution in size of the muscles which have worked to excess. The man who exhausts himself by work burns up his muscular tissue, and we thus see that two opposite causes lead to the same effect. Muscle atrophies from inaction, it atrophies also from over-use; whereas moderate work, accompanied by sufficient nutriment, increases its size and strength.

Exhaustion may show its effects in several internal organs, notably the heart. The heart, being a muscle, should hypertrophy under the influence of muscular work, for all increased exercise causes increased action of the heart-muscle. Usually, in fact, this organ does become hypertrophied in the true sense of the word, that is to say it becomes thicker, heavier, with stronger walls and able to propel the blood more vigorously. *True* or *concentric* hypertrophy of the heart has been observed in many athletes and gymnasts. It has also been seen in race-horses, notably in the celebrated Eclipse, whose heart was five or six times the normal weight. But in the heart, as in other muscles, excessive exercise induces wearing and degeneration of the fibres, lessens the resisting power of the organism and, while producing dilatation of the cavities of the heart, at the same time leads to a thinning of their walls and to diminished strength of their fibres.

This condition is very often observed in persons who have abused exercises capable of inducing overwork of the heart, running for instance. Professional runners, some of whom in Africa traverse almost incredible distances, are in the end usually affected with passive dilatation of the heart, resulting from exhaustion of the organ. They have generally to cease active work towards the age of forty years, and they then suffer from the serious disturbances of health produced by cardiac affections.

Sometimes the action of exhaustion is especially manifested on the central nervous system, and the exhausted man becomes neuropathic.

Nervous exhaustion is a condition which has been observed and studied under different names in all periods, and of which now, more than ever before, we daily see examples. It is the termination of intellectual as well as of physical overwork, and is also the result of excessive enjoyment, which however does not prevent its being also an accompaniment of violent grief, and all forms of intense mental disturbance. All the physical and moral causes which demand an undue quantity of work from the nerve-centres can induce a state of fatigue analogous to that observed in muscles after over-use.

We shall show later how certain physical exercises need the energetic co-operation of the nerve-centres in the work of the muscles. These exercises, if practised to excess, can then lead to excessive destruction of certain elements of the nerve-fibres and cells. It is necessary to perform an intellectual operation, to coordinate, weigh, and measure, the action of the muscles in all exercises of precision. Hence the neuropathic form of overwork is rather the result of such exercises, than of those grosser forms of work which merely demand a mechanical employment of physical force. Hence the superiority of movements which need no application, no apprenticeship, when we have to deal with patients whose nerve centres are already over-worked by intellectual labour.

Whatever exercise is practised, however, it may induce nervous exhaustion, for the nervous substance must come into play to produce contraction of the muscular elements, and when the brain is not required to produce movements — in automatic actions for instance — it is the spinal cord which comes into play, and it is this which must feel, if the work is excessive, the effects of overwork. It is thus that the coincidence of epilepsy with forced marches has been pointed out, and many observations have been made in which convulsive disorders have followed the traversal of long distances on foot in a very short time.

But nervous exhaustion may be established as a result of overwork in a more indirect manner. Excessive work may produce an impoverishment of the blood, a condition of anæmia which, while affecting the whole system, may more especially influence the nerve-centres in predisposed patients.

Mental physicians have long pointed out that exhaustion and anæmia of the nerve centres is a frequent cause of certain forms of melancholia. We have ourselves been able to observe that physical overwork, impoverishing the constitution, often leads to certain remarkable disturbances of the cerebral functions.

During a country medical practice of eleven years we have been struck by a considerable number of cases of mental alienation coming in series at certain periods of the year, and especially struck by the fact that all these cases presented the type of melancholia. As a rule, these patients recovered pretty speedily, and their mental disturbances disappeared in two or three months, without the necessity of confining them in an asylum. After for some time seeing nothing in these numerous cases but series, simple coincidences, we came to understand the bond connecting them. We had to do with cases of nervous exhaustion from exaggerated physical fatigue.

The beginning of the autumn was always the time when we observed these cases of transient insanity, and it is just at this time that the great labours of the harvest-season come to an end.

For those who know the life of the peasant in France, the harvest season means the season of overwork. In ordinary times country-people make no great expenditure of muscular force. They are always on their feet, always exposed to bad weather, always engaged in work which keeps them in the open air and habituates them to exposure, but it is work which demands neither great speed nor great muscular exertion. But at the end of June, there begins a period of three months during which the peasant is mowing and reaping, working fast for fear of rain, carrying heavy sheaves or great loads of hay. The countryman is then leading an athletic life and sweating profusely, for he works under a burning sun. He does not repair his strength by sleep, for he gets up very early in the morning ; his bed is uncomfortable, he is eaten up by parasites of all kinds, further he is ill-nourished ; instead of eating heartily every day the peasant prefers to feed like a wolf, and he reserves himself for two or three great feasts in which he gorges himself until he is sick.

Excessive work, excessive perspiration, insufficient food and sleep, such are the influences to which the peasant is exposed every summer. From these fatigues there do not usually result the febrile disturbances which we have described as occurring in persons who abuse work without preliminary training, for the peasants, who work always, are always in training. The reaping which overworks them does not produce in them that intoxication by waste-products which we see in persons passing from inaction to forced work. The peasant, wasted by daily work and underfeeding, has none of those tissues of luxury which we have called reserve materials. Hence in him fatigue does not show itself in the form of poisoning of the system and of infective fevers of a typhoid character, but by a condition of exhaustion of varied type, in which nervous disorders play a great part.

Owing to a widely spread error, it is generally said that work in the fields frees the peasant from the nervous disorders so common in towns. Public opinion on this matter is founded on the ideas of J. J. Rousseau, and other intuitive hygienists, who pretend that, given exercise, open air, and pure morals, no illness is possible. It is merely necessary to open our eyes to assure ourselves that these preconceived ideas are far from being in accordance with the facts.

In country-women especially we are able to study the phenomena of exhaustion. Like the men they work, perspire, sleep ill and feed badly. Further they have to care for and suckle their usually very numerous children. The life of a young mother of a family in a peasant household is a life of continual exhaustion. Hence women in towns are wrong in believing themselves to have a monopoly of nervous disorders. There are as many neuropathics in the country as in the town, but the neuropathics of the country have not such noisy manifestations. This moderation in the symptoms is due to the simple fact that these patients have not time to complain, and the persons around them have no time to sympathise with them. They do not suffer less, but they hide their suffering more, for fear lest their husbands should add to it by ill-treating them. But neuralgia, gastralgia, vertigo, and neuroses of all kinds are the chief illnesses of peasant-women exhausted by work. As regards hysteria, if its complete manifestations, in the form of seizures, are rarer than in the town, this is due to moral causes which we must point out in passing. For women of the world "to be nervous" is a mark of distinction, "to have crises" is always a means of awakening a lively interest in the persons around. In the country a "nervous crisis" is synonymous with an attack of epilepsy.

The salutary fear of epilepsy which exists in the country is a powerful protection against the convulsive movements and the contortions of an hysterical fit, in which moral causes play so great a part.

CHAPTER X.

THE THEORY OF FATIGUE.

Fatigue is a Regulator of Work—Organic Conditions which hasten the onset of the Sensation of Fatigue; Weakness of the Organs; Excess of Reserve Materials—Order and connection of Phenomena of Fatigue—*Local* and *General* Fatigue; *Immediate* and *Consecutive* Fatigue—The different Processes of Fatigue: (1.) Traumatic Effects of Work on the Motor Organs. (2.) Auto-Intoxication by the Products of Dissimilation. (3.) *Organic* Exhaustion through *Autophagy*. (4.) *Dynamic* Exhaustion through Expenditure of all the Force at the Disposal of the Muscular and Nervous Elements. Insufficiency of existing Physiological ideas for explaining all the Phenomena of Fatigue.

WE have reviewed the principal physiological phenomena which accompany work, and the changes in the organism which result from muscular activity. We can now briefly sum up and expound the conclusions to be drawn.

Taking a muscular action from its outset, the muscular contraction, and studying it to its termination, which is consecutive fatigue, or stiffness, and to its most serious pathological consequences, overwork and organic exhaustion, we can give a complete picture of the phenomena of fatigue, and we can formulate a rational theory.

I.

Fatigue is the consequence of the material action exercised by work on the organs of movement and on the great organic systems which associate in exercise. The sensation experienced by the individual after excessive muscular activity is a true regulator of work, which becomes the more sensitive the greater the danger which the exercise is causing the organism.

In a much enfeebled man the sensation of fatigue is very painful: this is because in a very feeble body the organs, having less resistance, undergo more easily the damages due to fatigue. In a man of inactive life, whose body is overcharged with reserve materials, very intense fatigue is produced by very little work. This is because violent exercise would, owing to the excessive quantity of reserve materials, very quickly induce stiffness and overwork.

If we examine together the phenomena of work and the phenomena of fatigue, it is easy to see that the one set is derived from the other, and it is easy to grasp the relations of cause and effect by which they are united.

When a muscle contracts forcibly, there occur in all the sensitive parts of the region performing the work shocks and frictions which cause pain. There occurs further in the muscle, by the very fact of work, a process of dissimilation leading to the formation of organic poisonous substances, and the presence of these products of combustion is the cause of the sensation of local powerlessness experienced in a muscle which has been at work.

But the whole organism associates in the work of a single muscle. By the very fact of muscular contraction the blood undergoes an acceleration which necessitates increased activity of the heart. The lungs receive more blood than usual and become congested, the respiratory movements are increased in frequency. Then a new cause of discomfort comes into play, the saturation of the blood by carbonic acid, resulting from the combustion of work. A general suffering in the system results from this transient intoxication, against which the lungs strive by their efforts to expel the noxious gas: breathlessness comes on.

To breathlessness are added the painful sensations due to the heating of the blood, and to the influence which this overheated blood has on the nerve-centres, and thus is completed the picture of General Fatigue following exercise.

But as soon as the work is over, the functional disturbances of the heart and lungs diminish, through the slowing of the blood current. At the same time the production of carbonic acid diminishes, and the excess which had been formed is rapidly eliminated. The temperature of the blood falls through radiation, and through evaporation of the sweat with which the body is bathed.

All disorder should then cease, but if the exercise has been carried too far, the organism, notwithstanding the muscular repose, finds itself under the influence of a persistent suffering which is Consecutive Fatigue. The limbs which have been at work still suffer from some pain which is not entirely dissipated by repose, for the muscles have been subjected to actual mechanical lesions during the work: shocks, little lacerations of fibrillæ, frictions of surrounding sheaths and synovial membranes, contusions of joints.

But there are other troubles which are not to be explained by any mechanical cause: these are the fever, the general discomfort, the feeling of weakness and prostration, symptoms indicating that the organism is under the influence of a toxic agent. These disorders are due to the passage into the blood of the products of dissimilation with which the muscles are loaded, and which the blood gradually removes from the muscular fibres in order to carry them to the kidneys whose office it is to remove them from the system. The cleansing of the muscular machine by the blood lasts the longer the greater the amount of dross left by the exercise.

During the time which elapses between the formation of these waste products and their expulsion by the urine, the system is in a condition of real poisoning, whence arise the fever of stiffness and the sensation of general discomfort. The nitrogenous waste-products to which febrile stiffness is due, are slowly removed from the muscles and slowly eliminated by the kidneys. During the time preceding their elimination the organism is under their influence and is struggling against them.

Thus is explained the slow onset of consecutive fatigue, and its persistence after the work is over.

Finally, if the waste-products are too abundant, or the resisting power of the organism insufficient, these noxious substances give rise, by a process of which we are ignorant, to other similar substances, which renew themselves in the blood during many days, and give rise to the severe fevers of overwork.

We are thus led to say that the starting point of all the general phenomena of fatigue is a poisoning of the organism by its own products of dissimilation. All the phases of general fatigue, from the simple discomfort which causes momentary muscular powerlessness, to extreme breathlessness to which animals succumb, and to the fever of overwork which simulates typhus, are due to these more or less active poisonous substances, retained a longer or a shorter time in the blood.

But all the disturbances of nutrition which follow work are not to be explained by an auto-intoxication of the body. In certain forms of overwork we see the processes of nutrition carried on by feeding on the tissues most essential to life. The reserve materials being exhausted, the tissues forming the woof of the organs are in turn attacked, and the body, instead of assimilating its own noxious materials, as in the other forms of overwork, robs itself on the contrary of the organic elements indispensable to the equilibrium of health. There is no longer, in this case, auto-intoxication, but *autophagy* and exhaustion.

II.

Among the phenomena of fatigue there is a whole series of which the methodical classification seems at present impossible, because too little is known about them. They cannot be classed with the mechanical phenomena, such as the little lesions from which the muscle suffers, nor with the nutritive disturbances such as the intoxications due to waste products, and the exhaustion due to diminution of the mass of the organic tissues. We shall call them the *dynamic* phenomena of fatigue, because they seem to manifest themselves simply by a loss of force, without any lesion, any chemical change, any loss of substance, being discoverable in the organ. When we hold the arm outstretched, at the end of five minutes we are forced to lower it by fatigue.

What has happened in the muscles during the short time contraction has lasted? The fatigue is not due to the formation of waste-products; five minutes of contraction would not suffice profoundly to alter the nutrition of the muscles; it is not due to material frictions of the fibres; it would last longer. We can only suppose, in the case we are considering, that there is a *dynamic* effect, a loss of the energy contained in the muscle, without any anatomical change being appreciable in its tissue.

This dynamic fatigue of muscle is quite similar to that which may be observed in nerve-elements after over-use. If a nerve be stimulated very frequently, it ends by losing for a time the power of transmitting stimuli: similarly the nerve-centres lose their auto-motor power when they have been in action too long.

We call an organ which has thus momentarily lost its specific energy *exhausted;* but we must not confuse this dynamic exhaustion with the *organic* exhaustion which we have described, and which is characterised by the diminution of certain anatomical elements. In exhausted nervous tissue, we do not see any diminution in the mass of material molecules, but simply a lessened manifestation of the energy peculiar to these molecules.

Can we discover in fatigued nerves nutritive disturbances at present ill-understood? Everything leads to this belief, for we know that nervous tissue becomes heated and congested when in action. Its work is subject to the same physiological conditions as that of muscle, and its fatigue should be subject to the same laws. But in muscle we have been able to establish that there is an exhaustion of muscular contractility, which seems due, in certain cases, to a similar expenditure of the energy of the fibres, independently of any intoxication by products of dissimilation, and of any material loss in the organ. We cannot then refuse to admit, among the phenomena of fatigue, a series of phenomena due to a simple loss of vital energy in consequence of the very activity of the element which has been at work. We must make a provisional category of these facts under the title of *dynamic fatigue*, and admit that this form of fatigue is due in the nerves and nerve-centres, to a too great expenditure of the force which we will call, for want of a better name, *nervous energy.*

Nervous energy, like heat and electricity, results from the liberation of a force which existed as *latent energy* in the molecules of the nervous substance, from which certain circumstances have caused its discharge. A bar of red hot iron plunged into water cools by loss of heat which the cold liquid abstracts from it. A nerve which is stimulated in order to cause a muscular contraction seems to be deprived by its work of transmission of a certain quantity of energy, and just as the red hot iron had only a definite quantity of heat to give up, so the nerve when at rest had only a limited quantity of nervous energy at its disposal, which has been expended in the work.

The analogy up to this point seems satisfactory; it ceases to be so when we consider that the heat lost by the cooled iron is not spontaneously reproduced, while the nerve, left to itself, recovers its energy after a little time. The provision of force which has been exhausted is renewed without any other condition being necessary than a temporary cessation of expenditure,

Let us suppose there is a large reservoir in which the water gradually accumulates from a very feeble source of supply. Open the reservoir and use the water contained in it to move a water-wheel: after a time the supply of water is exhausted and the wheel no longer turns. But the conduit does not cease to feed the reservoir, and if the outflow is stopped the mass which gradually accumulates will soon become sufficient to move the wheel again. Such is, in default of a satisfactory explanation, the simile we propose, that we may make the succession of the phenomena understood.

We have been obliged to give the reader as complete and clear a theory of fatigue as was possible; the gaps and imperfections in this chapter will be excused, in consideration of its novelty. No author has hitherto arranged after a methodical plan all the phenomena which may be a consequence of work, or has endeavoured to determine their laws.

The phenomena of fatigue are *local* or *general*, *immediate* or *consecutive*. If we endeavour to sum up the physiological laws according to which these phenomena are evolved, we shall see that they relate to four orders of causes:

1. Material lesions of the motor organs
2. Auto-intoxication by the waste-products of work.
3. Exaggerated use of the living tissues.
4. Dynamic exhaustion of the motor elements.

CHAPTER XI.

REPOSE.

Repair of the Animal Machine—Cleansing of the Organs; Elimination of the Waste Products of Combustion—Diminution of Combustions during Repose—Fall of Temperature and Depression of Vital Functions during Sleep—The Duration of Repose must vary according to the Form of Fatigue—Short Period of Repose necessary to dissipate Breathlessness—The Runners of Tunis—Difference in the Rapidity of Elimination of the various Products of Dissimilation—Dynamic Effects of Repose; they are still unexplained—Influence of Periods of Repose in relation to the Conservation of Energy—The English Boxers.

I.

In a steam engine, barring accidents, the work continues as long as the fire is kept up.

In the human body, in spite of the richest diet, muscular movement becomes impossible after a certain period of exercise, and the work is necessarily stopped: the organism has need of repose. The human machine can only work intermittently. But this apparent imperfection is in reality the result of a great superiority to the steam engine. Repose is wanted because of the power of *repair* possessed by the living organism.

The machine at work is slowly but fatally used up: the more work it does, the less it becomes fitted for work. We can calculate in advance the amount of work in kilogrammetres which an apparatus or instrument will be able to perform before it is used up. A cannon is useless after a certain number of shots has been fired. The more a machine performs, the more it deteriorates, and loses its fitness for performance. Contrariwise, the more the living body works, the more resistant, and the fitter for work it becomes. It is a law of vital movement that function strengthens the organ, whereas the working of a machine wears out its wheels.

The organs of the human body repair the losses which they have suffered during work, and make in compensation new acquisitions; now it is a law of life that the losses of work are not repaired during the work, but only after it is over. A period of repose is then necessary that the organs may repair the losses they have suffered during the period of activity.

What is the nature of the actions which join in repair of the organs after a period of activity? These actions are numerous and complicated; some of them are known to us, but we are still ignorant of many.

Repair of the organs is, strictly speaking, a complete renovation of the organs. A muscle which works makes *waste*, that is to say is the poorer for certain portions of its tissue which are detached from the organ and rejected. In their place the blood, drawn to the muscle in abundance by the very act of contraction, carries to it new materials which are installed in place of those which have been eliminated. Every moment a fresh particle is being detached as waste, and its place being taken by a molecule of new formation. In this manner the muscle is in the end entirely renovated, and it is thus that the process of nutrition makes the new instruments of work.

Thus the body is a machine the wheels of which are constantly renewing themselves and undergoing continual repair. It is owing to this repair that the body is not worn out by work.

The blood current passing through a muscle exercises on it a true process of cleansing by disembarrassing it of the waste products of combustion resulting from work. This cleansing takes rather a long time, for according to our observations, twelve, and even twenty-four hours are sometimes necessary for the elimination of the waste products by the urine. During this time successive waves of blood carry off the deteriorated molecules which form the waste products, and at the same time carry to the muscles from which these waste products are being given off, nitrogenous materials which are necessary to replace them.

It is easy to understand that this operation cannot be properly accomplished until the work is over, for the continual formation of new waste products annihilates the result of the cleansing performed by the blood current. The materials for the re-formation of the tissues cannot be assimilated by the latter while they are still loaded with waste products which, pending their expulsion, act as foreign bodies, and the muscle is not repaired.

The result of an insufficient period of repose will then be, on the one hand, the accumulation of the materials damaged by combustions, and on the other defective repair, insufficient nutrition of the organs of work.

It is in this way that auto-infection by the waste products of work, a consequence of overwork, is produced in individuals who have to work for too long a time, and whose periods of rest are too short and too infrequent. Further, insufficient repose leads to exhaustion and to diminished mass of the tissues burned up by the work. However abundant the nutriment, an exercise too long continued or too often repeated will lead to loss of flesh, because there is not time for the processes of nutrition to transform into tissue the materials elaborated by digestion.

It is necessary then, in the hygiene of exercise, carefully to balance the periods of work and the periods of repose. The more or less frequent repetitions of periods of repose is as important to define as the quantity of work done.

All exercises do not need the same periods of repose ; the time for which exercises can be continued without inconvenience is variable.

Exercises which produce breathlessness render necessary very frequent rests, but these may be very short.

These exercises produce much carbonic acid in a very short time. This product of combustion can very quickly cause serious accidents: whence the necessity for its prompt elimination. On the other hand it is very volatile and very easily displaced; hence it is very quickly removed from the system in the breath. In certain districts of Tunis there are still commissionary runners or carriers of despatches, called *rekas*, who have an unparalleled power of resisting fatigue and breathlessness.

When a *reka* finds that his respiration is becoming embarrassed he stops, counts up to sixty, and starts afresh. In this rest he regains his breath.

Exercise of endurance causes fatigue less quickly than exercise of speed, but it necessitates longer repose. A walker who is not accustomed to long distances can, if an energetic man, walk for five or six hours without stopping; but if fatigue comes on slowly, it is also slow to disappear, and it would not be merely one or two minutes before he could start again, but one, or even two days. This is because the waste products of fatigue are not in this case, gaseous substances, like carbonic acid and aqueous vapour, and cannot be very rapidly eliminated from the system. These waste products, as we have explained, are nitrogenous substances, solids, sparingly soluble, and needing a long time (six to eighteen hours) for their elimination from the body by the urine. Hence the lengthy period of repose which is necessary. If the exercise is begun again too soon, if the period of repose is too short, new waste products are formed before those which had collected have been eliminated from the body, and their accumulation will become excessive. In this way the various degrees of intoxication due to overwork are produced.

Rest is then the essential condition for the elimination of the waste products of work; for during rest the formation of these waste products is lessened. It is also the essential condition for the repair of the organs, because the process of assimilation in virtue of which repair takes place is hindered by the process of dissimilation which goes on so actively during work.

II.

But the elimination of the products of dissimilation and the repair of the tissues do not explain all the ways in which repose gives to fatigued muscles a new power of contraction.

When the arm is horizontally outstretched, and, after five minutes, fatigue compels us to drop it, it is enough to leave it inactive for a minute to become able to hold it out again. What has happened in the muscle during this period of repose?

It has been too short to allow the blood-current to *wash out* the muscle, and to carry away waste-products which are loading its fibres. Further, a minute would not suffice for the material repair by the substances brought in the blood, of the losses undergone. We must suppose a dynamic effect, although we are unable exactly to say in what it consists.

The muscle, by the very fact of ceasing to work, makes a new provision of this force inherent in its fibres, contractility, which the long effort had exhausted.

This explanation is more like a confession of ignorance than a theory; but, however insufficient it be, it conforms to the facts, in the sense in which it implies the existence of a force peculiar to the muscle, and independent of that brought to it from outside. If we cut off all communication of the muscle with its nutrient vessels bringing blood; if we divide all the nerve filaments which connect it with the motor centres of the spinal cord and the brain, the muscle, thus reduced to the unassisted energy of its own elements, will be able to pass through the alternate stages of exhaustion by work, and of return to power of contraction under the influence of repose, just as if it were still in association with the organs of circulation and innervation. If we stimulate it electrically without stopping, it will become fatigued, and will cease to respond to the current; if we then leave it for a certain time at rest, its power of contraction will gradually be restored, as if its elements were capable of constantly elaborating a certain quantity of contractile force to replace that which has been exhausted by too prolonged contraction.

There is a last category of phenomena for the explanation of which another influence must be invoked, if we wish completely to account for the effect of repose. The cessation of a muscular effort seems sometimes merely to have as its object the stoppage of the pain which contraction is causing in the muscle.

A muscle is traversed by numerous sensory nerve-filaments, and these filaments are necessarily rubbed when a muscle contracts. Everyone knows a phenomenon which shows how painful muscular contraction may become when it is extreme in degree; *cramp* is merely involuntary and exaggerated muscular contraction. It shows how painful are the effects which may be produced by muscular contraction. The pain accompanying the persistent rubbing and shaking of the sensory nerves by the muscle is often the true cause of the sensation which urges and compels us to relax the muscle, and give up a fatiguing position. A thing which seems to confirm this hypothesis is the power possessed by hypnotised persons of supporting during a very prolonged time extremely fatiguing attitudes, such as that with the arm outstretched, without any sensation of fatigue. We may believe that, in these persons, the absence of fatigue is due to anæsthesia of the nerve filaments and the abolition of painful sensations. This anæsthesia is manifested, as is well known, by all nerves during the hypnotic state, for the skin may be pinched or deeply pricked with pins without causing any pain.

Thus to sum up, the effects of muscular repose are these:—

1. The cessation of certain painful sensations when the contractions which cause painful frictions of nerve-fibres and shocks of muscle-fibres cease.

2. Time is given for the elimination of the waste products of combustion.

3. The plastic elements of the blood are enabled to repair the materials removed from the organs during the combustions of work.

4. Finally, time is given to the muscular and nervous elements for making a new provision of energy by a physiological mechanism which is still unknown.

Repose is the condition which is diametrically opposed to work, and the phenomena observed in these two so different states are absolutely inverse. Muscular work causes exaggeration of vital phenomena, and gives to all the functions a greater intensity: it quickens the pulse and respiration and raises the temperature of the body. Rest slows the pulse and respiration and lowers the temperature.

Like work, repose has its degrees, and these degrees are very relative. In a practised runner, to walk for a time is to rest; in the sick man, used to lie on his back, to sit upright is work.

Sleep is complete repose, because in this condition all the muscles of animal life are relaxed, and those of organic life work with less energy. The respiration and pulse are less frequent, the temperature lower than in the waking state. Further, an organ which works without ceasing when we are awake, the brain, rests during sleep, and the circulation in it is less active, as has actually been observed in men with holes in the skull.

The fall of temperature during sleep is a proof of diminished combustion, and of minimal formation of waste products. Further, it has been observed that only half as much carbonic acid is eliminated in the sleeping as in the waking state.

The fatigue produced by continuous work is intense in proportion to the expenditure of force. A violent effort cannot be long sustained; but if the most violent exercise is interrupted by periods of rest which, though very short, are sufficiently frequent, the exercise may be carried on for a very long time.

In prize-fights, the fight is stopped every two or three minutes, and two minutes' rest is taken. This interruption of the fight at short intervals would seem at first to lessen its brutality; but it is really a way of rendering its results more murderous. Formerly, when the rounds were longer, lasting ten minutes, the boxers quickly became fatigued. Their blows became less certain, and produced less serious injuries. Weariness, quite as much as wounds, made it impossible to continue the fight. Now-a-days, with short rounds and frequent rests, the adversaries husband their strength, and their blows are as hard at the end as they were at first. The beaten man has to yield, not because he is wearied, but because he is seriously injured. In spite of their strength and their wonderful staying powers, the combatants could not, without these periods of rest, endure the prolonged fatigues of these fights, which often last several hours.

PART III.

HABITUATION TO WORK.

POWER OF RESISTING FATIGUE—MODIFICATION OF ORGANS BY WORK—MODIFICATION OF FUNCTIONS OF THE TISSUES BY WORK—TRAINING.

CHAPTER I.

POWER OF RESISTING FATIGUE.

Variability in the Power of Resisting Fatigue—Effects of Inaction—Effects of Habitual Activity—Different Mode of Life causes Different Conformation; Frugivorous Animals and Hunting Animals; the Flesh of the Hare and the Flesh of the Wolf—The Labourer and the Scholar—How we must explain "Habituation" to Work.

MEN who have for a long time abstained from bodily exercise, and whose system most keenly suffers from the want of it, are those by whom fatigue is most to be dreaded, and those who have most risk of suffering from overwork. Those who, on the contrary, daily perform muscular work acquire the power of braving fatigue and successfully striving against its most serious manifestations.

But this immunity which is gained by work is very quickly lost by inaction; it can only be preserved by the habitual practice of muscular exercise.

We may say that too prolonged repose is the condition which most effectively predisposes the organism to fatigue. Stiffness is unknown to men who lead a life of continual muscular activity, and the consequences of overwork affect them with difficulty. Fatigue in all its forms and all its degrees especially makes its effects felt on those who take too much rest. We see women who never walk a step in the street; their carriage renders it unnecessary; they do not even make any movements in dressing themselves; they have a maid to save them the trouble. These persons suffer from stiffness if they walk the length of the street. If one day by chance, on the advice of their medical man, they decide upon an hour's walk, they are in bed with a fever the next morning. The doctor is sent for with all speed, and it is explained to him how barbarous he has been to compel his patient to use her legs. On the other hand, a postman in the country walks his 20 to 25 miles a day, goes to bed without feeling any the worse, and wakes up each morning the more fit for his walk.

Moral energy is not the true source of the power of resisting fatigue. In most cases what makes the difference between the power for work of two persons is less the manner in which they are physically and morally endowed than the preparation they have undergone or the life they have led ; it is less a matter of temperament than of acquired aptitude.

Amongst domestic animals there are great differences in the matter of fitness for work. Wild animals, on the contrary, have sensibly the same power of enduring prolonged muscular effort. Two wolves of the same age have nearly the same speed and the same staying power. Two dogs, even from the same litter, often show considerable differences in their power of resisting fatigue. The differences which domestic animals present among themselves as regards the power of resisting fatigue is due to the numerous variations in their mode of life to which domestication leads. The remarkable equality of wild animals, from the same point of view, is due to the similarity of their conditions of existence.

What are the conditions producing power of resisting fatigue ? This question was long ago answered empirically, and by facts. We know that the practice of certain muscular exercises associated with certain rules of diet, called as a whole *training*, very quickly induces in men and other animals the power of supporting, without ill effect, a violent and prolonged exercise which, without such preparation, would have had serious consequences to the system. We also know that, the power of resistance due to training is lost as soon as the animal returns to the mode of life which he had for a time given up.

Why does a man who daily performs muscular exercise acquire, by the very fact of working, the power of working without fatigue? A very simple answer is usually given to this question: it is said that the man has become "accustomed" to fatigue. Those who wish to give their explanation a more scientific ring speak of the "habituation" of the body to work.

If we consider fatigue as pain, it is absurd to say that a man becomes accustomed to fatigue. A man cannot become accustomed to pain so as not to feel it any longer. Ask a man suffering from severe neuralgia if he suffers less because he has been suffering for a long time! It is not right to say that a man accustomed to work "supports" fatigue well. He has not to support it at all, for it is not produced.

A well-trained man resists fatigue easily, not because he despises the painful sensation which habitually accompanies work, in the way in which the Stoics despised pain, but because this sensation is not produced in him, or at least is produced in a very slight and easily bearable degree. Thus the power of resisting fatigue is not due to the greater tolerance of the worker, but to the diminished intensity of the discomfort to be borne.

The power of resisting fatigue is due to a material change produced by an exercise which is often practised in the structure of the organs by which the work is performed. When we say that a man is "hardened" to fatigue, this expression must be taken in its literal, never in its figurative sense. Work produces in all the tissues of the body changes of nutrition which make them more resistant, firmer, which in a sense arms them against shocks and friction, and insures them against the accidents of work. Prolonged repose, on the other hand, makes the tissues softer and more vulnerable.

A gardener who works from morning till night does not hurt his hands by holding the spade; a scholar who performed the same exercise for an hour would complain that his hands were painful. Has the gardener, then, more energy than the savant? No; he merely has a thicker skin. No blisters form on the callous skin which covers the parts of his hands habitually in contact with the tool. This is as evident as it is possible. It gives us an example of what occurs daily in the organism under the influence of work. Every organ which works undergoes a material change, from which results a greater fitness for performing work without being pained by it.

Through daily exercise the muscles become harder and more elastic: they are thus more ready to resist shocks and strains, more fitted also to protect from external violence the sensitive parts which they cover: nerve filaments and internal organs. A well-trained boxer no longer feels a blow with the fist, his flesh has become so hard that it is not injured by the blow; it is the fist of his adversary which is injured by striking it.

Exercise does not merely harden the skin and the muscles; it consolidates all the organs of work. Domestic animals which do hard work acquire tough and solid tendons. Amongst wild beasts there is a great difference between frugivorous and carnivorous animals. The flesh feeders which live by the chase and are always on foot to watch for and pursue their prey, show to an extreme degree the type of the trained animal. Their tendons, the fasciæ which sheathe their muscles, and the muscles themselves, are as hard as wood. To get an idea of the hardness of the tissues in a hunting animal, it is necessary to dissect, as we have done, an old wolf. The knife will hardly cut the tendons and fibrous tissue. Similarly with birds which live by the chase, the falcon and the hawk. All the animals which lead a life of rapine and brigandage are in continual movement, and the uninterrupted exercise changes the structure of their organs so as to give them a surprising power of resistance.

The other wild animals which live on plants have a quite different organization. The hare, the partridge, the quail, saving the flights given them from time to time by the hunter, pass their time in feeding on a nutriment which abounds at every turn; they sleep peacefully and do very little. And their flesh is fat and tender, their muscles soft and saturated with savoury juices. We eat the hare and the quail, their flesh melts in our mouth ; we do not eat the flesh of the falcon or the wolf ; we should leave our teeth in it.

It is the difference of work which causes the marked differences of structure observed in animals. The same differences are to be seen in man. If we dissect a man who throughout life has performed violent exercises or hard work, we are struck by the remarkable power of resistance and by the solidity of all the tissues concerned in movement. We easily understand how these large and firm muscles, these thick and solid fasciæ, these tendons, dry and hard as steel, could resist without suffering all the shocks of work.

The bones themselves become adapted, by an increase in size and density, to the more energetic work of the muscles attached to them. The bones of horses which have done violent work in a circus for some years have been weighed, and compared with those of horses of the same build which have spent their life quietly at grass ; the skeletons of the circus horses were much heavier, their bones were harder and firmer. In man also, muscular work causes an appreciable change in the nutrition of the bones. It is easy to say, by simple examination of a human skeleton, whether the person to whom it belonged has led a life of muscular activity, or if he has lived in physical idleness. The bony points to which the muscular fibres are attached are smooth and regular if the muscles have been inactive : on the contrary if the man was active, the points of muscular attachment are prominent, and there are roughnesses which furnish a stronger attachment to the fibres.

Besides these changes which are so easily discovered in the organism as a result of work, there are certainly many others of which we know less. There is no absurdity in thinking, for instance, that the epithelium of the synovial membranes must undergo, under the influence of the energetic friction caused by work, changes analogous to those occurring in the thickened epidermis, and thus become more able to support severe pressure without injury. Similarly, everything leads us to believe that the nerve filaments which pass through the muscles receive a similar protection. A nerve is surrounded by a fibrous sheath, the neurilemma; the elements forming this protective envelope probably participate in the more energetic nutrition which goes on in all the fibrous tissues in consequence of work; thus, doubtless, may be explained the steady decrease of the pain felt in a region of work. The repeated muscular contractions become less painful because the nerve filaments which traverse the muscle are better protected against the pressures and frictions by a firmer neurilemma.

To sum up, muscular exercise has a considerable influence on the process of nutrition, and it is to this influence that are due the changes which occur in the conformation of a person whose muscles are habitually in action.

The body of a man or an animal, under the influence of a regular exercise progressively increased, is modified in a manner which makes the performance of the work more easy. Herein lies the secret of "habituation."

CHAPTER II.

MODIFICATION OF THE ORGANS BY WORK.

Function makes Structure—Disappearance of Organs when their Function has Ceased; Maintenance of Organs by Persistence of Function—Why Gymnasts remain Supple even in Old Age—Modification of Motor Organs by Exercise—Modification of Organic Apparatus associated with Movement; Amplification of the Lungs—Changes in the Living Tissues due to Work—More active Assimilation; Growth of Muscles—More rapid Dissimilation; Diminution of Reserve Materials—Increase of Strength through Growth of the Muscular Tissues—Lessening of Fatigue; It is due to the gradual Disappearance of the Reserve Materials—How this Result is Explained—Fat causes Breathlessness—By what Mechanism? Insufficiency of admitted Explanations—Theory of Trainers: the "Internal Fat." Objections to this Theory—Practical Observation—Reserve Fat and Constitutional Fat—Fat Runners—Easy Dissimilation of Reserve Fats, causes Breathlessness by Excessive Production of Carbonic Acid—Reserve Proteids and Consecutive Fatigue—Disappearance of Stiffness of Fatigue in Connection with the Disappearance of Urinary Deposits after Exercise—Personal Observations of Fatigue.

I.

THE physiologists say that "*function makes structure.*" This means that the human body adapts itself, by changes of conformation, to any frequently repeated action.

It is always difficult to get a clear idea of anything enunciated in a general and abstract form. We will try to give definite form to the idea we have mentioned by an example. Suppose that a man has suffered from a dislocation at the shoulder-joint, the head of the humerus has slipped out of the articular cavity, and is somewhere in the neighbourhood of it. If not reduced, the luxation will not heal of itself, the head of the bone will not return into the hollow from which it has escaped, the limb will be motionless in the false position due to the accident, and after some months *anchylosis* occurs. If the surgeon is now called in, it is too late to replace the luxated bone; and he can only give this advice, to move the arm as much as possible in the hope of restoring its powers. In fact by regular daily movement of the arm, its functions may be re-established, and although in an abnormal position, it once more becomes capable of action.

We see patients in whom the head of the humerus has lodged between the clavicle and the upper ribs, an inch away from the normal joint cavity, and who yet recover by daily exercise of the arm, a great part of the movements of the limb. If we have the opportunity of making an autopsy in such a case, we find that the head of the humerus has hollowed out a new cavity for itself at the expense of the clavicle and ribs with which it is in contact. If the dislocation is old, and the patient has done much work with the limb since the accident accurred, the new joint-cavity has all the appearance of a normal one. A synovial membrane, articular cartilages, fibrous capsule, in fact all the elements which form a joint, have developed in an abnormal position.

This is known as a *false joint.* A joint, an organ indispensable to movement, can then be created by movement itself.

Thus "function makes structure." But there is a corollary to this law, which may be thus formulated, "the cessation of the function leads to the disappearance of the structure."

In the case just quoted for instance, the articular cavity from which the head of the humerus has escaped, being no longer the seat of movement, soon loses its shape and ordinary structure; the synovia which served to lubricate the surfaces of the joint, being no longer of use, is no longer secreted; the synovial membrane itself disappears; further, the articular cartilages are gradually replaced by bone, and after a time the whole articular cavity fills up and disappears. The cessation of function has caused the disappearance of the structure. The law of the intimate connection of the existence of an organ with that of its function is nowhere more evident than in muscular work. It not only applies to the formation of a new organ by a new function, but also to the improvement of an already existing organ by the fact of more frequent use.

The phenomena observed in a man who performs regular muscular work fully bears out the law we have just enunciated. Muscular work tends to modify the nutrition of all the motor organs and to give to them a structure which is favourable to the performance of movements. If we review all the organs which concur in the performance of work, we see that all are subject to this physiological law of adaptation to function, or, in other words, of improvement by work. We also see, by observing the converse phenomena, that defective function of an organ leads to its decline and to arrest of its development.

Muscles increase in size through work, at the same time as their fibres become free from any clogging materials, and are freed from the fat which hinders contraction. Repose, on the other hand, causes atrophy of the muscular tissue, and the muscle which remains inactive too long becomes infiltrated with fat.

The joints are the parts of the body whose perfect action is of the utmost importance for the proper performance of movement. And there are none which feel more fully the influence of muscular exercise. To learn this we must compare a joint which has long been motionless with one which has undergone repeated movements. That which has been much at work has acquired a marvellous ease of movement; that which has remained inactive becomes in the end anchylosed, that is, the bones forming the joint become ossified together. Exercise of a limb preserves the mobility of its joints, and it is for this reason that gymnasts preserve in old age supple movements and youthful attitudes.

Age tends to cause the deposit of calcareous salts in all the tissues of the economy ; the arteries of the old man are hard and deficient in elasticity ; his fibrous tissues tend to become indurated, and his ligaments are more and more ossified. But continual movement of a joint opposes the tendency to calcareous degeneration ; work renders anchylosis and calcareous degeneration of the fibrous tissues impossible ; as long as a man keeps his muscles at work he remains able to use his limbs. The persistence of function preserves the integrity of the organ.

The internal organs, under the influence of muscular exercise, also undergo changes which favour the performance of the often-repeated action.

The lungs, the air-cells of which are brought more into play by a more active respiration, expand, and push outwards in all directions the osseous walls of their prison ; the thorax expands, the ribs are raised, and the chest assumes a very characteristic convex shape. All professional gymnasts show a kind of vaulting of the part of the chest corresponding to the upper ribs and to the clavicle. Measurements of young soldiers at the Gymnasium at Joinville have been taken, and in a few months an increase has been noted of several centimetres in the circumference of the chest under the influence of muscular exercise.

It is easy to understand how respiration must be facilitated by this increase in the size of the thorax. A much greater volume of air is introduced into the lungs, and the elimination of the respiratory waste-products takes place over a much larger field, breathlessness during exercise diminishes.

The heart likewise undergoes a change in size and structure. Its muscular fibres become larger, and the whole tissue becomes firmer and denser ; it frees itself from the fat which oppressed it, and diminished the elasticity of its fibres. This change favours the performance of exercise, for a vigorous heart drives the blood more energetically, and makes it traverse the capillaries without difficulty. The more energetic impulse given to the blood opposes the engorgement of the pulmonary capillaries during exercise, and this puts out of count a very potent cause of breathlessness; passive pulmonary congestion.

II.

By what mechanism does muscular exercise lead to the changes in the organs of which we have given a brief sketch? To answer this question we must go more fully than we have done into the details of the changes undergone by an organism which works every day, and study the influence of exercise on the nutrition of the living tissues.

The first effect of muscular exercise is to render the vital combustions more active, and consequently to diminish the mass of the tissues on which these combustions feed. But it also causes a more active process of assimilation, that is, a process of adding to the existing tissues new molecules derived from the products of digestion. Hence the second process compensates for the effects of the first, and the losses sustained in the act of work are repaired by new acquisitions which are also a consequence of work.

But these losses and gains, if balanced in quantity, do not take place in the same anatomical elements. Certain tissues are used up by the combustions of muscular exercise, and these tissues are of another order to those which benefit by the increased activity of the process of nutrition. Under the influence of work the muscles increase, while fat disappears. Now these muscles are the organs of work, and their greater development increases the strength of the subject. Fats, on the other hand, are an incumbrance, useless in the mechanical execution of movement, and able to hinder work in various ways. The process of nutrition is then directed by muscular work in a manner which renders the individual fitter for the performance of work.

When we examine the details of movement, we see that at each muscular contraction an increased quantity of blood flows to the muscle, bathes the motor fibres, and remains in contact with them for a long time; in this way the elements of the nutritive fluid can be deposited in the muscular elements, which are gradually increased in size. Fatty tissue undergoes during work chemical changes to which its composition renders it especially liable. It is made of elements which have a great affinity for oxygen, for it consists of carbon and hydrogen. Now oxygen is the most active principle of vital combustions. It is at the expense of the hydrocarbons that the chemical combinations which give rise to vital heat are by preference carried on. At every muscular contraction there is an expenditure of heat in proportion to the force of the contraction, and, according to the most recent theories, it is by the combustion of fats that the heat expended by muscles at work is supplied.

If we endeavour to display the consequences of these facts from the point of view of fitness for work, we shall find that the progressive disappearance of fat and the increase in the size of the muscles are two conditions equally favourable to work.

The increased volume of the muscular tissues leads to a proportionate increase in strength. We know that the contractile power of muscle varies directly as its cross section.

The diminution in the quantity of fat facilitates work, for reasons which we must consider in some detail.

In the first place, the disappearance of the fatty masses amongst the organs lightens the body and facilitates all the movements concerned in changing its place, walking, running, and jumping. This result is one of the most important and most desired in the methods of training which prepare a man for speed. But fat does not only hinder work by its weight: it is a cause of excessive heating of the body during muscular exercise, it is opposed to the ready cooling of the blood owing to its low power of conduction: the body surrounded by a layer of fat tends to preserve its heat as if it were enveloped in a thick layer of cotton wool. When a fat man becomes heated by work it is with difficulty that the heat radiates to the exterior, through the layer of fat with which he is covered, and the blood can cool but slowly. We may observe further the converse of this. Very thin animals bear cold badly. Race horses deprived of their fatty covering by training are very liable to take cold, and cannot, without serious danger, dispense with warm wrappings and comfortably appointed stables.

Finally there is another cause of fatigue which results from the accumulation of fat in the system: it is the facility with which this tissue undergoes dissimilation.

We know that fat is the type of the reserve tissues. The object of these substances is to furnish the supplementary expenditure of heat which may be rendered necessary by an increased muscular work: they are stores amassed in the body, and always ready to serve as fuel for combustion. We may say that these substances do not form an integral part of the organism, and are intermediaries between the organs round which they accumulate, without entering into their intimate structure, and the foods from which they are derived, and form as it were a savings' bank.

The reserve materials, being destined to disappear, have then less power of resistance than those which form the fundamental woof of the organs; hence they especially are attacked by the vital combustions. A man very abundantly supplied with fatty tissues expends more heat, for an equal amount of work, than a man of the same weight whose build is lean, and who is very muscular. The combustions in the fat man seem to be with difficulty held within bounds, and the quantity of heat produced greatly exceeds that which is expended in the work. When a fat man has lost his fat we may say that the yield of his muscles has increased; their contraction is caused by more moderate combustions, and the expenditure of heat tends to approach more nearly the figure of the mechanical equivalent.

But other elements of fatigue tend to disappear in a man who becomes thin, in proportion as his expenditure of heat diminishes; these are the products of dissimilation. These products vary much according to the nature of the chemical compounds which are the source of the heat produced; they are still but little known, but we cannot help thinking that their composition depends upon that of the tissues giving rise to their formation. We must believe, for instance, that the fatty tissues, built up chiefly of carbon and hydrogen, must furnish by their combustion, by their combination with oxygen, much carbonic acid and water. This opinion is confirmed by observation, which shows us how fat people lose their breath, other things being equal, much more quickly than thin ones, and also that they perspire much more freely.

The breathing of very fat men and animals becomes easier in proportion as training removes the excess of fat from their bodies. All trainers know well that this improvement is not merely due to the loss in the total weight of the body, and the lessened work which, in running for instance, has then to be performed. In fact, a well-trained horse, and also a prize-fighter in perfect "condition" may weigh as much as they did at the outset. They have acquired muscular tissue which compensates for the loss of fat.

We believe that this freedom from breathlessness is largely because the absence of the hydrocarbon reserves leads to the elimination of the products of combustion of which hydrogen and carbon form the basis, and particularly to the lessened formation of carbonic acid. A well-trained man must produce, by an equal quantity of work, less carbonic acid than he did before training began.

In training race-horses, great importance is attached to causing the disappearance of fat, and it is well-known that by diminishing the quantity of this tissue, the horse is enabled to breathe more easily. But trainers give a fantastical explanation of this fact: they pretend that the "internal" fat hinders the movements of the lungs, and that by its removal these organs have freer play. This explanation is quite unsatisfactory. Firstly, the lung is, of all the viscera, that least subject to fatty deposit. Further, the immunity from breathlessness during work is seen in all trained persons alike, even in those who have more fat about them than many untrained individuals.

In fact there are persons who, according to the technical expression, "train fat," that is to say, in spite of the work, and in spite of the power they gain of enduring it, retain a large quantity of fat. In these persons a certain amount of fat forms an integral part of the system, and this cannot be lost without at the same time lessening their power of resistance. This fact is well known to men who have to do with horses, and is pointed out in the excellent work of Stonehenge on the training of race-horses. Many gain great speed, and breathing-power, without losing their fat as completely as others.

If we go into the society of men given to athletic sports, we see that the same thing holds true of men as of horses, and it is not rare to meet with very agile athletes, and even professional runners, who show at the same time considerable amount of fat, and very free respiration without tendencies to breathlessness. By the side of these men we may see others who hardly have under their skin two or three millimetres of fatty tissue, and yet—not being trained—get out of breath very much sooner than the persons who are at once fat and in training.

If the fat were only a hindrance by reason of the space it occupies, this would not be the case; but it acts chiefly by the ready tendency it has to undergo dissimilation, or, in other words, by the ease with which it is burned during work. But fat does not always burn at the same rate. In certain temperaments fat forms an integral part of the organic structure; it is a constitutional tissue, it has so to speak freedom of the city amongst the anatomical elements which accompany it. In other persons, on the contrary, thinness is the dominant attribute of their temperament, and all the fat they possess is a superadded element, only forming part of the constitution by a provisional title, and consequently destined to disappear very readily. In some, fat is a "constitutional" tissue, in others it is merely a *reserve*, a provision to be consumed at the first demands of the system.

It is then opposed to the facts of observation to speak of "internal fat" which disappears, and of "external fat" which remains. Fat is equally distributed throughout the system; and if any cause, such as work, brings about a diminution in its quantity, the parts which work most are earliest free from it.

When we see fat men take to fencing in order to get thin, we notice that in them the internal fat is far from being the first to disappear; the abdomen is the region which retains with most tenacity its supply of fat. There can be nothing more awkward than the shape of the body of a man in this ungrateful period when the fat has disappeared from his arms, his chest, and his legs, while his belly remains as large as ever. The regions which have been made to work in fencing have lost their fat; the arms and legs appear slender, and the chest, which has been freed by the work of the pectoral muscles, appears shrunken by comparison with the abdomen which has remained of its original size. It is only by continuing his exercise for some weeks still, that the fat man is able to gain what he above all desires, the diminution in the size of his belly. Now the respiration has become easy and breathlessness has diminished long before the disappearance of the fatty masses of the abdomen, the persistence of which must singularly hinder the vertical enlargement of the thorax.

The diminution of breathlessness in the trained man or horse, is much less due to the greater freedom of the lungs owing to the removal of the fat in their neighbourhood, than to the lessened production of carbonic acid which results from the disappearance of the provisions of combustible tissue which give rise to too great a quantity of this gas.

Persons who practise running very soon gain the power of not losing breath, for running is the exercise which most quickly causes the disappearance of the fatty tissues.

The combustion of the fatty tissues during work gives a satisfactory explanation why the practice of muscular exercise lessens the tendency of a man to become breathless. The man in training has no longer in his system the elements capable of producing this excessive quantity of carbonic acid, as was the case before he began regular exercise. The disappearance of the tissues rich in hydrogen, explains also the lessened perspiration of the man in training. Sweat mostly consists of water, and the burning of a substance rich in hydrogen must tend to cause the formation of an excess of aqueous secretion.

Breathlessness is not the only form of fatigue, just as fats are not the only reserve materials. There are, produced by work, nitrogenous products of combustion which cannot be derived from fatty substances. There are, among the reserve materials, proteid substances, and it is from them that the nitrogenous substances excreted by the urine are derived, which diminish when the organism has for some time assiduously practised muscular exercise.

These substances play the same part in the production of stiffness as belongs to fats in the production of breathlessness. Fat, in being burned, gives rise to carbonic acid and other products rich in carbon and hydrogen; proteids, in being burned, produce a whole series of nitrogenous compounds of which uric acid and the various extractives are the type. We believe—and we hope that we have proved it by sufficiently cogent arguments *— that the nitrogenous waste-products of combustion which are formed during work, and which stay sometimes in the blood when work is done, are the cause of the general disturbances, febrile or non-febrile, which constitute consecutive fatigue or stiffness.

In the man accustomed to work there are no disorders following exercise. This is one of the most remarkable results of training, and would be quite inexplicable unless we were to admit that daily exercise causes the disappearance from the body of the organic substances to which the phenomena of consecutive fatigue are due.

* See pages 111 *et seq.*

We believe that these substances are the nitrogenous reserves contained in muscle. We think that these nitrogenous reserves are contained in the muscles themselves; observation shows that men accustomed to one definite kind of exercise have no immunity from fatigue, and can experience the general effects of stiffness, if they suddenly take to another exercise, bringing into play muscles which have not yet been modified by work and which have not yet lost their reserve materials.

Exercise modifies the muscle then not only by increasing the size of its elements, but also by changing its structure, by eliminating from the organ not only fat, but also the nitrogenous substances capable of giving rise to superabundant waste-products of combustion, which cause auto-intoxication and general consecutive fatigue.

Thus the more we analyse the phenomena of work, the more we see that the frequent repetition of muscular movement produces, in the nutrition of the living tissues, material changes which are able to shelter the system from the various disorders of fatigue.

CHAPTER III.

MODIFICATION OF FUNCTIONS BY WORK.

Increase in the Contractile Force of Muscle—Probable increase in the Power of Conduction of Nerves—Improvement in Faculties of Co-ordination of Movement—Education of the Muscular Sense—Domination of Reflex Actions by the Will; Regulation of the Respiratory Movements—Changes produced in the Nervous System by Muscular Exercise—Material Changes in the Nervous Tissue: Are they purely hypothetical?—An observation of Luys—Functional Changes in the Nervous System—The *Memory* of the Spinal Cord; its Use in the Performance of often Repeated Actions—Psychical Modifications due to Habituation to Work—Skill—Physical Courage—Incredible Energy of Prize-fighters.

WE have studied the material changes which take place in the system in consequence of work; we have just seen how exercise, powerfully influencing the process of nutrition, has the power of changing the organs and of profoundly altering the structure of the tissues of the body. A man used to work shows important peculiarities in his external conformation, and has further very characteristic ones in his internal structure. All the wheels of the human machine have been gradually adapted to the performance of the great quantity of work daily demanded from them, and have undergone a material improvement which renders them more fit for their function.

Under the influence of exercise man is physically transformed, and we may sum up in a few words the changes which have taken place in his system, in passing from an inactive mode of life to habits of work. We may say that all parts of the organism capable of favouring the performance of work have been developed, and all the materials which could be a cause of hindrance in the performance of movements have been diminished in quantity and tend to disappear.

From these two orders of organic modifications there result two different powers acquired by habituation to work : power of producing more energetic movements, owing to the greater development of the motor organs ; power of better enduring prolonged muscular efforts, owing to the disappearance of the reserve materials, the products of the dissimilation of which, when too abundant, lead to auto-intoxication of the body, the most important cause of the phenomena of fatigue.

The material changes which take place in the human body when work is regularly performed, can explain in great part the increase in strength and in power of resisting fatigue. But we should have an incomplete idea of the benefits due to habituation to work if we did not take into consideration another advantage gained by a man who exercises his muscles ; it is the improvement in all the functions which take part, directly or indirectly, in the performance of work.

I.

Under the influence of well-planned daily exercise the muscles do not only become larger and firmer, their power of contraction also increases. "The muscles of a man *in training* contract with extraordinary force under the influence of the electric current" * said Royer-Collard many years ago in his Paper on the training of English prize-fighters. Muscular fibre gains by exercise an increase of its power of contraction and can obey more vigorously the orders of the will, as well as the stimuli from an electric battery. We observe that two muscles being of equal size, the muscle which is in the habit of contracting is stronger than the one which has long remained inactive.

The same improvement is observed in the respiratory function under the influence of work. The lungs have not only been increased in volume by exercise ; they have further gained a greater power of performing their movements with calmness and regularity amidst the violent disturbances in the system which are caused by

* *Royer-Collard.* Paper read before the Academy, 1842.

exercise. In a man accustomed to violent exercise the breathing long maintains its regular rhythm, whereas it is quickly disturbed by work in a man usually inactive.

The heart, besides gaining by well-directed exercise a structure more favourable to work, through being freed from fat with which it may be charged, also learns to work more regularly. It tends to lose that excessive excitability which, in the man who is a novice in exercise, promptly disturbs its regular action on the slightest change in arterial tension, the slightest rise in the temperature of the blood: it no longer becomes uncontrolled when violent exercise is performed.

A comparison may be useful to render these facts more clear, rather than to explain them—for no satisfactory physiological explanation has hitherto been given. A man who is accustomed to work improves his organs, and becomes like a workman who does his work with better tools. But the workman learns from day to day to use his tools better, and in the end makes the best possible use of them. Similarly the man who exercises his body every day becomes better able to use his organs, and gets more work out of them through making them serve him better.

The purely functional improvements which take place in the work of organs through exercise are nowhere so striking as in the performance of movements.

Every movement, even that apparently most localised, is, as we have explained in detail, an action necessitating the concourse of several muscles, some synergic, others antagonistic. It is the central nervous system which has to group together all the muscles which must work for a common end, and to give to each the amount of action which is necessary.

Let us suppose that a certain number of men are employed in moving heavy burthens. If these men, although very strong, are ill directed, if their movements are not harmonious, and their forces are not exerted together, ten of them will not do as much work as five would do if well directed and accustomed to work together.

Similarly, an athlete who has well-trained muscles at his disposal, that is to say, muscles used to work together, will do more work than a stronger man who does not know how to use his limbs.

The work which a man can perform does not only depend on the real strength of his muscles, but also on his knowledge of the way in which to use them.

Muscular education leads to an economy of force. Every muscular contraction in a well-trained man has a direct and useful effect on the desired movement: in an unpractised man the action of many muscles is paralysed by the awkward intervention of their antagonists. It is only after unconscious and often repeated trials that the will knows to which muscle it must apply for the performance of the desired movement. Every movement becomes more perfect through an apprenticeship, because the performance is in the end entrusted to the muscles most fitted for the purpose.

We should be tempted to believe that every muscle has a purpose fixed in advance, and that it is enough to wish to displace a portion of the body in a given direction to immediately know to which muscular group the performance of the movement should be entrusted. In general it is easy for a man, or even an ape, to imitate very faithfully a movement or an attitude shown to him, for, as a rule, these are muscular actions which the individual has already performed often enough. But this is not the case as regards new actions to which the body is not accustomed, and assiduous practice is needed to learn certain movements not already known, or even to improve movements already known.

There is only one useful way of studying movements: to perform them. In doing them ourselves, we easily understand how for each action, even the most insignificant, there are several methods of which the difference usually escape the spectator, but which are felt by the performer. By an apprenticeship we learn to make a choice among these different methods, and to take, naturally, that which represents the greatest economy of force for the work done.

Hence the great difficulty of estimating the strength of an individual by measuring his effort. We may assert that no kind of dynamometer can give an exact measure of the strength of a man, for each has his own way of striking, drawing, or pressing the dynamometer.

What exercise is there which at first sight appears to be more entirely dependent on brute force, to be less subject to muscular education, to be more independent of the dexterity of the individual, than the act of striking an anvil with a heavy hammer? But the force of the blow does not only depend on the strength of the smith. Everyone must have seen at fairs a kind of dynamometric apparatus, consisting of an upright post with a horizontal platform at its base. The man who wishes to try his strength strikes this platform with a long-handled hammer. By a simple mechanism, the blow of the hammer is communicated to a doll, which rises along the post. The height to which the doll rises measures the force of the blow. Now, usually, the most vigorous men do not drive the doll as high as the proprietor of the machine, though he may be a man of quite ordinary strength, for he hashad leisure to practice with his machine, and knows best how to use it. There is method in striking a blow with a hammer; those who have not the trick of the thing hold back their blow, that is, they throw into action muscles which are opposed to the movement. By the antagonistic action of these muscles the force of the blow is lessened, and although there is greater expenditure of muscular strength, since a greater number of muscles are in action, the apparent result is less.

There is method in walking, method in running, method in raising a burthen with as little effort as possible. The practice of an exercise leads then to a diminution of muscular expenditure, to an economy of work, whence results an apparent increase of the strength of the man who does the work.

The influence of education is not only exercised on muscular movements: all the great functions are modified by practice in order to adapt them to the needs of an action performed every day. If the pianist learns to move his fingers with precision and rapidity, the singer learns to breathe deeply and to regulate his breathing, so as not to interfere with the song by an ill-timed inspiration.

In violent exercises the education of the breathing has a capital importance. Experienced runners gain control over the reflex respiratory movements, and make very deep respirations, while novices, obeying blindly the needs of their inexperienced lungs, get out of breath through too precipitate and shallow movements of the thorax. It is possible to regulate the breathing according to certain methodically enunciated principles, but a man attains this regulation just as surely, if not as quickly, by the more or less conscious feeling his way which is necessary in every new exercise.

By daily resisting a reflex movement at first irresistible, it is not impossible to learn to control it. People who restrain tears or laughter, who check a sneeze, or stop a fit of coughing, prove that an energetically directed effort of will can strive effectively against an instinctive impulse and an organic need.

On the other hand it is possible, by surrendering to spontaneous movements, to create real illnesses. Certain patients, coughing habitually to excess, suffer in the end from constant paroxysms of *nervous coughing*, which no remedies cure, unless there be added to them a strong effort of the will.

The education of reflexes, the subjecting of movements which are ordinarily spontaneous to the control of the will, may then lead to great diminution of fatigue in the performance of bodily exercise.

II.

The purely functional changes which occur in the system through practice can only be attributed to the regulating agent of the organic functions, that is to say to the nervous system.

It is the nervous system which presides over all the functions and controls the activity of all the organs. If there is any disturbance in the structure, the nutrition, or simply in the working of the nervous system, various disturbances in the organic functions immediately ensue, notwithstanding the perfect integrity of the apparatus by which they are carried on. In the muscles we see paralyses, contractures or convulsions follow the slightest injuries of the brain, the spinal cord, or the nerves. In the internal organs also we see serious disturbances in the frequency, the rhythm, or the intensity of the movements of the heart and lungs, in the absence of all injury to the apparatus of respiration and circulation, under the simple influence of a transient disturbance of the circulation in certain parts of the nerve centres. Finally the glands may present a complete perversion of their secretions under the influence of the slightest lesions of the nerves by which they are supplied.

We can only attribute to the nervous system, and to changes in its elements, the improvements observed in the working of the organs when these organs show no changes of structure capable of explaining them.—If a muscle after reaching the maximum development of which it is capable, continues to increase in power through practice, although it does not increase in size, we can only explain this purely dynamic increase in strength by changes—known or unknown—in that part of the nervous system which has to do with its contraction.

Now in studying the structure of the nerves in a man accustomed to work, we can point to no appreciable change, any more than we can in the spinal cord or the brain. Between the nervous substance of a man given to physical exercise, and that of a man habitually inactive it is impossible to recognise any differential characters corresponding to the well defined differences between the fibre of a muscle often at work, and of a muscle usually inactive. But we must admit that the law of the transformation of the organs by practice cannot affect all the organic apparatus of the body to the exclusion of one only. It has been proved that the grey matter of the brain is indispensable to the performance of voluntary movements: how can we believe that its nutrition is uninfluenced, and that no trace is left by this repeated activity, when we see that all the organs which are even indirectly associated in work, the lungs and the skin for instance, have an external conformation and an intimate structure which betray to the experienced eye the habits of work of the possessor.

If it has been demonstrated that "function makes structure," if work changes the apparatus by the aid of which it is performed, muscular exercise must necessarily produce changes in the brain, an instrument indispensable in the performance of voluntary movement. The nervous working which goes on in the grey matter of the brain for the purpose of throwing a muscle into action, must influence the nutrition of this portion of the brain just as much as contraction influences the nutrition of muscle.

The changes in the motor cerebral cell, under the influence of muscular work, have not yet been apparent to the eye, and observation has not hitherto given direct confirmation of these ideas which seem so legitimate on analogical grounds. But one observation has at least been recorded which may serve as an indirect proof of this hypothesis. This is the observation recorded by Dr. Luys in his work on *The Brain*, proving that after loss of the function of a limb certain parts of the grey matter of the brain undergo atrophy, due to defective action of the motor cells. If defective action can cause atrophy of the cells which preside over certain movements, we cannot refuse to admit that their frequent activity should promote their increased development.

It is then probable that certain portions of the brain which preside over voluntary movement are developed by muscular exercise, just as certain other parts of this organ, concerned in intellectual operations, may be developed by mental work. Certain portions of the nervous system form a part of the organs of movement, and we cannot believe that the law "*function makes structure*" should not be as true for the nervous elements as for the other elements associated in work.

The material changes undergone by the brain as a consequence of work, extend in all probability to the spinal cord and the motor nerves.

The motor nerve conducts to a muscle the order of the will, but we have seen * that the stimuli which pass

* Part I. Chapter I.

along the nerve-filament are strengthened in transit in the manner shown by Pflüger in formulating his *avalanche* theory. A nerve is a reinforcing apparatus as well as a conducting organ. We may well believe that a still unknown molecular change increases its amplifying power and thus allows a more moderate voluntary effort to produce a stronger muscular contraction. In any case the man accustomed to use his muscles seems to obtain from them without effort a much more considerable amount of work, and this without an increase in the muscular fibres sufficient to account for the greater ease with which they contract. The nerve seems to transform a moderate stimulus which passes along it, into an energetic one, and a man accustomed to work performs, *without effort of will*, movements which would formerly have caused him excessive voluntary strain.

As for the spinal cord, it acquires by work, powers which cannot be understood unless we suppose there is concomitant organic change: it remembers often repeated movements, and we may see, in an animal deprived of its brain, the automatic performance of complicated muscular actions, such as walking, without the intervention of conscious will.

The power of automatism acquired by daily practice comes to our aid constantly in the performance of difficult and rapid movements. In fencing for instance, many actions often performed have become automatic, and are performed so quickly that there could not be time for the successive co-ordination of all the movements. How can the spinal cord have the power of reproducing automatically without the conscious help of the brain, a very complicated movement, if the repeated performance of this movement had not impressed on the nervous tissues which call it forth, persistent modifications?

Does it seem strange to speak of a movement leaving a material imprint on the nervous tissue? But would it not have seemed strange, twenty years ago, to hear it said that a word spoken aloud should leave on a metallic plate an imprint capable of reproducing it? But the *phonograph* has shown that this was no chimæra.

Thus it is difficult to prove by direct arguments that the nervous system participates in the organic changes produced in the human body by the influence of work. It will doubtless be still more difficult to demonstrate scientifically that the psychical faculties are influenced by muscular exercise, and are modified, by the very fact of work, in a sense favourable to the performance of an exercise which is daily practised. Still it is incontestable that certain faculties of the soul come into play in bodily exercise to excite the contraction of muscles and to co-ordinate movements; it is also incontestable that these faculties are improved and developed by exercise.

The faculties which preside over the co-ordination of movements are developed by the performance of difficult exercises, and their improvement endows a man with the quality we call *skill.*

The faculty which orders a muscle to act and which gives it the stimulus necessary for its contraction, is called the Will: it also is developed and improved by the repeated use made of it. It shows its acquired superiority, in the sphere of movement, by a greater persistence of effort, by a greater tenacity in muscular action. The person who, every day, in spite of the different pains of fatigue, sustains energetic and prolonged muscular efforts, acquires a greater power of *Willing*, and from this acquisition result certain very striking changes in his moral disposition. The habituation to work gives to a man greater energy of will considered as a motor force, and from this change of a moral order, as much as from that of a material order, results a particular form of courage which we may call Physical Courage.

Physical courage is manifestly increased by the practice of muscular exercises. It is almost exclusively in men whose daily work is laborious, or who are given to violent exercises, that we see bold and energetic actions. If we see in the street a passer-by seize the head of a runaway horse or try to stop a dangerous malefactor, we may at once be almost sure that the man is a labourer used to hard work, or a sportsman fond of physical exercises. The practice of muscular work and the habituation to bodily exercise dispose a man to brave all forms of material danger.

The most remarkable proof of the development of physical courage by the habituation to work is furnished by the spectacle frequent enough in England, of a prize-fight. The preparation of prize-fighters is, of all forms of training, that which demands the most complete habituation of the body to all kinds of muscular activity pushed to extreme limits. But at the same time that he acquires the power of resisting fatigue, and increase of strength, the ordinary results of habituation to work, the prize-fighter gains also an energy of will, a tenacity in fighting which is almost beyond belief.

"In a celebrated fight between Maffey and Macarthy, which lasted four hours forty-five minutes, one of them was knocked down one hundred and ninety-six times before allowing that he was beaten." * In another fight one of the champions received in the first round a blow which broke his left arm. He put the fractured limb in a sling and went on fighting for an hour and a quarter, till a blow, which made him lose consciousness for some minutes, compelled him to allow that he was beaten.

This incredible strength of will, which enables the prize-fighter to remain firm before such terrible blows, is not derived from anger. It is an axiom in prize-fighting that "a boxer who no longer smiles is a boxer beaten." † When the open mouth of anger replaces the smile on the lips of one of the champions, betters abandon him and his opponent becomes the favourite. It is only training, that is, habituation to violent and prolonged muscular exercise, which gives such a surprising energy to these men, whom Royer-Collard declared to be "so different from other men."

* *Royer-Collard. loc. cit.*

† *Leboucher.* Manuel de Boxe.

CHAPTER IV.

TRAINING.

Various meanings of the word *Training*—Training, as we understand it here, is the Adaptation of the Organism to Work—Natural Training and Methodical Training. Methods of Training; rarely put in force in France; very widely Practised in England—Training of Boxers—Training of Oarsmen. A Specimen of Method—Physiological explanation of the Phenomena—The Loss of Weight; Diet; Care of the Skin—Capital Importance of Muscular Work in Training—Temperament of the Trained Man. Advantages and Disadvantages of his Condition.

I.

WE call *training* a series of practices the object of which is to render a man or an animal, as completely and quickly as possible, fit for the performance of a given work.

The word training is often used in a wider sense. It is used as synonymous with "preparation," and is applied to methods in which muscular work plays no part. Thus divers are *trained* in order that they may be able to hold their breath longer; jockeys are *trained* to make them lighter, and to facilitate the work of the horse which carries them; the word is even used in an intellectual sense, and we say that cerebral training improves a man's understanding.

In reality all the varieties of training may be reduced to one: adaptation of the organism to certain particular conditions of activity. To be *trained* implies that the organs have undergone modification; we may believe that the brain of a man of science differs from that of a porter; we are certain that the conformation of a prize-fighter in perfect *condition* is not the same as that of a student.

But we must say that the changes in the structure of the organs produced by training are not very profound: they are quickly produced and quickly disappear.

A man in training has for the time a particular temperament. He has acquired a new conformation which gives him special aptitudes, but in nature he is unchanged; if he returns to the mode of life he relinquished when he began training, he at once loses all the powers he had gained. To keep himself in the trained state, or, as trainers say, in *condition*, he must continue the practices which have brought about the perfect conformation of his organs and the easy performance of their functions.

From the point of view of muscular exercise, the condition of training inevitably results from the habituation to work. All professions which demand a great expenditure of muscular strength maintain the persons who practise them in perfect *condition*; they make them as strong and as resisting as their constitution permits.

A very active and laborious life is then enough to bring about in the end fitness for work and power of resisting fatigue, without it being necessary to observe the hygienic and dietetic practices recommended by trainers. Wolves have no need to abstain from certain articles of food, or to limit the amount of water they drink, in order to make their muscles as hard as iron and to have lungs to which breathlessness is unknown.

But we must recognise that the benefits derived from work are gained with astonishing rapidity when the athlete submits to a certain regulation of his diet, and to certain accessory hygienic performances which make up a method much in vogue in certain countries, under the name of *training*.

This method is not yet common in France. In this country the mass of the public only knows of training as it applies to race-horses and jockeys, who are regarded as emaciated beings who are made to fast to an extreme degree in order to reduce their weight.

This loss of weight is however only apparent in race-horses, and generally these animals, angular and thin, weigh at least as much as, and sometimes more, than they did when training began. Only the nature of their tissues is no longer the same; their diet has caused the disappearance of all the materials useless to movement, and developed on the other hand the tissues necessary for work. Their fat has almost entirely disappeared and been replaced by muscle.

The training of jockeys effects only half of this. In them the fatty tissues disappear, but the muscular tissues do not increase; in this manner the loss is not compensated by receipts, and the mass of the body diminishes. In the jockey there is no desire for an increase in muscular strength, only for diminution in weight, for the object is to put as light a man as possible on the back of the horse.

The training of jockeys will not serve as a type in this study; it is an abuse of language to call a man *trained* who is made to become as thin as possible without trying to develop in him any special energy. Training, as we understand it, supposes the acquisition of certain active qualities, of a certain superiority in the performance of the special movements of an exercise. As regards the jockey, we will rather apply the word training to the period of time in which he is learning to ride. The man entrusted with the breaking in of a young thorough-bred colt, undergoes training in the fullest sense of the word, for the struggles of his pupil make him bring vigorously into action all the muscles necessary for keeping a horseman in the saddle, and these muscles are very numerous.

In France the racing stables have *trainers* for their horses. In England men also have trainers who prepare them for walking, rowing, or boxing contests. The betting mania is the origin and the motive power of all these methods intended to give a champion every possible chance; but an unheard-of resistance to fatigue, an incredible vigour, and perfect health, are the consequences of them.

Here are the facts exposed by Royer-Collard in 1842 before the Academy of Medicine, concerning the results of systematic training, which produces this model of a man who has gained the acme of development of strength, and power of resistance, and who is called a prize-fighter.

"The man who has been trained has not sensibly lost weight, unless he was very fat before he got into *condition*. Usually, indeed, he weighs a few pounds more, but his limbs have singularly increased in size. His muscles are hard, prominent, and feel very elastic; they contract with extraordinary force under the influence of an electric shock. The abdomen is retracted, the chest expanded; breathing full and deep, capable of long efforts. The skin is firm, sleek, free from all eruption. We notice that the skin over the axillary regions and the sides of the chest does not tremble during the movements of the arms; it seems to be perfectly adherent to the subjacent muscles. This firmness of the skin and density of the cellular tissue, resulting from the absorption of liquids and of fat, oppose the formation of effusions. (*Comptes rendus Acad. de Médicine.*)

Let us see what the author says about the powers in fight of these men whom we have just described:

"Prize-fighters are naked to the waist, and try to strike their adversary with all possible force anywhere between the head and the umbilicus. If one of them is knocked down, dizzy from a violent blow, he is allowed a minute's rest. Before the whole minute has passed he gets up and goes on fighting, or he is declared beaten. Ordinary fighters, in a fight of an hour and a half, stop in this way thirty or forty times.

"The combat may last for from some minutes to four or five hours. We may imagine that serious injuries, and even death, may be the issue. Sad instances of this have occurred, but they are extremely rare. Usually a few days afterwards there are no traces of these terrible blows.

"A prodigious strength, a singular skill, and incredible insensibility to blows, and at the same time perfect health, such are the phenomena presented by these men, so very different from other men."

To bring a man to this degree of vigour and resistance to fatigue, six weeks are sufficient. During this short period the man performs a gradually increasing quantity of muscular work; but he must also confine himself to a particular diet, and follow certain special hygienic practices.

All methods of training have a double object:— 1. To develop the muscular energy of the subject; 2. To increase his power of resisting fatigue. These two objects are attained by means empirically ascertained, the excellent effect of which has been shown by experience, without, hitherto, a satisfactory explanation having been given. To get an idea of the usual processes of training, it will be enough to read the account of the training of a certain J. G., a butcher, preparing for a rowing match under the direction of Symes.

This training much resembles that of prize-fighters, for its object is to develop the whole muscular strength of the subject, and to increase to the highest possible degree his power of resisting fatigue. It differs however in one important detail; the weight of the oarsman must be diminished as much as possible in order to lessen the weight he has to pull. So it will be noticed that the subject of the following remarks lost 37 pounds in weight, while the prize-fighters are of the same weight at the end of training as when they began the course. We borrow the following observation from Dr. Worthington's work on "Obesity."

We give the regimen followed, and its results:—

"*April 1st.* To get up at 6 a.m., take 40 grammes of sulphate of magnesia, and walk gently for half-an-hour.

8 a.m. breakfast, composed of mutton chop or beef steak, watercress, half a pint of tea with a little milk and sugar, a small quantity of dry bread or toast.

9 a.m. to noon, to walk at the rate of three miles an hour.

1 p.m. dinner, composed of (lean) roast beef or mutton under-done, or well-done, according to taste, green vegetables, three quarters of a pint of old ale, a small quantity of stale bread.

2 p.m. to 4 p.m. to walk at the rate of three miles an hour.

5 p.m. half a pint of tea, dry bread or toast, two raw eggs, beaten up in the tea, or else two soft-boiled eggs.

6 p.m. to 8 p.m. to walk at the rate of three miles an hour.

9 p.m. supper, half a pint of old ale with a piece of dry bread; to walk gently for half an hour.

10 p.m. to go to bed.

Same regimen for three days.

April 4th. To get up at 6 a.m.; to walk gently for half an hour.

8 a.m. breakfast as before.

10 a.m. to dress in several complete suits of flannel for loss of weight (wasting); *to walk for two hours as quickly as possible, and to take a shower-bath immediately on returning, perspiration being at its maximum.* A small glass of sherry or a gill of old ale, if thirst is unbearable.

1.30 p.m. dinner as before.

2.30 p.m. to 4 p.m. to walk at a moderate pace (three miles an hour).

4 p.m. to row two miles.

5.30 tea as before.

April 5th. Result of the course of wasting: *a loss of weight of 8 lbs.*

Exercise before breakfast, breakfast as before.

11.30 a.m. to row two miles, followed by a cold shower-bath.

12.30 p.m. a glass of sherry, or a gill of old ale.

1.30 p.m. dinner as before.

2.30 p.m. to 4 p.m. to walk quickly.

4 p.m. to row one mile *as quickly as possible.*

5.30 p.m. tea.

9 p.m. supper.

10 p.m. to go to bed.

April 6th. Same regimen: to row two miles twice a day, followed each time by a cold shower-bath. To proceed thus till April 14th.

April 14th. Loss of weight through exercise: 7 lbs.

Second wasting: same regimen in all respects as on April 4th.

April 15th. Result of second wasting; a loss of weight of 4 lbs.

To continue the ordinary regimen, that is to say, without the wasting, till April 23rd; loss of weight through exercise, 7 lbs.

April 27th. Third wasting: loss of weight 3 lbs.

Till May 7th, ordinary regimen of training: loss of weight through exercise, 5 lbs.

May 8th. Fourth wasting: loss of weight, 3 lbs.

Till *May 15th*, the day of the race, ordinary regimen of training; no loss of weight."

The training had lasted six weeks and had caused a loss of weight of 37 lbs. It is curious to note how little persistent was this result so rapidly attained.

"*June 15th*—one month later—the same individual wished to be trained for a rowing match of two miles. Having returned to his ordinary habits *he had gained 21 lbs. in weight.* As he was much pressed for time his training only lasted eight days.

This short space of time was, however, sufficient to disembarrass him of his 21 lbs., and put him in condition easily to win the race."

This observation shows us how little stability there is in the changes produced by training. We see that the athlete had returned in a month, by resuming his ordinary habits of life, to the conformation which violent exercise and regulation of diet, etc., had so profoundly modified in six weeks.

If we analyse the method of Symes, we notice there are two classes of practices: one destined to increase the volume of the muscles by work; the end of the others being to diminish the mass of the tissues by every kind of outlay.

We know that the muscles increase in size by the very fact of exercise, and we need not insist on this to explain how muscles which have become larger, make the person stronger—but it is necessary to explain the effect of the evacuations in increasing the power of resisting fatigue.

We know that any loss undergone by the system tends to increase the power of absorption of the vessels. Profuse sweatings, copious diuresis, repeated intestinal evacuations, large losses of blood, very greatly increase the desire for the assimilation of liquids. This desire leads us to produce a kind of compensation between the losses and gains of the blood. It is usually satisfied at the expense of liquid nutriment from without, and shows itself as increased thirst, but it is also manifested by a tendency to absorption of certain materials from the organism itself. In this case the process of assimilation is known as *resorption.*

In therapeutics we often make use of the force of compensatory resorption to bring about the disappearance of morbid substances which have accumulated in certain parts of the body. Thus liquids effused into the natural cavities or infiltrated through the skin and the muscles, may be removed by free purgation, or by the prolonged use of diuretics, and even by the influence of repeated sweatings. We then see these patients freed from the pathological liquids which were embarrassing them, and they lose weight.

The compensatory work of resorption is not confined to liquids, but often influences unstable solid tissues, such as fat. We see persons become thin under the influence of excessive perspiration. It is in virtue of a compensatory resorption that the fat of a man who is training can diminish under the influence of purgations, and of the sweats produced by the operations he goes through.

What is the advantage of the resorption of fats from the point of view of resisting fatigue ? We have already discussed this at length and it will be sufficient here to repeat : (1) that fat increases the useless weight, *the dead weight* of a man ; (2) It hinders the cooling of the body during work; (3) It increases by its combustion the production of carbonic acid. Increase of mechanical work, the movements being the same; increase of the disturbances due to excessive heating of the body; increase of breathlessness for the same muscular effort: such are the causes of fatigue due to excess of the fatty tissues.

Loss of weight is then the first stage of training. This result is obtained by the very fact of work, owing to the combustion of the reserve materials; but it is rendered more rapid by a number of accessory means, rubbing, wrapping up in damp cloths, vapour baths, very thick clothing, etc.

We may convince ourselves by experiment that the disappearance of fat always leads to the diminution of certain of the discomforts of fatigue, and above all of the heating of the body and of breathlessness. A series of hot air baths render a man fit for work, even before he has undergone any training.

The other practices of training may be summed up in three precepts: (1) to avoid any article of diet which would tend to the replacement of the lost fat: (2) to favour the functions of the skin: (3) to supply the lungs with well-oxygenated air.

Watery beverages are forbidden a training man, since they may, by too quickly replacing the lost sweat, diminish the tendency to the resorption of fat. For a similar reason they are forbidden farinaceous food, sugars, and all fattening articles of diet, and all substances said to check tissue waste, such as alcohol.

The functions of the skin are of great importance and their perfect regularity is necessary from two points of view. In the first place the skin is an excretory organ: it eliminates some of the liquid and gaseous waste-products resulting from the combustions of work, and we have said that the disorders of fatigue are chiefly due to an intoxication of the blood by these waste-products. There is then every advantage, from the point of view of resistance to fatigue, in favouring their prompt discharge from the system. In the second place the skin is a respiratory organ which absorbs oxygen from the air, and we know how well-oxygenated blood is vivifying and plastic.

There is another prescription to which very great importance is attached by trainers : this is the tranquillity of a man's mind. The man " in condition " is to be kept free from all mental disturbance, all depressant emotion. He must avoid all nervous excitement, and all keen sensations ; he is forbidden sexual intercourse as well as anxieties and moral distress. We will add, from our own observations, that mental work must also be forbidden. Mental work in addition to exercise increases the tendency to dissimilation of the tissues, and favours loss of weight, but it is opposed to the reconstitution of the muscular elements ; in such a manner that the person given up at once to intellectual fatigues and to muscular work quickly becomes thin and does not replace by muscle, the tissues which waste. He tends to fall into the condition of overwork by *organic exhaustion.*

Finally, perfect ventilation of the place in which the subject lives, is to be considered a capital condition of successful training. A man who is training must keep away from large towns and breathe air which is vivifying and able to make his blood richer in oxygen.

But, amongst all the agents which modify the organism and are employed by trainers, the most important is work. It may take the place of all the others, and can be replaced by none. Work alone is in fact able to produce the double result which is sought, increased size of muscles, and diminution of reserve materials. It directly burns the fats by using them to feed the muscular contraction ; it also uses them up indirectly by raising the temperature of the blood, and by warming the body just as would a stove, or thick clothing. Under the influence of work the combustions of the tissues are more intense, and a more copious perspiration brings about the loss of weight desired by the trainer.

Besides these effects which are common to muscular work and to the accessory means made use of in training, there are results which muscular work alone can give. Firstly, often repeated muscular contraction is the only way of developing the muscles, and consequently increasing the strength. There is further a form of fatigue which cannot be diminished, like breathlessness, by the resorption of fatty tissues, that is stiffness. We know in fact that this form of fatigue is not due to products resulting from the combustion of fats, but to products resulting from the dissimilation of certain nitrogenous materials, which are stored up in the fibres of an inactive muscle.

Now work seems to dispose of these nitrogenous reserves. The sweatings and artificial wastings which much diminish the tendency to breathlessness, do not give the slightest immunity from stiffness.

Thus all the results obtained by accessory means, such as regulation of diet, purgations, and sweatings, could be derived from muscular work alone. But then the result would be more slowly attained. We must also say that it would be more lasting.

The changes observed in the temperament of a living being under the influence of methodical training are very quickly produced, but they are very easily lost. Six weeks of severe regulation bring about perfect "condition," but a month's interruption causes the loss of all the benefits of the training, and a return to the former state.

Observation of ordinary facts shows us on the other hand the permanence of the modifications acquired by persistent muscular work.

We daily see men and animals whose life is one of continual muscular work, acquire in the end the conformation which is so quickly produced by training. If there then comes a complete change in their habits, they may lose the attributes of the trained man, but it will not be in a month that, as in the man mentioned by Worthington, an excessive quantity of reserve tissues will be produced.

When a man has spent his life in the rough labour of the fields, or in the assiduous practice of physical exercise, he rarely fails to keep a slim and muscular conformation for years after he has given up work. Similarly, an ox employed in hard work for a long time, and then prepared for eating, is fattened with difficulty, and his flesh remains firm and coriaceous. In spite of absolute rest and superabundant food his muscles cannot lose all at once the hardness gained by long labour.

II.

If we examine a man modified by the preparations we have just summarily described, we shall see that profound changes have occurred in his system which have made of him, so to speak, a new being. He differs in the structure of his tissues, in the conformation and in the working of his organs, from his condition before he began training.

From the physiological standpoint, the essential character of the trained man, is the increase in the tissues whose purpose it is to move the body, and the almost complete disappearance of those which simply have to feed the combustions without which movement would be impossible.

A trained man may be compared to a heat-engine of which the machinery has been improved, but which no longer carries about a provision of fuel to feed the fire. After the training, the reserve materials have disappeared, and it is solely from his food that a man obtains the materials necessary for sustained work.

Thus we must not confuse the power of resisting fatigue with the power of enduring privations. The racehorse, so well fitted for intense and prolonged work, supports ill a lack of nutriment, and cannot be kept on the meagre rations which are enough for a Breton nag. Similarly with a man in training: if there is insufficient food, exhaustion will be very rapid. On the other hand, the combustions not being fed by materials too easily dissimilated, produce less waste-products. Fatigue, which results from auto-intoxication of the body by the waste-products of combustion, will not be so easily produced.

In a man in perfect "condition," the products of excretion which are removed from the body by the eliminating organs will not be the same as before training, for the tissues, the dissimilation of which gives rise to them, will be different. The lungs will eliminate less carbonic acid for an equal quantity of work, and will no longer eliminate certain little-known gaseous products, which result from the combustion of materials which have been too long retained in the body. The skin will no longer exhale the volatile fatty acids, the smell of which is sometimes so marked in persons of sedentary life. The kidneys, after intense muscular work, will no longer eliminate the excess of urates and other nitrogenous waste-products which are found in the urinary deposits, and which are so abundant in untrained persons attacked by stiffness.

Hygienists have long pointed out the fact that all the excretions vary in a striking manner in different individuals, according to their mode of life. The exhalations of human beings have even a different smell, according as they emanate from a man who is in the habit of performing muscular work, or a man who leads a very sedentary life. The odour of a prison has been said to differ characteristically from that of a barrack. Both result from volatile products eliminated by the lungs and skin of a great number of men crowded together; but the men of one class have led an inactive life, the others have been in continual activity.

We may certainly say that the system of the trained person has undergone sufficiently profound changes to make of him a being physiologically very different from another who has not undergone the same training. His conformation is different, the structure of his tissues has changed. His organs have undergone a transformation and their working is no longer the same.

The person modified by training, and he who has led an exceedingly sedentary life, must be considered, from a standpoint of observation and experiment, as very different physiological units. If we place them in identical conditions, in which they are submitted to modifying agents, they will not react in the same manner. Work, in especial, will modify in a different manner the working of all their organs. For the same number of kilogrammes of work done in a given time, we shall not observe in them a like quickening of pulse and respiration ; the air they expire will not contain the same quantity of carbonic acid ; their urine will not eliminate the same quantities of uric acid.

Hitherto insufficient notice has been taken of the profound changes produced in the results of work by the transformation undergone by the organism in becoming habituated to muscular exercise. The greater number of the observations made on men to estimate the products of excretion resulting from work, are fallacious, owing to the fact that, the influence of this important factor has not been taken into account, the condition of training of the subject.

This is doubtless the cause of the great differences amongst authors who have examined the effect of work on the excretions, especially on the urine.

PART IV.

THE DIFFERENT EXERCISES.

PHYSIOLOGICAL CLASSIFICATION OF EXERCISES—VIOLENT EXERCISES—EXERCISES OF STRENGTH—EXERCISES OF SPEED—EXERCISES OF ENDURANCE—MECHANISM OF DIFFERENT EXERCISES.

CHAPTER I.

PHYSIOLOGICAL CLASSIFICATION OF BODILY EXERCISES.

Quantity of Work done in an Exercise—Gentle, Moderate, and Violent Exercises—Quality of Work in Exercise—Exercises of Strength, of Speed, and of Endurance.—Mechanism of the various Exercises.

WE have just studied the general effects of muscular work on the organism which performs it. If we endeavour to sum up the conclusions to be derived from this study, we see that the results of work vary according to the quantity done and the method in which it is done.

Exercise performed without moderation or rule induces all forms and all degrees of fatigue, and exposes the human machine to the various injuries which we have described as the accidents of work.

On the other hand, muscular work performed in gradually increasing quantity and according to the rules of graduated training, brings about a progressive adaptation of the organs to the performance of more and more violent exercise. It improves the human motor by giving to all its machinery a greater strength and ease of working.

Such are the results of exercise considered as an abstract factor and reduced to the *quantity* of work represented by it. But it is only by a mental effort that we can isolate the work done by the system, from the organs concerned in its performance. Now these organs are not the same in all cases, and do not work in the same manner in all forms of exercise. Thus the practice of different exercises produces different effects on the system.

Hence the use of a rational classification of the different exercises, and the necessity of making a choice from among them in accordance with the effects desired.

At the outset we notice a difference between the various exercises practised: they do not all necessitate the same quantity of work. Exercises are called *violent* when they demand considerable and repeated efforts from the muscular system; they are called *moderate* when they do not demand much work: finally, when the muscular exertion is reduced to a minimum, the exercise is called *gentle*. Running is a violent exercise, walking at a fair pace is a moderate exercise, and walking slowly is a gentle exercise.

The quantity of work done is evidently the chief element in the classification of bodily exercises, for it is that which most influences their effects. But, the amount of work done by the system being the same, it is not indifferent, from the hygienic standpoint, whether the work is done slowly or quickly, whether it is uninterrupted, or there are frequent periods of rest. It is important also to know if the exercise needs complicated and difficult movements, if it exacts great attention of the will, or if it can be performed automatically, and without needing the intervention of the conscious faculties.

Finally, besides the different forms of the work, it is also important to determine the mechanism of the exercise, to say what parts of the body are especially concerned in its performance, and what are indirectly associated with it. This is one of the least known points in the therapeutics of exercise, for the analysis of the different exercises of the body has not yet been made in a satisfactory manner. It is however one of the most interesting and most practical points in this branch of hygiene, for upon the intimate mechanism of an exercise depend its local effects. A bodily exercise is often prescribed with an orthopædic object, but we cannot exactly foresee its effects unless we know exactly which group of muscles performs the work, which articulations and which bony levers support the pressures and the shocks, and by what attitudes the whole of the body associates in the movement of the regions at work.

A physiological classification of bodily exercises, taking especially into account the effects produced on the system by the different exercises, must have for its basis three elements: the *quantity* of work which they need, the nature or *quality* of this work, and finally the *mechanism* by the aid of which the work is performed. But these three elements of classification are combined in so varied a manner in the different exercises practised, that they cannot logically serve for their grouping. Some exercises allied by the quantity of work they represent, differ in the mechanism of their performance; others, on the contrary, are similar as regards movements, but differ in the intensity of the work.

So these three elements, *quantity*, *quality*, and *mechanism* of work, will not be taken here as the basis of a systematic classification of exercises. They will rather serve as landmarks to guide us in the physiological analysis of these exercises, and as labels for their grouping in categories corresponding to certain effects, now salutary, now harmful, according as they conform to, or are in opposition to, the indications furnished by the temperament and morbid state of the patient.

CHAPTER II.

VIOLENT EXERCISES.

Violent Exercise must not be confounded with Fatiguing Exercise—Difficulty of appreciating the Quantity of Work expended in an Exercise—Difficult Movements—Feats of Strength—Gymnastic Pedants – Children's Games and Gymnastics—Skipping compared with Climbing a Rope—Analysis of Exercises—How the Physiological Effects of Work may indicate its Degree of Intensity.

THE quantity of work represented by an exercise is the basis of the classification of bodily exercises into *gentle*, *moderate*, and *violent*.

This division appears at first very logical and extremely easy to establish, but an attentive analysis is sometimes necessary to determine the real expenditure of force represented by an exercise. The estimation is often, and erroneously, based on the difficulty experienced in performing the work or on the fatigue felt by the muscles engaged. Now it may happen that the expenditure of force necessitated by an exercise is masked by the ease with which the muscular action is performed. It may happen that an insignificant work produces a lively sensation of fatigue. It is always easy, even to a very heavy man, to go up ten steps of a staircase. But he would often find it very difficult to go up ten rungs of an inclined ladder hanging by his hands. Still, if the vertical distance between the rungs and that between the steps is the same, the mechanical work is strictly the same in the two cases, for it represents an expenditure of force capable of raising the same weight through the same height. The fatigue experienced is however much greater after going up the ladder than after going up the stairs. This is because in the first case the work has been done by the small muscles of the upper limbs, and in the second case by the powerful muscular masses of the lower limbs.

Neither the difficulty of an exercise nor the local fatigue caused by it can serve as a basis for determining the quantity of work done.

Violent exercise is often wrongly confused with a "feat of strength," or a "difficult" exercise. In all feats of strength it may happen that the work, without being considerable, may be executed by means of a very small number of muscles. The exercise is then merely a kind of demonstration of the muscular strength of the individual, who for example performs with ten muscles a work which other people can only do with twenty. A man who seizes a horizontal bar with one hand and raises himself with only one arm, shows that he has a very strong biceps, but the mechanical work he performs is, in the end, strictly equal to that done by a man who pulls himself up with both arms.

Sometimes so-called feats of strength are only feats of skill. In gymnastics there are many movements which need a long apprenticeship and which in the end can be performed with the expenditure of an insignificant amount of force when a man has learned the trick. The difficulty in the performance of these exercises does not consist in the expenditure of very great muscular force, but in finding from experience, or from teaching, the muscles which must be thrown into action. Numerous movements performed on the trapeze, and in "German" gymnasia, need more science than strength.

We must not confuse "quantity of work" with "difficulty of work." This is a mistake of daily occurrence, and the result is that the preference is given from the hygienic standpoint to exercises which are merely clever, while the really violent exercises are abandoned, being those in which force is expended, without any laborious calculation how to use it.

Now the general effects of exercises are in proportion to the expenditure of force which the exercise renders necessary, and not to the difficulties presented by the details of its execution.

In our day the trapeze seems almost to be considered as the regenerator of the human species. It seems that the art of moving the limbs can only be acquired after long researches and profound meditations. We fall under the rod of the gymnastic pedants, and doubtless a time will come when we shall be as astonished at taking exercise in walking as M. Jourdain was at talking prose in speaking. By young men, and even in girls' boarding schools, we see the most complicated machinery used and the most difficult—we might say the most grotesque—movements performed. For want of an attentive analysis people do not understand that many of the games of young children are in reality violent exercises, while many of the exercises of the orthodox gymnast are merely feats of skill.

We may prove by figures that the expenditure of force, the end to be obtained by gymnastics, is greater in certain children's games than in certain exercises of the gymnasium which seem to demand exceptional strength.

Let us suppose that a little girl is amusing herself by skipping. It is easy to jump 0.1 metre high 100 times a minute. The work done, therefore, will be equal to an expenditure of force capable of raising her body to a height of 10 metres. Now there are not many gymnasts who could climb with their hands alone to a height of 10 metres in a minute; there is not probably one who could go on climbing for three minutes at this pace, while there are many little girls who can skip for five minutes or more without stopping.

In the act of skipping, the work is not done by the same muscles which are used in climbing a rope, so the local effects of the two exercises will be different. But if in both exercises the number of kilogrammetres of work done is the same, the general effects of the work will be identical, *for the changes in the great organic functions, and particularly the changes in breathing, are in direct ratio to the sum total of work done in a given time.* Now, in the application of exercise to hygiene, the general effects of work are especially sought; we wish to render the blood current more active, to increase the power of the respiratory movements, and in a word to associate all the great organic functions of the economy in the work.

It is not always easy to estimate the quantity of work represented by an exercise. The effort is not always apparent, and does not always show itself in moving the body. In certain cases the force expended by a man has its effect negatived by an equal force expended by an adversary. We see this, for instance, in wrestling. In other cases the apparent work is not increased, but the expenditure of force is rendered greater by the unfavourable arrangement of the bony levers which perform the movement. Thus the exercise of *making a plank*, only needs to sustain the weight of the body by the strength of the arms ; but the horizontal attitude taken by the trunk and limbs increases tenfold the expenditure of muscular force, and consequently increases the violence of the exercise.

It would need too lengthy an analysis to find the exact amount of work in kilogrammetres demanded by each exercise, and the changes in this amount produced by different methods of performance. It will be enough to repeat that there are artifices for diminishing the expenditure of force in any exercise, and other artifices for increasing it. There are movements which make use of the impetus derived from the speed of the body, and there are others which suppress all impetus, and force antagonistic muscles to hinder the action of the muscles which are doing the work, and to make the movements slower. In this manner slowness in the performance of a muscular action may much increase the expenditure of force ; to stoop quickly we have merely to relax all the muscles of the thigh, whereas if we wish to stoop very slowly we must keep the extensor muscles in vigorous action in order to sustain the weight of the body, and to maintain it in successive attitudes of descent by acting on levers placed at a very unfavourable angle.

It is important to determine the real quantity of work done in an exercise and to distinguish a violent exercise from a difficult exercise or a " feat of strength," for the efforts are very different in the two cases.

In a " feat of strength " the quantity of work done by the organism may be quite small, but generally the local work is very considerable in relation to the strength of the muscles which perform it. The effect of the exercise is then especially local, and may perhaps have no appreciable influence on the whole system. By continual practice in raising weights with the arm outstretched it is possible very greatly to develop the muscles which extend the arm on the shoulder; but the great organic functions, respiration, circulation. etc., will participate very little or not at all in the work. The exercise will represent an expenditure of force capable of rapidly tiring the few muscles in action, but not enough to have much influence on the blood-current or the movements of the lungs.

In a difficult exercise, the performance of which needs the perfect co-ordination of movement, the exact weighing of the effort of each muscle, the chief expenditure will be of nervous energy, and the muscles will only perform a feeble mechanical work. The nerve centres will then have more to do with the exercise than the muscular fibres; the psychical faculties will come more into play than the muscular strength.

Gymnastics, as now carried on at educational establishments in France, make a man who devotes himself to them, spend most of his time in a long apprenticeship and in true mental work. The trapeze, the horizontal bar and the rings, are things on which feats of skill are done, rather than work, in the mechanical sense of the word. Many pupils spend months in learning a *breast* or a *balance*, and when they discover the method, the muscular trick, they do all at once with the greatest ease the muscular action which the day before seemed to be beyond their strength.

If we try to sum up what we have explained in this chapter, we shall come to the conclusion that it is not always easy to estimate at the first glance the amount of work done during an exercise, and to determine the degree of "violence" of this exercise. Neither the difficulty in the performance of the movements, nor the local effort they need, are characteristic of the intensity of the work, and a rigorous analysis is often necessary to estimate the expenditure of force.

But, failing a mechanical analysis, the physiological effects of an exercise may serve to help us to appreciate the degree of violence. The great vital functions are more energetically associated with muscular exercise in proportion to the greater intensity of the work.

We have shown in the chapter on *Breathlessness* the close relation between increase of the respiratory need and increase of muscular work. The energy and the frequency of the movements of the heart increase according to the same laws. The quickening of respiration only becomes excessive in exercises determining a great expenditure of force. Muscular fatigue may, on the other hand, be severe without the amount of work done being considerable; in the case for instance in which the work is done by a small number of muscles.

The form taken by fatigue after exercise, may give, physiologically, a measure of the work done in a given time. The muscular fatigue of any region of the body may serve to estimate the intensity of the local work; the measure of the total work will be given by the violence of the disturbances of the heart and lungs, that is to say, the intensity of breathlessness and the quickening of the pulse.

The measure we suggest can evidently only be applied to the same individual, or to two individuals equal in power of resistance, in strength, and in habituation to work; but with this restriction we can adopt, as a criterion of classification, the following indication:—

When, after an exercise, a man of average strength has experienced neither fatigue nor breathlessness, the exercise may be called *gentle*. When the exercise has caused local fatigue without inducing breathlessness, it will be *moderate*. It will be called *violent* when it is accompanied and followed by breathlessness.

This division seems to us to be the best from the physiological standpoint; it is not based upon the difficulty of the exercise but on the physiological reaction of the system. Now this reaction is always, in the same person, in proportion to the quantity of work performed by the organs in a given time.

CHAPTER III.

EXERCISES OF STRENGTH.

Gymnastics — Frequent Intervention of *Effort* in Exercises of Strength—Why it is Impossible to have "a Smile on the Lips" in practising an Exercise of Strength—Charles Bell on the Facial Movements—Intensity of Breathlessness in Exercises of Strength—Wrestling—Advantages of Exercises of Strength. Their superiority to Exercises of Speed for Increasing the size of the Body—Inconveniences of Exercises of Strength. Danger of Effort: Frequency of Hernia; Frequency of Rupture of Blood-vessels—Overwork and Exhaustion in Forced Labours.

I.

WE call exercises of strength those in which each movement represents a great quantity of work, and brings into play the contractile power of a great number of muscles.

The lifting and carrying of heavy burthens is the type of works of strength, and it is really in the hard manual professions that we can best study their effects.

Evidently the movements of gymnastics, whose usual object it is to displace the body in various directions, cannot give rise to muscular efforts as intense as those of a man who displaces at the same time a heavy burthen and his own body. And, in fact, gymnastic exercises are rarely exercises of strength. There are, however, movements performed with the aid of apparatus, which seem at first to need an enormous expenditure of force, owing to the unfavourable positions in which the bony levers act; but we soon see that muscular effort in these movements is in direct ratio to the inexperience of the gymnast. By practice we are always able to discover a process which facilitates the performance. The human machine represents an articulated system made up of a great number of movable pieces joined together. Hence there is an infinite number of combinations of attitudes Often an imperceptible variation in the direction of a limb totally changes the conditions of the work. An undiscoverable variation in the performance of a *breasting* movement diminishes by nine-tenths the expenditure of force. Thus an exercise which at the outset seemed athletic, only needs, after some months' practice, very moderate work.

Exercises of strength may be better studied among wrestlers than among gymnasts. They form what may be called athletic gymnastics, and wrestling is perhaps now the only bodily exercise which can be placed in this category: skill and trick have, however, a great place in this sport.

The exercises in which a man must employ his whole strength need the intervention of two factors: the muscles and the will. It is especially in these exercises that we can understand the importance of nervous energy as an agent of work. Two men who are equally well endowed in the matter of physical conformation, and completely equal as regards their muscles, will often show a very considerable difference in exercises of strength. We may predict with certainty that the advantage will lie with the one whose will is most energetic, for this energy is manifested, on the physical side, by a more intense stimulation of the muscles, and hence by a more powerful contraction.

The exercises of strength demand the simultaneous action of a great number of muscles. They demand, further, that every muscle in action should bring its whole force into play: for this it is necessary that the muscle should take a very firm attachment to a fixed point of the skeleton. Now the bones of the skeleton being movable on each other, it is necessary, as a preparation for athletic movements, that all the bony pieces should be strongly united by a vigorous pressure to make up a rigid whole. This necessity of soldering together, as it were, a number of movable pieces to make a resistant whole, is a very characteristic point of the physiology of exercises of strength. Athletic gymnastics implies the frequent intervention of the action called *Effort.*

We described effort at length in the second chapter of the first part of this book, and explained the modifications of respiration which result from it. Effort may be called the characteristic sign of exercises of strength. It is impossible for a man to use his whole strength without the production of that violent contraction of all the muscles of the trunk whose object it is to render the ribs motionless, and which results in the stoppage of respiration. If a man has to raise from the ground a very heavy burthen, we are struck by seeing the whole body stiffen from head to foot, and all the bones pressed together by the energetic contraction of the muscles attached to them. Each limb, made up of two or three segments, seems now to form one rigid piece; the trunk, neck, and head, share in the general rigidity, and even the muscles of the face are violently contracted during an effort, though it is difficult at first to account for the share, for instance, of the eyelids and cheeks in the action of lifting a bale of goods on to the shoulders.

The drawn face of a man momentarily using his whole strength is a matter of common observation. We remember hearing the boast of a strong man at a fair that he would hold out a heavy load at arms' length "with a smile upon his lips." He did it, but the pretended smile was merely a grin in which the eyebrows and eyelids took no part, being contracted in association with the effort. The physiologist, Charles Bell, long ago gave a reason for this association of the muscles about the eyes, with effort. During effort, the flow of blood in the orbital vessels causes them to swell up, and to project the globe forwards. The muscles in front of the orbit contract instinctively in order to support the globe, and to check its protrusion.

The first effect of an exercise of strength should be to induce quickly fatigue of the muscles from which enormous work is suddenly demanded. But breathlessness precedes fatigue in the course of these exercises. However slow the movements, respiration is very quickly embarrassed, and the wrestler or the porter with a heavy burthen must often stop for breath, long before their muscles are fatigued.

We explained at length, in the chapter on *Breathlessness*, the mechanism of this respiratory distress after great expenditure of muscular force. The muscles in action produce carbonic acid in proportion to the intensity of the work done. In the exercises of strength there is produced in the system at every movement, more carbonic acid than the lungs can eliminate, and the surcharge of the blood with carbonic acid induces dyspnœa.

Further, effort has a very powerful influence in inducing respiratory distress in exercises of strength. This action causes a stoppage of breathing during the whole time occupied by the muscular contraction: it thus hinders the elimination of carbonic acid just at the time when this gas is being produced in excessive quantity. It further leads to violent compression of the great veins of the thorax, of the great arteries, and of the heart itself, and produces profound disturbances in the pulmonary circulation, the regularity of which is an essential condition of aëration of the blood.

Among bodily exercises there is one which may be considered as the type of exercises of strength: this is *wrestling*. If two wrestlers who understand each other are making a pretty looking play before the public, wrestling is rather an exhibition of agility and suppleness than an athletic exercise. But if the adversaries, using all their strength, seek to overthrow each other, there is an enormous expenditure of muscular force. Very considerable muscular efforts may be made without apparent work, that is to say, without the bodies of the wrestlers making any movement. The thrust of one of them is paralysed by the resistance of the other, until the stronger, maintaining his most powerful contraction, causes weariness in the weaker, who, at the end of his resources, yields and falls.

At this moment we observe in both men an extreme degree of breathlessness. A wrestler who is beaten has respiratory disturbances as intense as those of a runner who stops for want of breath. Wrestling is not merely an assault of brute force ; it has its feints, attacks and tricks. But the characteristic of this exercise is the necessity of throwing into the movements of attack and defence a man's whole strength, so that, even for the cleverest wrestlers, this exercise always demands a great expenditure of force, and is the most brutal of all bodily exercises. It is the exercise in which the quantity of muscle is the essential element of success. It is thus the one which has most tendency to develop muscle and to increase the weight of the body, for every exercise tends to give to the body the conformation which makes this the fitter for its performance.

II.

Exercises of strength demand great muscular expenditure, but they produce all the conditions necessary for energetic tissue-repair. They need very little work of co-ordination and do not demand a frequent repetition of movement. They occasion less disturbance in the nerves than exercises of speed, and do not demand, like exercises of skill, great brain work.

Forced labour is nearly always performed by the aid of slow and sustained contraction. The muscular fibre of a wrestler is tense in one direction for sometimes an entire minute ; the muscles of a fencer are changing every moment from repose to action, and moving the limbs in the most varied directions. Powerful and sustained contractions favour the nutrition of the muscular fibre. The nutrition of muscle is more intense in slow contractions, because the flow of blood is more regular and more prolonged.

Exercises of strength and *forced labour*, in spite of the great quantity of work they need, have little influence on the brain, they affect the functions of nutrition much more than those of innervation. The energetic and sustained muscular contractions which they render necessary draw blood to the muscles in great quantity and keep it there a long time. The muscular fibres benefit from this, and increase in size. On the other hand the blood is enriched with a great quantity of oxygen, for increased respiratory need is the first effect of great expenditure of muscular force. This need finds free and easy satisfaction in the period of repose which inevitably follows each effort. Finally the intensity of the combustions due to a great quantity of work, promotes the using up and prompt disappearance of the reserve materials, and the need of quick repair; whence increased appetite. On the other hand the repeated contractions of the abdominal muscles in the frequently recurring efforts, performs a sort of massage on the intestines which favours the onward movement of the fæces and makes the bowels regular.

Exercises of strength are then favourable to all the nutritive functions. They increase energetically, and even violently, the working of all the organs of the body, while leaving in relative repose the nerve-centres and psychical faculties. Now calm of the nervous system is a valuable condition for the repair of the losses sustained in work.

Observation of facts shows that athletic exercises, when they are not beyond the strength of the subject, place him in the most favourable conditions of nutrition. Under the guidance of a quiet nervous system, the functions of repair are performed with the most perfect regularity, and we see that the acquisitions made by the system through more perfect assimilation exceed the losses brought about by work. Exercises of strength tend to increase the weight of the subject.

Exercises of strength seem then to deserve the preference from the hygienic point of view, and it is in fact in the professions in which work is taken in large doses that we find the most vigorous persons. But in order to be salutary these exercises need several conditions which are not always present.

In the first place they must be performed by solidly constructed organs which are free from all defects of nutrition. The muscles, the tendons, the aponeuroses, even the bones undergo tractions and pressures which are so violent that ruptures of all kinds would be produced had not a progressive state of habituation gradually consolidated them. Accidents of all kinds, rupture of muscles, lacerations, dislocations, are frequently seen during exercises of strength. Other more serious lesions, such as hernia, laceration of the lung, rupture of great vessels, and even of the heart, are liable to occur unless the internal organs are perfectly sound. Organs which have undergone some degree of degeneration are soon incapable of resisting the violent strain of *effort*.

Finally it is necessary, to avoid overwork, that the work should be gradually increased and not done in the largest quantities till after complete training. If a man who attempts an exercise of strength is too freely provided with reserve materials, these undergo dissimilation in mass, and an excessive quantity of waste-products is produced. This causes auto-intoxication by poisonous substances, alkaloids or others.

Thus are to be explained the fevers of overwork, often taken for typhoid fever, in young recruits. Facts show that these fevers have a special predilection for the services which need forced labour, the Artillery for instance.

To perform exercises of strength with impunity, the food must be sufficiently abundant to supply the losses undergone. If the food is not sufficiently restorative, the work is done at the expense of the materials of the body; the worker becomes thin and is quickly exhausted.

Exhaustion will also result from excessive work which exceeds a man's strength even if he is well fed. If a man wishes to get out of his muscles a quantity of force, out of proportion to their contractile power, he is obliged to make an energetic effort of will, and he needs a great expenditure of nervous energy to excite more powerfully the weak muscular fibre. He can thus perform a work beyond his strength, but it is by taking "from his nerves" that which his muscles are unable to give. In this case the exercise of strength will not have its usual result. of economising nervous energy. A work of the nerve-centres is necessary to increase the irritability of the muscles. We do not know exactly in what this work consists, but we can determine its effects. The excessive exertion of the will in the work leads quickly to nervous exhaustion. The man becomes thin, eats and sleeps ill; he suffers from overwork by exhaustion. It is thus that we see horses rapidly waste and get ill, although they are well fed, if they are forced to draw too heavy a load, and their ardent and generous nature impels them to go on working up to the last limit of their strength.

CHAPTER IV.

EXERCISES OF SPEED.

Accumulation of Work by the rapid Succession of Movements. Common results of works of Strength and Exercises of Speed; the "Thirst for Air"; Breathlessness — Strength and Speed combined—"Forced" Exercise; its Dangers—Part played by the Nervous System in Exercises of Speed—Law of Helmholtz; the Loss of Time in Muscle; "Latent Period"—Irritability of Muscle; its part in Exercises of Speed; its Variability in different Kinds of Animals; the Snail and the Bird—Its Variability in different Individuals and different Nations: Dutch Rowers—Effects of Exercises of Speed—Effects due to the Accumulation of Work; they resemble the Effects of Exercises of Strength—Effects due to Expenditure of Nervous Energy; resulting Influence on Nutrition—Why these Exercises cause Loss of Weight.

I.

WE call those exercises which need the very frequent repetition of muscular movement, exercises of *speed*.

There are great differences among the various exercises of speed as regards the intensity of work. Many of them are typical violent exercises: running, for instance. Many on the contrary need so insignificant an expenditure of force that they hardly deserve the name of exercise. A pianist playing scales, notwithstanding the extreme speed of the movements of his fingers, performs but a trifling muscular work.

The essential character of exercises of speed is the rapid multiplication of muscular movements. A series of inconsiderable efforts, often repeated, thus allow the performance in a short time of a considerable quantity of work, without bringing into play very important muscular masses. In fact ten movements each needing an expenditure of force of ten kilogrammetres must represent the same work as one movement in which the expenditure of force is a hundred kilogrammetres, and we can easily understand that ten rapid movements may be performed in the same time as one very slow one. As regards the quantity of work done, an exercise of speed may thus be absolutely equivalent to an exercise of strength.

Exercises of speed, as well as exercises of strength, may then produce a great quantity of work in a short space of time. From this common condition are derived certain identical effects, breathlessness for instance. But each of these kinds of exercise has its own character, from which are derived very different results. The one kind needs that the muscles should contract with all the energy they possess; the other does not need this, but the muscles must pass at very short intervals, and a great number of times in succession, from repose into action.

The essential character of exercises of speed, that to which their very remarkable physiological effects are due, is this frequently repeated change of the muscles from the condition of relaxation to that of contraction.

We have thus to study exercises of speed from two very different points of view: (1) the rapidity with which the work accumulates, (2) the speed with which the movements succeed each other.

The rapid accumulation of work depends upon two factors which are, the quantity of work represented by each muscular effort, and the number of these efforts in a given time. Whether the work accumulates owing to the intensity of the efforts or to their number, the results are the same. Thus the breathlessness will be the same after 100 movements each representing 10 kilogrammetres, as after 10 movements each representing 100 kilogrammetres, if, in both cases, the same quantity of work has been done in the same time.—A man who slowly goes up a staircase with a heavy burthen on his shoulders is doing a work of strength. A man running as fast as he can along a level road is performing an exercise of speed. Both of them do a great quantity of work in a very short time, one by slow movements each representing a great expenditure of force, the other by rapid movements, each of which taken alone represents a very much smaller quantity of work, but which, when multiplied, make in the end a considerable expenditure of force.

Thus the exercises of speed can, as well as the exercises of strength, lead to an accumulation of work. The man who runs is taking, quite as much as the man who wrestles, exercise in "large doses."

In this manner speed can supplement force, and enable certain persons, whose muscular development is feeble, to benefit from the general effects of violent exercise, without needing intense efforts which they would be unable to perform. The intensity of the combustions of work is in proportion to the total quantity of force expended, whether this expenditure has been made in mass at one effort, or has been made in successive fractions, by little efforts at very short intervals. Now the formation of the waste-products of combustion, such as carbonic acid, is in proportion to the intensity of the combustion, and it is from the quantity of carbonic acid accumulated in the system that the intensity of the respiratory need results, and from this the amplitude and frequency of the respiratory movements. The need of absorbing oxygen is intimately connected with the need for the elimination of carbonic acid, and *thirst for air* is the inevitable result of very intense muscular work, be its mode of performance strength or speed.

Exercises of speed produce, quite as much as exercises of strength, this *thirst for air* which is to respiration what appetite is to digestion. Skipping, running, and the numerous children's games whose essential character consists in rivalry of speed amongst the players, are as valuable, and more, as exercises of strength, from the point of view of respiratory hygiene. A child which has just been playing at running has absorbed without making any painful muscular effort, in simple "play," a greater quantity of oxygen than one which has been made to use heavy dumb-bells. Now the absorption of the greatest possible quantity of oxygen seems to be, on the whole, the thing most desired, when we need the general effects of exercise with a hygienic end in view.

Among the Ancients, the exercises of speed always held the first rank. Running was regarded as a criterion of athletic superiority, and the characteristic of Achilles in Homer was the quickness of his legs.

If we compare exercises of strength and exercises of speed we find in them the common character of rendering respiration more active. But the exercises of strength only bring about this result at the price of intense muscular fatigue, while exercises of speed allow the work to be carried on till breathlessness is produced without the muscles becoming painful from the work. In fact four successive movements each representing a force of ten kilogrammetres, do not submit the muscular fibres to as severe a trial as a single movement representing forty kilogrammetres. It may happen in an exercise of strength, that the intensity of the contraction causes in the organs of movement a strain up to the very limits of their resistance, sometimes even beyond, for ruptures of tendons and aponeuroses, and even fractures of bones are frequent accidents in exercises of strength. In exercises of speed the muscle does not use nearly all the contractile force which it possesses, except in the rare cases in which the two elements, strength and speed, are combined to form *forced* exercise.

Now the repetition, even if very frequent, of a moderate muscular contraction, cannot produce in the organs a strain comparable to that produced by contractions which though slow, are carried to the utmost limits of muscular power. To be convinced of this it is enough to perform very rapid movements of the arm, holding a very light weight, and very slow movements holding a very heavy weight: it will be apparent that the latter proceeding is more painful than the former.

Rapid onset of breathlessness, and a speedy intoxication of the system by carbonic acid, are the characteristic results of exercises of strength when they are performed with some speed. The rapid repetition of a muscular effort, already representing, taken alone, a great expenditure of force, must, we can easily understand, produce in a very short time a great accumulation of work, by multiplying the sum of the kilogrammetres represented by each effort by the number of efforts which take place in a given time.

Exercises which need at the same time a great expenditure of strength and a great speed, may be called *forced exercises*. They demand more work from the animal machine than it is capable of performing and must only be continued for a very short time, under pain of causing serious accidents. We rarely have to observe in men the effects of this excessive accumulation of work. In animals we often see examples, especially in the horse, that noble animal which, as Buffon says, "dies for better obedience." An eager horse harnessed to a heavy cart, and made to gallop up hill, is doing at once a work of strength and of speed, and often gives an example of the accidents of forced exercise: threatened with asphyxia from the accumulation of carbonic acid in the blood, exposed to ruptures of vessels, or to visceral lacerations by the violent pressure occasioned by the effort, the animal sometimes dies suddenly from a rupture of the heart, or falls down paralysed by a hæmorrhage in the spinal cord.

Thus, to sum up, the exercises of speed have the advantage of producing the same quantity of work as the exercises of strength, and of producing the same intensity of respiratory need. Further, they increase the activity of the respiratory functions with less fatigue of the lungs and heart, owing to the absence of *effort* which only exceptionally occurs in exercises of speed, but which is obligatory in exercises of strength. Hence a first cause for preferring exercises of speed when the object is to increase the oxygenation of the patient.

As regards the muscular system, an exercise of speed, for an equal number of kilogrammetres in a given time, will produce less fatigue than a work of strength, and will subject the motor apparatus in a less degree to the various accidents resulting from shocks and frictions of its constituent parts.

But these advantages are counterbalanced by another which we must recognise in exercises of strength, the greater development given to the muscles. The flow of blood to the muscular fibre is more considerable in proportion to the intensity of the effort, and more prolonged in proportion to the duration of the contraction. This fact is proved by the following observation. In a man who is being bled, the blood runs from the veins for a little while and then the flow stops. If we then cause him to move the muscles of his forearm the flow recommences, not because the veins are emptied by increased pressure, but because the contraction draws more blood from the muscles.* Now if the muscles contract in an energetic and sustained manner the flow of blood is rapid, full, and uninterrupted. If we cause the patient to make a series of small, rapidly repeated contractions of the muscles of his forearm, the flow becomes jerky, small, and in the same period of time will furnish a lesser quantity. This experiment proves that less blood traverses the muscles during a series of small contractions frequently repeated than during one long sustained contraction.

No further demonstration is needed to prove that the nutrition of muscle must be less active during exercises of speed than during exercises of strength, for we know that the nutrition of a region of the body is active in direct proportion to the quantity of blood with which it is supplied.

The deductions we have just made, based upon the physiology of muscular work, are fully confirmed by the direct observations of facts. The exercises of speed do not sensibly develop the muscles, while the exercises of strength cause a great increase in their size. Every

* *Marey.* La Circulation du Sang.

one knows the exaggerated muscular development of the strong men at a fair, and also that professional runners often have small calves. On the other hand the exercises of speed develop more than others the size of the chest, and no athletic exercise improves the breathing more rapidly than long-distance running.

II.

There is a very interesting point for study in the physiology of the exercises of speed; this is the excessive expenditure of nervous energy which they occasion. Speed in the movement demands an increased work from the nerve-centres which can, we believe, be satisfactorily explained by the physiological facts we are about to put forward.

A muscle never obeys *instantaneously* the will which commands a movement. This fact was brought to light by Helmholtz in 1850. This physiologist showed that when, by means of an electric discharge, a given point of a motor nerve is stimulated, an appreciable interval is always observed between the moment of stimulation of the nerve and that of the contraction of the muscle. This retardation is in part due to the time taken by the stimulus in travelling along the nerve; but, taking into account the duration of this passage, which can be easily measured, it is found that there is still an appreciable period of time during which the muscle which has already been stimulated has not yet begun to contract.

Helmholtz has given the name of *latent period* to the silent time in which the motor organ, having already heard the call of the will has not yet responded by a movement.

Now different conditions may cause variations in the length of the latent period, and make the obedience of the muscle to the stimulus it receives more prompt or the reverse. Among these conditions, some are inherent in the muscle and may be summed up under one head, which is the greater or less *irritability* it possesses; the others depend on the exciting agent of the muscle, and are in subordination to the greater or less intensity with which this agent makes its action felt.

The most efficient condition for shortening the latent period is the intensification of the stimulus received by the muscle. If we suppose a motor organ to be set in action by an electric current, the latent period being, for instance, two hundredths of a second, with an electric force we will call 1, its duration will be reduced to one hundredth of a second if we double the intensity of the current. Let us suppose now that the muscle is stimulated by the will: the same law will be applicable to the duration of the latent period, and this will be shorter in proportion as the order of the will is accompanied by a stronger stimulation of the muscular fibre. Now a stronger stimulation of the muscular fibre can only be obtained, as we said in the first part of this book, at the expense of a greater disturbance in the cerebral cells and the nerve fibres which are the conducting organs of the voluntary nervous stimulus.

The effort of the will,—a synonym for the nervous disturbance,—will then be the more intense the shorter the time between the order of the will and the performance of the movement.

Exercises of speed which demand the very frequent repetition of movements, that is to say the very rapid change from relaxation to contraction, from repose to movement, will then necessitate a supplementary effort of will in order to hasten the response of the muscle to the call made upon it. Hence there is an increase of nervous expenditure which is not translated by a more *energetic* contraction, but by a more *speedy* one, and which does not lead to an increase of the work done, but to a diminution of the *latent period*.

This explanation, which we believe may be deduced from the law of Helmholtz, is confirmed by the observation of facts, for exercises of speed are accompanied by certain phenomena of fatigue out of proportion to the quantity of mechanical work they represent, and which must be attributed to an increase of the nervous work.

We have seen that, among the conditions which may cause variation in the latent period, we must take into account in the first place the greater or less *irritability* of the muscle. Irritability is the property possessed by a muscle of responding by a contraction to a stimulus which it receives from an external agent, whether this be the will, or some other.

There are causes which diminish the irritability of muscle; the commonest is fatigue. A fatigued muscle no longer responds to feeble stimuli which were at the outset sufficient to throw it into activity. Further, if the stimulus becomes stronger, and gains sufficient intensity to provoke a contraction, we notice that this contraction occurs slowly, and that the latent period is longer than it was when the muscle was fresh. To obtain a very prompt response from a fatigued muscle, we must have recourse to stimuli of very great intensity. This explains how it is that muscular fatigue makes a man lose his fitness for speed, before he loses the power of making energetic muscular contractions.

The more irritable the muscle, the more ready is it to obey the will quickly, the more capable is it of performing exercises of speed. Now—and this is a point worth noticing—all the muscles have not naturally the same irritability; all have not the same aptness for responding quickly to a stimulating agent.

In certain kinds of animals we notice a very long interval between the electric stimulation of a muscle and its contraction. These are the kinds commonly noted for the slowness of their voluntary movements. It is curious to see the muscle of a tortoise, for instance, not beginning to contract for two hundredths of a second after stimulation, while in the muscle of a bird the latent period is only seven thousandths of a second. This difference is still more striking in a snail, the muscle of which does not begin to contract till three tenths of a second after receiving a shock.

When we have frequented a gymnasium and have observed many men performing exercises, we have been struck by noticing the different irritability of the muscles in different individuals. In some persons rapidity of movement is, so to speak, natural, and exercises of speed do not demand any great effort; their muscular tissue is very irritable. In other persons, on the other hand, the muscles, although energetic, only obey the orders of the will with considerable slowness. A great expenditure of nervous energy is necessary to obtain a rapid movement. These differences are often racial, and at the first glance are seen in the deportment. The vivacious step of the Southron contrasts with the calm posture of the man of the North. The motor fibres of the former are more irritable than those of the latter. It is curious to see these differences manifesting themselves in physical exercises, and to ascertain the difference of aptitudes resulting from them for this or that form of work. The English and the Germans have never been able to rival the French and Italians in fencing. English boxing needs above all massive strength and power of resistance; French boxing needs on the contrary, agility and readiness in the blows, that is, great suddenness of attack and quickness in reply.

A boating newspaper reviewed recently the different methods of rowing prevalent in different regions. We were struck by noticing that in a regatta, the French rowed forty strokes a minute, the Dutch only twenty-five.

Speed is then a quality of work which depends upon two elements; the irritability of the muscle and the strength of the stimulus which it receives.

Engineers passing from theoretical to applied mechanics all know what a step there is from theory to practice. It is necessary to take into account, for instance, the different elasticity of the various materials employed, their greater or less impressionability to hygrometric or thermic influences. In a word, each body has, besides its mass, a peculiar physical individuality which modifies the conditions under which it receives the influence of the forces.

Similarly in living beings we must take into account the variations in muscular irritability if we wish to estimate exactly the amount of force expended in a movement. The less irritable the muscle, the greater must be the expenditure of nervous energy the object of which is to hasten its entry into action. This expenditure of force is not appreciable by the dynamometer; it is estimated by another method; by the time necessary for bringing into play the muscular contractility. This expenditure is not, in reality, borne by the muscle, but rather by the agent which stimulates it, an agent the nature of which is still obscure, and called, for want of a more exact word, by the name of *nervous energy*.

From the very active intervention of the nervous system in exercises of speed, are derived certain very important hygienic results.

After an exercise necessitating the very frequent repetition of movements, the fatigue experienced is more painful than that which results from a more intense work, but is performed by the aid of slow movements. The fatigue which follows an exercise of speed is unlike that experienced after an exercise of strength. Under the influence of a muscular contraction which is intense, but slow and prolonged, the fatigue is felt especially by the muscle. The limbs are weary, they are also congested; the blood flows to them and swells them up. This is because the muscular fibres have been the essential agents of, and almost the only factors in, the work. After movements representing a small expenditure of force, but performed with very great speed, we experience a fatigue which recalls the sensation of a nervous disturbance of a moral order.

In place of this lassitude which is an open invitation to repose, and which is a really pleasant condition after a great quantity of work quickly performed, there is felt, after an exercise of speed, a kind of exhaustion accompanied by nervous excitability; a feeling of enervation is experienced, which may either be characterised by prostration, or by excitability, or even by undue sensitiveness. The expression "nervous fatigue" gives a good idea of this kind of disturbance which will easily be recognised by those who have ever immoderately prolonged an exercise of speed. We may say in a general sense that the fatigue left by exercises of speed is not *reparatory*. It invites less plainly to sleep, and excites the appetite less than the fatigue resulting from a slow expenditure of force.

The great expenditure of nervous energy which the exercises of speed render necessary is certainly the cause which makes the repair of the system after these exercises more difficult. We know the important office of the nervous system in nutrition, and the rapid atrophy which regions of the body undergo when the distribution of nervous energy is hindered, whether by section of the nerves or by a paralysis of central origin.

It is then no doubt to the considerable expenditure of nervous energy and to the inevitable prostration which follows it, that we must attribute the loss of weight observed in exercises of speed. We observe this tendency to malnutrition in all circumstances of a physical or moral order which call forth a great expenditure of nervous energy. A man rapidly becomes thin under the influence of continual mental distress, or very sustained intellectual work.

We believe that if an exercise of speed causes loss of weight, it is not so much due to the excessive expenditure which accompanies it, as to the defective repair which follows it. Hence, from the excessive expenditure of nervous energy which occurs in order to hasten the muscular contraction, there results a temporary exhaustion of the forces which preside over nutrition, and the tissues burned in the work have no tendency to repair.

There occurs during an exercise of speed a nervous commotion resembling that which follows a strong emotion or a powerful mental strain. The fatigue due to speed often prevents appetite and sleep. These results are especially marked in impressionable persons, and it is among them that we may see how fatigue caused by speed is adverse to the repair of the system. Many children, after running about too much, can neither eat nor sleep. Many horses which are too nervous refuse their oats after a hard day's hunting. We do not see this capricious appetite in coarsely built animals which do collar-work all day.

In man it is remarkable to note the different effects on nutrition of exercises of speed and of exercises of strength. Navvies, porters, strong men at a fair, have usually a massive build which becomes more and more marked by the exercise of their profession. Runners, dancers, fencing-masters, are generally slender and thin.

If we wish to sum up in a few words the effects of exercises of speed, we see that we must distinguish between the effects due to the accumulation of work, and those due to the frequency of movements.

Exercise of speed has one point in common with exercise of strength; this is the great quantity of mechanical work which it can produce. The rapid succession of a great number of efforts, leads, in ultimate analysis, to the same results as the great intensity of a small number of efforts at longer intervals. We may say, to borrow an idea from therapeutics, that these two modes of exercise have for result the habituation of the system to "*large doses*" of work.

But exercises of speed have special results very different from those of exercises of strength. These results are not due to the great quantity of mechanical work done, but to the rapid succession of the movements. The speed of movements has on the system a peculiar influence, independent of their greater or less energy. It is by the nervous system that this influence is felt, and it is, in ultimate analysis, to an increased work of the nerve-centres that the very specialised effects of exercises of speed are due.

CHAPTER V.

EXERCISES OF ENDURANCE.

Conditions of Exercise of Endurance; Moderation of Efforts; Slow Repetition—Fractional Work—Conditions Inherent in the Worker. Men and Animals who have "Staying Power"—Need for perfect Equilibrium between the Intensity of the Work and the Power of Resistance of the System—Importance of Respiration in regulating Exercise of Endurance — Exercise of Endurance makes the Functions more Active without Fatiguing the Organs—Association of the Great Functions with Moderate and Prolonged Muscular Work; Respiration more Active without Breathlessness; Circulation Quickened without Palpitation — Indications and Contra-indications for Exercises of Endurance—Parallel with Exercises of Speed—Why Children bear Exercises of Endurance badly—Veterans and Conscripts.

I.

WE call exercises of *endurance* those in which the work must be continued for a long time.

In these exercises the expenditure of force is determined less by the intensity and rapid succession of efforts, than by their duration. It is necessary that the muscular effort shall not be too considerable, and the movements not too rapid, in order that fatigue under its various forms may not interrupt them too soon. So that an exercise of endurance is only moderate exercise if it lasts a short time, while it may become forced exercise if it be continued too long.

In these exercises the quantity of work done after a long time, at the end of a day, for instance, may be very considerable, but the expenditure of force is made in such small fractions that there is no painful muscular effort, nor any marked disturbance in the organic functions. So that a man performing an exercise of endurance may pass, almost without noticing it, to strong doses of muscular work.

The animal machine is made in such a manner as to be able to perform without fatigue movements of a determined intensity and speed. When these limits are not exceeded, no appreciable disturbance is produced in the system, and the work is done amidst complete tranquillity of the vital functions. Thanks to the perfect equilibrium between the muscular exertion and the power of resistance of the subject, he is able in exercises of endurance to go on working for a long time, and let the useful effects of work insensibly accumulate, without causing any disturbance to the various parts concerned in its performance.

We see at once the importance and usefulness of exercises of endurance when we have to do with a feeble system, with a person of low resisting power, to whom we wish to give the benefits of muscular work, while enabling him to avoid the dangers of fatigue. Similarly we are sometimes able to give a sick man a very energetic remedy by administering it to him in "fractional doses."

The division of work into fractional quantities sufficiently small to enable the system to support each one without disturbing its normal functions, such is the essential condition of exercises of endurance.

Another condition is necessary to constitute an exercise of endurance; the muscular efforts must be at intervals sufficiently long that the effect of a second may not be added to that of a first. Between two successive doses of work there must be a sufficient time for repose.

There are organs in the human body which perform a considerable work continuously throughout life. It is surprising, for instance, to think how the hollow muscle we call the heart, goes on contracting from birth till death, without ever suspending or slackening its work. This is because the cardiac muscle performs a work of endurance. The expenditure of force at each beat is well balanced with the power of resistance of the system of which it forms a part, and the interval between two beats is a time just long enough to rest the fibres.

But if some circumstance occurs which increases the work of the organ, as we see in constriction of the orifices for instance, or if the contractions become immoderately frequent, as is the case in palpitation, the conditions of work are changed. The heart, instead of having to do a simple work of endurance, has to do a work of speed or strength incompatible with continued work; the muscle becomes fatigued, its fibres lose their elasticity and their energy, there is overwork of the heart, and a condition of *asystole* comes on, of which death is the inevitable consequence.

Similarly in the muscles of animal life, increased energy, or more rapid succession of movements, tends to make the exercise of endurance pass into one of speed or of strength.

In an exercise of strength there is *accumulation* of work, because each muscular effort is very intense. In an exercise of speed there is *multiplication* of work, for the movements have little energy, but the rapid succession of efforts of small intensity leads in the end to an accumulation of work. In an exercise of endurance, on the contrary, the efforts being repeated at sufficient intervals, the work is *fractional*, for at any moment the quantity of work performed by the organism does not exceed its power of resistance.

Among exercises ordinarily practised, which are those we may call exercise of endurance? This question raises a first difficulty, for the same exercise may represent in turn a work of speed, a work of strength, or a work of endurance, according to the conditions in which it is performed.

Rowing, for example, is a work of speed in a rowing-match, and a work of endurance in a long course. Walking, which is the type of exercises of endurance, may present the characters of an exercise of strength when it is performed on a very steep slope. Thus in certain ascents in which it is necessary to climb almost perpendicular slopes, each step represents a great expenditure of muscular force, and the tourist is obliged to interrupt his work as frequently as if he were walking in the plain with a heavy burthen on his shoulders.

The conditions under which the man performing the exercise is placed have no less importance than the exercise itself in determining its character as one of endurance.

Exercise of endurance is characterised by the necessity for perfect equilibrium between the intensity of muscular effort and the power of resistance of the system. Now there is nothing so variable as the power of resistance of each individual. So that which is for one man an exercise of strength or of speed, becomes for another, stronger or better trained, a simple exercise of endurance. A canter is an exercise of speed for a cart horse, used only to walk; it is an exercise of endurance for a thoroughbred, which can sustain this pace for an entire day without stopping. Rowing seems an exercise of strength to a man who is learning; after a quarter of an hour he is out of breath. For a waterman it is an exercise which he can perhaps keep up a whole day without any fatigue.

There are then two conditions necessary to constitute an exercise of endurance: (1) a certain moderation in the violence of the exercise, (2) a certain power of resistance on the part of the system.

This is why the word "staying-power," which conveys the idea of length of time, applies rather to the qualities of the man or the animal, than to the nature of the work they perform. A work of endurance is one whose mode of performance enables it to be long continued; and a man or animal with "staying power" are those whose system is fit to support prolonged work.

Certain persons are unable to perform the most moderate exercise without showing, after a very short time, the signs of extreme fatigue. There are others who keep up with surprising power of resistance the most violent exercises, and for them exercises of strength and of speed become exercises of endurance.

Generally these differences in power of resistance, in the staying power of different people, are due to differences in their respiratory powers.

We may say that the respiratory fitness of the individual is the true regulator of a work of endurance.

In order that an exercise may be long continued the first condition is that it does not lead to breathlessness. We can go on walking in spite of weary legs and sore feet; but we cannot go on running when we are out of breath. We saw in the chapter on *Breathlessness* that this form of fatigue is due to an intoxication of the blood by an excess of carbonic acid. To escape from this intoxication, which renders the continuance of the work impossible, a man must eliminate the excess of carbonic acid as fast as it is formed, and, the formation of carbonic acid being in proportion to the quantity of work done in a given time, we may definitely conclude that in an exercise of endurance, the work of the muscles must be subordinated to the power of the lungs. Thus all the conditions which increase the respiratory power increase the fitness for keeping up intense work for a long time, and a man has "staying power" when he has "wind."

II.

The effects of exercise of endurance may be exactly deduced from the conditions in which this exercise is performed. Evidently an exercise which is incompatible with breathlessness will lead to none of the accidents of forced respiration. During such an exercise there will be no fear of rupture of tendons, of laceration, or of excessive shaking of muscular fibres, for the movements must never become so violent as to exceed the power of resistance of the organs. Further, exercise of endurance does not sensibly disturb the working of the organs, hence in it there will be no very energetic association of the great functions of the economy with the muscular work. In a man walking, for instance, there will not be the rapid rise of temperature, the copious perspiration, the excessive quickening of the pulse and the violent panting which we observe in a runner.

Still we must not imagine that even the most moderate exercises, when long continued, can be compatible with the maintenance of the functions in an absolutely calm and normal condition. The most moderate and most localised muscular contraction will in the end bring about an association of the great functions of the economy in the work. We have already quoted the curious experiment of Chauveau, proving that the work of mastication, as moderate and localised as work can be, can influence the general circulation of the blood. In a horse moving its jaws in chewing oats, we can ascertain that the blood-current is sensibly quickened in the muscles of mastication. A more energetic call for nutrient fluid is made by the fibre at work. For some minutes the quickening is confined to the blood vessels supplying the muscles in action ; but soon, if the chewing movements go on, the quickening movement gradually spreads, and involves the heart itself, so that the number of pulsations is increased through the whole extent of the circulatory system.

Such is the influence of the duration of a muscular action. A work which is local and insignificant, if prolonged a certain time, comes in the end to make its effects felt on the general system by associating in the work of the muscles the most important of the great functions of the economy, the circulation of the blood.

But the blood-current cannot be quickened without the other functions being associated in the increased activity. The blood, by the very fact of its more rapid movement, rises in temperature from increased friction against the vessel-walls. The nerve-centres receiving more blood and hotter blood must be excited to a degree ; and the lungs are also subjected to two influences capable of making them more active ; on the one hand, the blood passing through their capillaries is increased in quantity and needs, for its aëration, a greater quantity of oxygen ; hence increase of the respiratory need and quickening of the respiratory movements ; on the other hand, the warming of the blood tends to make the respiration more active, for heat stimulates the respiratory movements.

We see how the duration of work, an essential character of exercises of endurance, forces the whole system to associate by a greater activity of all its functions, in muscular actions the effects of which at first sight appear to be localised in particular portions of the body.

This association of the great functions in the work, or, in other words, the *general effects* of the exercise, are never as considerable in exercises of endurance as in exercises of speed or of strength. We do not observe, for instance, in the foot-soldier making a long march, these violent movements of the respiratory apparatus and the palpitation of the heart which are inevitable in the runner. Further, owing to the moderate nature of the work there is no need during the exercise to bring into action all possible force, and to make an *effort*. The absence of effort saves a man performing such exercise from the violent compression of the heart and great vessels which hinders the working of these organs and makes their sustained function impossible.

The physiological effect of exercise of endurance is, to spare the organs while increasing in a salutary degree the play of their functions. Its most essential character is to give to the system a power of repairing, even during the work, the greater number of the disturbances which occur in the machine. Thus breathlessness does not occur during exercises of endurance; the quantity of carbonic acid produced by the muscles never rises to a quantity in excess of that which the lungs can eliminate, it is removed from the blood as fast as it is formed, and passes unnoticed from the system.

To this immunity from breathlessness there is added in exercises of endurance, a considerable introduction of oxygen into the system. If we refer to the table of Dr. Edward Smith,* we find the following are the comparative effects of the different modes of exertion on the quantity of air which is introduced into the lungs:

* Health and Disease, p. 300.

The state of rest in the lying posture is regarded as unity.

Thus the effect in the lying posture being	1.0
That of the sitting posture is	1.18
The standing posture	1.33
Walking at 2 miles per hour	2.76
Running at 6 miles per hour	7.0

According to this table the amount of air consumed by a man sitting being 1.18, that of a man walking exceeds it by 1.58, and that of a man running exceeds it by 5.91.

Thus a man walking receives every minute the benefit of an excess of oxygen represented by 1.58, and a man running of an excess represented by 5.91. If we compare these two numbers we see that their ratio is nearly as 4 to 1; but from this little calculation we get a somewhat unexpected result that a man who has walked for four hours has passed as much oxygen through his lungs as a man who has run for one hour.

In other words, let us suppose—a thing much open to dispute—that the air introduced into the lungs is as well assimilated during running as during walking, it will be enough to walk for an hour to benefit from the same excess, from the same gain of oxygen as if we had run for a quarter of an hour. It is easier to walk for an hour than to run for a quarter of an hour, and the gain being equal from the point of view of the oxygen acquired, it would seem that walking is always to be preferred to running, and that, in general, the exercises of endurance are worth more than the exercises of speed. They are in fact preferable in all cases in which we have to do with persons whose lungs or heart are in a condition to cause anxiety to the doctor, and whose blood needs to be enriched by an increase of oxygen. They will make this gain on better terms.

On the other hand, the exercises of endurance, always leaving the working of the lungs comparatively tranquil, do not demand the great inspiratory efforts which force all the air-cells to open out. In the state of repose there is always a great number of air-cells remaining inactive; their walls are flaccid and collapsed, there are whole regions of the lung which take no part in the respiratory act. When the lungs bring their whole respiratory force into play, no region remains inactive, and the most remote air-cells are opened up. The lungs become as large as possible, and push out the walls of the thorax. Here is the most precious effect of the exercises which cause breathlessness. They tend to increase the capacity of the chest. Now the exercises of endurance do not lead to breathlessness.

The exercises of endurance render more active the gaseous interchange and enrich the blood with a greater quantity of oxygen, but their effect ceases there: they do not excite with sufficient violence the respiratory movements to modify the shape of the chest. They have their indications and their advantages; they also fall short in some directions. The doctor must weigh the pros and the cons, and must deduce from examination of his patient the formal indication for one exercise rather than another.

Those whose lungs are suspect, for whom violent respiratory movements would present dangers; those also whose heart is not in a state of perfect integrity, or in whom we suspect arterial degeneration which diminishes the strength of the vessels; all those, in short, whose organs of respiration and circulation present a certain fragility, should prefer exercises of endurance to exercises of strength or of speed.

III.

Aged men, persons suffering from gouty or alcoholic vascular degeneration, persons suffering from fatty infiltration of the heart, should confine themselves exclusively to exercise of endurance.

Patients who very easily lose breath, emphysematous persons for instance, cannot perform any exercise of speed or of strength, and the same is the case with phthisical persons. But still patients of both these classes have need of supplementary respirations to compensate for the insufficiency of the respiratory field which has been reduced by the disease, sometimes by as much as half. Exercises of endurance constitute in such cases a valuable means of treatment. They make it possible, through increasing by a very little at a time the carbonic acid formed by work, that the whole of this excess shall be eliminated at each expiration, there being in exchange a small excess of oxygen introduced during inspiration. If the exercise is well regulated it can be kept up for hours, and the patient will then have benefited without incurring the dangers of breathlessness, from a series of small quantities of oxygen the sum total of which will be equal to that gained by a healthy man in an exercise of strength or of speed. Referring to the calculation made above, we see that moderate exercise, like walking, kept up for four hours, makes a man absorb as much supplemental oxygen as a most violent exercise, such as running, does in an hour.

Generally we do not make use enough of exercises of endurance in treating patients with lung trouble. We should boldly prescribe for tubercular or asthmatic patients long walks on level ground, or sustained exercise at the oar, coming down stream and rowing with a very slow stroke.

Respiration is the most important of the functions influenced by exercise, but it is not the only one to be considered in exercises of endurance. The respiratory function is for the elimination of carbonic acid and of many other substances resulting from the combustions of work, but all the products of combustion are not eliminated by the lungs.

The fractional performance of work, which lends itself so well to the regular expulsion of carbonic acid, has not the same influence on the elimination of the other products of dissimilation, on the waste-products found in the urine for instance. If we refer to the chapter dealing with the urinary deposits which occur after work, we shall easily understand that the fractional performance of the work cannot hinder the accumulation of the products of combustion which are eliminated by the urine, because this elimination is a slow process. The carbonic acid formed during work is immediately eliminated by the lungs; the sparingly soluble compounds resulting from muscular waste are not found in the urine for at least three hours after the muscular work which has led to their production. If the slowness of the work can retard the time when these waste-products will accumulate, their accumulation is none the less inevitable, for in an exercise which has lasted three hours, the work will be finished before the system has got rid of any particle of these waste-products.

This is why an exercise of endurance, if it may retard the onset of fatigue, cannot save the system from its consequences.

Here is, moreover, a remarkable confirmation of our theory of stiffness. We believe that the stiffness of fatigue is due to an overcharge of the blood with urates, a kind of transient *uricæmia*, just as breathlessness, another form of fatigue, is due to the presence of an excessive quantity of carbonic acid in the blood. A man who, not being in training, goes out for a day's shooting, will inevitably suffer on the following day from a more or less severe attack of stiffness, and yet his exercise, the type of an exercise of endurance, will not have produced breathlessness at any time during the day.

These observations give us the key to a fact which is at first sight very surprising, and even inexplicable except on our theory, namely that young persons support better exercises of speed than exercises of endurance.

A child of seven years old will bear very well all the games which need rapid and prolonged running. This is owing to the wonderful ease with which its lungs adapt themselves to the exigences of forced respiration. The carbonic acid produced by work is eliminated with great rapidity and causes no inconvenience to the system.

But carbonic acid is not the only product of dissimilation due to work which must be eliminated from the system, and there are others whose exit is slower, notably those resulting from the dissimilation of the nitrogenous tissues. Now *dissimilation is much more rapid in the child than in the adult*, for the young tissues have less stability than the adult tissues. Hence the formation of nitrogenous waste-products, of which uric acid and urates are the chief, is more abundant. Exercises of endurance which allow of the elimination of the whole excess of carbonic acid with each expiration, lead to no accumulation of this gas, but they can cause an accumulation of the nitrogenous waste-products, for the elimination of these does not begin, as we have shown, for three or four hours after the muscular work which has caused their formation.* An exercise may then be continued for four hours, and give rise throughout this time to the formation of nitrogenous waste-products, not one particle of which is being eliminated. All these waste-products will be accumulated in the blood when the exercise has come to an end. The system which will have escaped the effects of carbonic acid, a gas which is eliminated as fast as it is formed, will not escape those of nitrogenous waste-products which will have accumulated in large quantities in the blood. There will be after the exercise of endurance is over, a true uricæmia, a surcharge of the blood with uric acid compounds.

This result explains how it is that young persons who, thanks to the adaptive power of their respiratory organs, have borne with impunity an exercise of speed, and have not lost breath, can easily suffer from febrile stiffness, and even from febrile overwork, after too long a walk.

Gouty persons are, like children, exposed to the accidents of consecutive fatigue after exercises of endurance. They have already a constitutional tendency to the accumulation of uric acid in the blood, and muscular exercise causing the production of nitrogenous waste-

* See above the chapter "Stiffness," p. 119.

products which cannot be eliminated as fast as they are formed, hence there is, when the long-continued work is over, an abundance of uric acid compounds in the blood. We know that an attack of gout is due to this uric saturation of the blood, and thus are explained the attacks of gout which, in gouty subjects, almost inevitably follow a very long day's shooting, when a man has not been prepared by gradual training, the salutary effects of which in preventing the formation of deposits of urates we have already studied.

To sum up, the exercises of endurance allow of the performance of such work with great economy of fatigue. They give the system the benefit of a supplementary acquisition of oxygen, without exposing it to the dangers of forced respiration. They quicken the circulation of the blood without fatiguing the heart or violently distending the vessels. In a word they spare the whole machine during work.

But if they preserve the system from the accidents of immediate fatigue, they do not save it from consecutive fatigue. If they enable it to escape breathlessness, this is not the case as regards stiffness.

Moderate and prolonged exercise, that in which the total work is considerable, but well-divided, is suitable for patients whose respiration needs management. It cannot be prescribed without preliminary training for gouty persons, and is absolutely unsuitable for children.

Exercises of speed are well suited to young persons, who easily eliminate carbonic acid. Exercises of endurance are better suited to persons of ripe age, whose nitrogenous tissues resist better the processes of dissimilation, and form less the nitrogenous waste-products. Conscripts are excellent for manœuvres of speed, and veterans for manœuvres of endurance.

CHAPTER VI.

MECHANISM OF DIFFERENT EXERCISES.

The Principal Action and the Indirect Actions in Exercise—Part Played by each Part of the Body in the Chief Exercises—Office of the Upper Limbs—Gymnastic Apparatus: especially bring the Arms into Action—*Suspension* and *Support* of the Body—*Breasting* and *Circling* in the Gymnasium—Rowing; Fencing; Single-stick; English Boxing; Dumb-bells — Office of the Lower Limbs—Walking and Running; French Boxing or *Chausson*—Usefulness of Exercises of the Legs in developing the Chest—Office of the Pelvis—Flexion of Pelvis on Thorax in Gymnastic Exercises. Development thus given to the Abdominal Muscles—The best "Girdle against Obesity"—Office of the Vertebral Column in Exercise — Importance of Position—The Horseman with a "Good Seat"—Active Share of the Vertebral Column in Exercise. Thrust from the Loins —Leaping—Passive Share of the Vertebral Column in Exercise —Orthopædic Effects of Attitudes of "Suspension"—Swedish Gymnastics.

I.

To understand the exact mechanism by the aid of which a given exercise is performed, we must discover what muscular groups are brought into action, and what bony levers are moved.

This analysis is not always easy, for besides the principal effort and most apparent movement, every exercise involves secondary efforts which associate in the work parts of the skeleton or regions of the body which we should not have expected to play any part. Different regions of the body may at one time have the chief, and at another only an indirect share in an exercise; and we see the arms, the legs, the head, the neck and the trunk, become in turn essential agents or accessory factors in a muscular action. But in general it is rare for an isolated region of the body to be exclusively charged with the work, and almost always several separate muscular groups are in association, and contribute with greater or less vigour.

In most exercises the chief part is played by the limbs; the vertebral column, the pelvis, the ribs and the head often have a merely secondary action: if burthens have to be raised or weights shifted, it is by the hands they are seized; if the body has to be moved it is the legs which have the direct part through their contact with the ground, or the arms through being the means of suspension in various gymnastic exercises. But wherever a very energetic effort is needed we see the trunk associated with the movement of the limbs. The muscles of the pelvis come to the aid of the lower limbs. Finally the muscles of the vertebral column and the ribs are associated with very violent movements of the limbs, for many of them are inserted into the scapula, the humerus, the pelvis, and the femur.

Often all the muscles of the body seem to be associated in the work of a principal muscular group, to work with it for a definite end. This association is more complete in proportion to the violence of the effort; and we may see the work, at first very localised, when it is insignificant, gradually spread, as it becomes more considerable, to more and more distant parts, and be propagated from above, downwards, or from below, upwards, according to the nature of the exercise, from one end of the body to the other.

To jump with the feet together for a short distance, only the lower limbs are brought into play. If the distance is greater, the muscles of the pelvis and the vertebral column are associated with the movement. If the man wishes to jump as far as possible, his arms even come to take part in the action, and they are violently swung in such a way as to increase the momentum of the body.

In raising a very light dumb-bell the arm alone is in action. If the weight is heavier, the muscles of the trunk are associated with those of the arm and shoulder. If finally the weight is nearly as great as the man can lift, we see the extensor muscles of the legs and thighs contract just as vigorously as the others, to produce a vigorous upward thrust. Thus a muscular action which seems at first to be a simple exercise of the arms, may render necessary a very energetic action of the legs.

The practical consequence to be deduced from these facts is of some importance. Through ignoring the indirect effects of muscular movement, we might expose a patient to the association in exercise of a damaged region which it would be important to spare.

The indirect association of a region of the body in work has sometimes the simple object of furnishing a fixed point of application to the limbs in action. The indirect muscular action is in this case a necessity imposed by the extreme mobility of the bony pieces which make up the skeleton. It is always necessary that one extremity of a muscle should have a fixed attachment, in order that the other extremity may pull efficiently at the bone into which it is inserted. The greater the expenditure of force, the more urgent becomes the necessity of providing a fixed attachment to the muscles in action, in order that they may contract with all possible energy. When the movement represents a considerable expenditure of force it is always necessary that the vertebral column and trunk should be rigid, they representing the centre to which all the limbs converge; hence arises the production of *effort* of which we have spoken at length in the chapter on *Movements.* But effort itself causes a momentary stoppage of respiration, and a compression of the great veins and the heart, and in this manner there may be produced a profound disturbance in the great functions of the economy on account of the contraction of a very localised muscular group.

The examples we have just given show the importance of accessory movements and of indirect muscular work in bodily exercises. The more we analyse these exercises, the more we are impressed by the intimate relation between all the muscular groups, and between all the pieces of the skeleton, and the more we are impressed with the fact that the local effects of exercise often influence regions which are at a considerable distance from that which seems most at work.

It is impossible for us to analyse here all known exercises and to show the part in their performance which devolves on this or that region of the body. Further, it is not our object to make a complete catalogue of all the exercises which it has pleased the fancy of gymnasts to invent, but only to indicate the fundamental notions by means of which we can form a judgment of the hygienic value of the chief exercises practised. For this purpose it will be most easy to glance at the various regions of the body, and to point out broadly what direct or indirect part each of them usually plays in the different exercises practised.

II.

In most exercises the principal and direct share devolves on the limbs, and the indirect on the trunk which associates in the work of the arms and legs, either by a muscular effort in the same direction, or by an attitude favourable to the performance of the movement.

The *arm* appears to be the object of all the exercises of modern gymnastics. Most of the exercises performed in a gymnasium need as a preliminary that a rope or bar should be seized. The upper limbs must then "suspend" the body to the apparatus held in the hands, or "support" it when raised above the hands. The *suspension* and *support* of the body are the fundamental positions of gymnastics with apparatus.

In these exercises the arms have to move the weight of the body in different directions. They usurp in a manner the office of the legs. But what the legs accomplish with ease by means of their powerful muscular masses, the arms perform with difficulty, and must use all their energy to raise the body, as when it is necessary to pass from the attitude of suspension to that of support in the movement known as *breasting*. A man who performs a *breast* does work represented by the weight of his body multiplied by twice the length of his arms. Most gymnastic exercises thus throw a considerable work on the upper limbs; hence the arms become quickly and greatly developed in those who practise gymnastics with apparatus.

Work of the arms is necessary in exercises which bring about the displacement of more or less heavy weights, the body remaining on the ground. Thus, dumb-bell exercise needs an expenditure of the muscular force of the arms in proportion to the weight of the masses raised. But never, at least in gymnastic exercises, are the weights as heavy as the human body. Hence the muscles and bones of the shoulder do not perform as much work in most of the exercises in which the feet do not move, as in those needing the support or suspension of the body by the arms.

When a gymnast balances on his hands, with his feet in the air, he makes his shoulders support the whole weight of his body, just as his hips do in the ordinary upright posture; but the pelvis with its solid bony girdle made of thick bones, strongly connected, is very fitted for support, and easily transmits the weight of the body to the two femurs firmly articulated in deep cavities hollowed in solid bones; whereas the shoulder joint is in no way fitted for such work. While the body is supported by the arms, the muscles surrounding the humerus, the scapula, and the clavicle must contract very energetically to fix these very movable bones, and thus create an artificial attitude at the expense of a considerable work of the muscles of the neck, chest and back.

We shall see, in speaking of *exercises which produce deformity*, the consequences of this exaggerated action of the muscles about the shoulder.

Most of the exercises of gymnastics with apparatus need constantly the support of the body on the arms, or the passage from suspension to support, as in the various *breasting* movements. Hence it is especially in men devoted to the trapeze, the horizontal bar, the rings, the parallel bars, that we observe this excessive development of the muscles about the shoulder, and this projection of the fleshy masses of the neck, which often becomes ungraceful from its exaggeration.

Many other exercises may demand great expenditure of force from the muscles of the arm without associating in their work so disproportionate an effort of the shoulder. Rowing for instance needs vigorous pulling of the oar, but this does not submit the shoulder joint to the violent pressure which occurs in the gymnastic exercises above described. In rowing the arms perform alternate movements of flexion and extension combined with movements of abduction and adduction. If the exercise is vigorous, the trunk associates in the work by bending forwards in a manner to favour the extension of the arms, then the whole body undergoes the movement of extension, with which is associated a thrust of the legs and thighs to continue the backward movement begun by the flexion of the arms. Thus, in handling an oar, the movements accord with the function of each muscle and each lever employed.

We shall see the importance of this fact in studying exercises which produce deformity.

In boxing, quarter-staff, single-stick, and fencing, the muscles also act whether simultaneously or singly, with only an insignificant load, or even with none at all. Hence the upper limbs do not present, in persons devoted to these exercises, the conformation noticeable in gymnasts, oarsmen, and occupations needing the movement of heavy masses. In prize-fighters the arms are very muscular, but this development, which adds to the force of the blow, is obtained by accessory exercises, such as dumb-bells.

The *legs* are the limbs most naturally exercised in the ordinary circumstances of life. It is on them that in man devolves the function of locomotion. They can perform, besides walking and running, the natural paces, a number of complicated movements, such as those performed in dancing.

French boxing needs on the part of the legs work which is quite different from walking, and one which rather resembles dancing. The peculiarity of the movement of this exercise is to force the body to support itself on one leg whilst the other gives a kick; it is difficult to keep balance in these attitudes in which the trunk associates in every movement of the limbs. To counterpoise the leg which carries the foot towards the opponent's figure, the body swings on to the other limb by a lateral flexion of the lumbar spine, then the great muscles of the pelvis strongly extend the thigh, on which the leg is itself also strongly extended. But the extension of the thigh presupposes the fixation of the pelvis, which itself cannot be fixed unless the ribs are rendered motionless by a deep inspiration with breath held at the end of it. Hence an "effort" must be made, and for this reason a well-applied kick is almost always accompanied by a kind of groaning which indicates the brisk expulsion of the air which had been retained in the lungs.

The legs can perform much work without fatigue because they possess powerful muscular masses. No exercise can produce for a very short time a sum of work comparable to that performed by a man who goes quickly up a staircase, or runs up a steep slope. If we try to perform an equivalent work by means of the arms in climbing up a ladder, fatigue very promptly stops the exercise, because the work required from the muscles in action is too considerable for their size. But breathlessness is proportional to the total quantity of work done in a given time; hence the exercises of the legs, if they do not induce prompt muscular fatigue, very quickly lead to breathlessness.

Here is a peculiarity worthy of note, and of great practical importance. The exercises which make the legs work actively almost all need the co-operation of the thorax. Running, walking up hill, leaping, exaggerate the movements of the ribs by the greater activity they give to the respiration. Hence we draw a practical conclusion which we shall develop further on: the exercises of the legs are generally to be preferred to those of the arms when we wish to develop the chest and raise the ribs.

The *pelvis* associates actively in all the exercises in which the body keeps the erect posture. Its position as intermediary between the vertebral column which it supports and the legs by which it is supported, obliges it to take part in all the energetic movements of the trunk, as well as in those of the vertebral column and the thorax.

In bodily exercises, the movements of the pelvis are almost always indirect and accessory. It is displaced in walking, in running, in leaping, always supporting the weight of the body, and is thus subject to shocks which its massive structure enables it to endure without injury.

In gymnastic exercises which need the suspension of the body by, or its support on, the hands, the pelvis is often displaced, but then it has not to support the weight of the trunk, and bears only that of the lower limbs. These exercises demand every moment a movement which hardly ever occurs in the ordinary actions of life, the flexion of the pelvis on the trunk. The result of this movement is to double up the body, and draw the limbs towards the chest. To circle the trapeze and to perform a like movement on the rings and on the parallel bars, flexion of the pelvis on the trunk is necessary. It is to the abdominal muscles that is assigned the office of flexing the pelvis on the trunk, or conversely of the trunk on the pelvis. Hence these muscles become very firm and very thick in professional gymnasts. Hence the rarity of big bellies in persons who do much work on the trapeze: the firmness of the muscular walls of the abdomen being an excellent preservation against fatty deposits. Firm and vigorous abdominal muscles form the best "girdle against obesity."

III.

The vertebral column represents the axis of the body; it is made up of a great number of movable pieces which can undergo displacements together or separately. There is no part of the body which more often associates in work, either as a whole, or one of its sections alone.

Different bodily exercises and different kinds of labour make very different uses of the vertebral column. It is sometimes associated in movement as a counterpoise to maintain equilibrium endangered by a displacement of the centre of gravity. It is a kind of balance, the changes of position of which are simply compensatory. Thus we stoop forwards or backwards, according as we are carrying a load behind or in front.

Many movements of the limbs need a co-operation of the vertebral column, not for any reason of balance, but owing to the necessity of a particular attitude favourable to the performance of the work. Certain professional labours need a stooping position, and the vertebral column associates in the work of the arms by bending forwards or to the side. In a man using a pickaxe, the work of the arms must be accompanied by a certain bending of the trunk to allow the hands which hold the tool to approach the ground.

In bodily exercises the part played by attitude is very important. The success of a gymnastic movement depends almost always upon good position of the body. Generally the arms begin a movement, but the muscles of the body finish it. On the rings, the trapeze, the parallel bars, no movement can be performed unless the vertebral column associates in the movement of the arms, whether by flexion or by extension.

In riding, the active work is apparently done by the thighs, which by their energetic pressure must make the horseman, so to speak, stick to his saddle. But firmness of seat comes rather from the perfectly balanced attitude of the trunk. All horsemen know that a man with a "good seat," that is to say, having an attitude favourable to equilibrium, needs very little force to keep him in the saddle. Further, in the shocks of rapid riding, the vertebral column, thanks to the extreme mobility of the pieces of which it is made up, undergoes a series of local movements in the lumbar and dorsal regions, which cause the movements of the horse to be deadened and lost without displacement of the trunk.

The vertebral column sometimes associates very intimately with the movements of the limbs, and accompanies them in their changes of direction. In fencing, for instance, in the movements of attack, in proportion as the arm is stretched, the vertebral column is lengthened by a movement of forced extension, and when the fencer lunges, stretching his arm towards his adversary, the dorsal spine is strongly projected in the same direction, and for this it is necessary to lean towards the side of the threatening arm, in such a manner that the foil, the right arm, and the vertebral column, tend to place themselves in the same axis and form a simple straight line.

This association of the vertebral column with the movements of the arm is also observed in the exercises in which the muscles of the trunk must help and reinforce the action of the upper limbs. If we endeavour to give a violent thrust with the hand, the spine, in order to associate in this movement as efficiently as possible, must bend to one side, to place itself in the axis of the arm, for this direction will be the most favourable for the assistance by all the pressure of the trunk of the movement performed by the extensors of the arms. A blow with the fist, say boxers, must be given with the loins and backed up by the whole body.

When the vertebral column thus comes to the assistance of the arms, whether actively or passively, one of two things may happen, either the direction of the vertebral column is associated with that of one arm only, as occurs in fencing, and then the bony column is inclined towards the arm in action, and bends to the right or left, as the case may be; or the vertebral column associates with both arms at once, and then the direction of displacement is not a lateral one, but an exaggeration of its natural curves.

In fact the shoulders are on a level with the upper end of the dorsal curve of the spine. If both arms are stretched out above the head, holding a heavy dumb-bell, the direction of the arms is parallel to the general direction of the vertebral column. But this column is not straight; it has several curves, of which one begins at the seventh cervical vertebra, that is at the level of the shoulders, and ends at the twelfth dorsal vertebra. The twelve dorsal vertebræ thus form an arc, of which the chord would be represented by a line having exactly the direction of the force which is being resisted by the arms. The vertebral column, in association with the vertical resistance of the upper limbs, undergoes a pressure which has the same effect on its dorsal curvature as is exercised on a bow by tension of its string; viz., its convexity is increased.

Finally, the vertebral column may play the principal part in a muscular effort. Many movements are performed by a thrust from the loins which sometimes flexes the trunk, as in ringing a heavy bell, and sometimes extends it, as in raising a heavy load from the ground. Many exercises necessitate alternate movements of flexion and extension of the vertebral column. Rowing, for instance, brings the vertebral column into play with each stroke, for it is flexed in carrying the oar back, and vigorously extended in pulling the stroke.

In a standing jump, the vertebral column is brought actively into play. The jumper, to gain impetus, stoops, and then vigorously straightens himself like a relaxed spring. In jumping with a run, the impetus thus gained is used to launch the body, but once in the air the jumper has to bring into play the muscular power of the dorsal region. In a very curious instantaneous photograph given by Marey * we see ten successive attitudes of a man doing a high jump, and amongst these attitudes corresponding to different moments of the leap, there are four or five in which we see that the vertebral column, at first strongly flexed by a movement which raises the knees and draws them towards the trunk, is two tenths of a second later in a position of forced extension owing to a swinging movement of the trunk which carries the lower limbs as far forwards as possible. The body of the jumper is then in a very oblique position to the surface of the ground. The axis of the trunk makes an angle of 45° with the horizontal, which is evidently incompatible with standing on the feet. A vigorous exertion of the loins is necessary to replace the vertebral column in the vertical position, under pain of falling backwards.

* *Marey.* La Machine Animale.

Thus every moment, in gymnastic exercises, the vertebral column actively associates with the action of the limbs to finish a movement which they have begun.

Most exercises performed with the aid of apparatus seem to make only the arms work, but they really need the very active concourse of the muscles which move the spine. Often in *breasting* movements the muscular action is facilitated by an imperceptible movement of flexion of the vertebral column which curves the back, or by an effort of extension which hollows it.

In the cases we have quoted, the vertebral column has an active part, through the muscles attached to it, which energetically participate in the work. There are other circumstances in which the bony column has a passive share, and simply is influenced by the weight. In a man hanging by the arms from a trapeze, whose body is vertical from its own weight, all the muscles of the back are completely relaxed, but the vertebræ to which they are attached undergo the traction of the weight of the body, suspended in space. The point of suspension, which is at the level of the shoulders, corresponds to the first dorsal or last cervical vertebra. From this point of attachment the whole body is subject to the weight which draws it down, and it is easy to understand how the dorsal curvature of the spine becomes diminished, for all the movable pieces of which it is made up tend to take the direction of a plumb-line.

The same result is brought about if the body, instead of being suspended by the arms, is supported by them. Instead of holding his arms above his head and seizing a bar, the gymnast can, with his legs downward, rest on the parallel bars supported by his arms. In this case the point of support will be at the same level as was just before the point of suspension, and the body will be just as passively abandoned to the weight which tends to efface the curves of the spine.

Numerous gymnastic movements need that the body should remain for a moment in this inert condition, supported, or suspended by the arms. But these are usually merely preliminary positions, and the spinal column is soon associated in various evolutions which no longer allow it to play a merely passive part.

On the trapeze, the rings, the horizontal bar, the period of suspension of the body by the arms is merely a sort of short preface to the exercise. Climbing a ladder or a rope by the hands alone, allow, on the contrary, a man to leave throughout the whole exercise his trunk inert and supple, while the arms alone are at work.

On the parallel bars the body is supported by the arms, and remains inert during the movements of horizontal progression brought about by the regular movements of the hands. A great number of the movements performed on the parallel bars allow the spinal column to benefit by the action of the weight which tends to lessen its curves.

From an orthopædic standpoint, the mechanism of the exercises of which we have just been speaking, has been made use of in the correction of deviations of figure. Most of the cures of the "Swedish" gymnastics are based upon the method of suspending the patient by the hands or supporting him by the arms, the body being abandoned to the weight which tends to straighten the crooked spine.

The compass of this volume will not allow us to study in detail the different exercises, and to analyse and explain their mechanism, that is the manner in which they bring into play the different bony levers of which the animal machine is made up. We have merely been able broadly to delineate the mode of action of each part of the body in muscular work, and to indicate the part played by the limbs, the pelvis, the vertebral column, and the ribs in the more common movements.

This rapid sketch has for its special object to make the changes comprehensible which each exercise can produce in the different regions of the body, whether by chiefly developing certain muscular groups which act more than the others, or by modifying the direction of certain bones or bony systems, which support directly or indirectly pressures and shocks, or are placed in vicious attitudes.

PART V.

THE RESULTS OF EXERCISE.

GENERAL EFFECTS OF EXERCISE—EXERCISES WHICH DEVELOP THE CHEST—LOCAL EFFECTS OF EXERCISE—EXERCISES WHICH PRODUCE DEFORMITY—EXERCISES WHICH DO NOT PRODUCE DEFORMITY.

CHAPTER I.

GENERAL EFFECTS OF EXERCISE.

Varying Nature of the Effects of Exercise—Its two Chief Results, the *Losses* and the *Gains*—Increased Activity of Combustions, Resulting in the Using-up of the Reserve Materials—Why is Nutrition more Active?—Part Played by Oxygen—The "Need for Exercise"; to What it is Due—Accumulation of Reserve Materials—Sluggish Nutrition—Why an Inactive Man "Fears Fatigue"—Insufficient Exercise—Unwholesome Effects on Nutrition—Slackening of the Process of Dissimilation—Obesity—Deficient Oxygen and Excess of Reserve Materials—Incomplete Oxidations—Gout—Necessity for Exercise—Effects Common to all Forms of Muscular Work—Special Effects according to the Quality of the Work—Observation on Horses—Trotting and Walking.

I.

If we go into a gymnasium and examine a group of men who are doing exercise by the doctor's orders, we can hardly believe that the same medicament can be suitable for such different temperaments, for such widely opposed disturbances of health. We ask how the same method of treatment can be advantageously applied to men of a stout build, with red faces and exuberant flesh, and to men who are thin, pale, and emaciated.

It will surprise us, however, after a few weeks, when we come to study afresh these different types, to find how much less contrast they now exhibit in structure and physiognomy. The heavy man has lost weight, while the man who was too light has gained it; the former has no longer the violet tint which announced vascular plethora; the latter, on the contrary, has a brighter colouring: the blood flows to his formerly discoloured cheeks, and his whole appearance announces a more intense life.

The practice of exercise tends to impress an identical seal on the most various temperaments, and to reduce to the same type the most opposite constitutions.

This is because exercise produces in the system two absolutely different effects; it increases the process of assimilation, thanks to which the body gains new tissues, and it accelerates the process of dissimilation, which leads to the destruction of certain materials.

The process of dissimilation is more active, owing to the greater intensity of the vital combustions. A muscle which works is a muscle which becomes heated, and this cannot occur without the burning of a certain quantity of tissue. The excessive production of heat which accompanies work, the rapid combustion of certain materials of the body, and their elimination from the system as waste-products of combustion, these are the causes of loss of weight in exercise.

It is not so easy to explain increase in body-weight, under the influence of methodical work.

"Under the influence of gymnastic exercise," says Dujardin-Baumetz, "the activity of the cellular functions increases and becomes more regular, the intra-cellular combustions become more active; the leucomaïnes, these toxic materials which the organic cell is constantly manufacturing, are more actively eliminated, and the general effect is that the fats are burned up, the cellular functions regulated, there is established an equilibrium between the cells of the spinal cord and those of the brain, in a word, general nutrition becomes more active." *

With due deference to the eminent professor, we cannot help thinking that the explanation he gives of the effects of exercise is insufficient. It simply states a fact: *nutrition becomes more active.* We can well understand how increased activity of nutrition implies the idea of more active absorption of materials derived from the food, and the more regular deposit of these materials in the living organs and tissues. But why does nutrition

* Bulletin de thérapeutique, May 15, 1887.

become more active under the influence of exercise? Because, says Dujardin-Baumetz, the activity of the cellular functions increases and becomes more regular. It remains to determine how muscular movement increases and regulates the activity of the cells.

It seems to us impossible to explain the greater activity of the cells, as a result of exercise, other than by an increase of the stimulus which they receive from the nerves and the blood. We know, in fact, that the properties of the cells are dependent on these two agents. If we cut the nerve-fibres going to glands, their secretions are profoundly altered or completely suspended. But, on the other hand, the nerves themselves are dependent on the blood, for ligature or obstruction of the nutrient vessels of the brain or spinal cord instantly abolish the functions of these organs.

It is then in the blood, the "regulator of the nervous system," that we must ultimately seek the causes capable of modifying "the cellular functions" which preside over nutrition. Now exercise profoundly modifies the composition of the blood.

At first sight the changes undergone by the blood seem to be of a nature to hinder the working of the nerve-cells. In fact Claude Bernard has shown, by analysing the blood returned from a muscle at work, that it is black, and contains no oxygen, while the venous blood from the same muscle at rest contains nearly as much oxygen as is present in arterial blood. Now we know that venous blood charged with carbonic acid and deprived of oxygen, exercises on nerve-cells and on all the organic elements a stupefying action which tends to render their functions less active.

But the consecutive effects of exercise differ greatly from the immediate effects, and, if the blood is deficient in oxygen during the work, it contains, on the contrary, much more than usual soon after the work is over. For during exercise, if the combustions are increased, respiration is greatly quickened. The oxygen which enters by the lungs takes the place of that which is used in the combustions, and the final result of exercise is not a loss, but a gain of this gas.

Exercise introduces more oxygen into the system than is actually needed for the combustions, at least, direct observation seems to show that, in the period which follows violent exercise, the blood, after being for a short time surcharged with carbonic acid, becomes on the other hand surcharged with oxygen. In fact, if we observe a man who has just been performing muscular work sufficiently intense to influence respiration, we find that after having exhibited the phenomena of breathlessness due to excess of carbonic acid, he shows in the end a remarkable diminution of the respiratory need and a notable slackening of the respiratory movements.

When we observe a man resting after intense and sustained muscular work, we see that his respiration, at first markedly accelerated, gradually returns to its ordinary rhythm, and if we continue the observation we see that the respiratory movements become still slower, and fall below the normal rate.

During an ascent in the Eastern Pyrenees, we made the following observation on ourselves and on a guide. At the foot of a hill when our breathing was uninfluenced by exercise, it was 14 per minute in our guide, and 16 in ourselves. After going up a very steep incline for twenty minutes the guide's breathing was 28, and our own 30. But after resting for six minutes the rate had fallen in the one to 10, and in the other to 9. The final result of the exercise had been a diminution of the respiratory need, a temporary *apnœa*. Now we know that an increase in the oxygen contained in the blood causes a diminution of the respiratory need.*

Thus a man taking exercise lays up a provision of oxygen. This gas becomes as it were stored amongst the anatomical elements of which he organism is built up ; it is especially bound to the red blood-discs, which become redder, and their vivifying power is increased. This more *living* blood, if we may use the expression,

* *Richet.* Revue Scientifique, May 4, 1887, p. 725.

carries to the organs a salutary stimulus which increases the activity of their functions.

It has been experimentally proved that all the elements of the system undergo a kind of awakening of their energies under the influence of strongly oxygenated blood. If such blood be injected we see glands secrete more actively, the contractility of fatigued muscles reappear, and even signs of life in the cerebral cells of a decapitated animal. *

We understand how, under the influence of powerfully oxygenated blood, the glands of the alimentary canal can more actively secrete the fluids necessary for the elaboration of the food ; how the contractile fibres of the intestine perform their peristaltic movements which are as necessary for digestion, with more energy ; how the absorbent vessels draw to themselves by a more powerful endosmotic process, the nutritive molecules elaborated in the digestive tract. Thus the acquisition of a greater quantity of oxygen leads to a greater intensity of the process of assimilation, and consequently to a gain in the weight of the body.

II.

Exercise produces then salutary effects alike in those who *assimilate* too little and in those who do not *dissimilate* enough; muscular work is a regulator of nutrition as indispensable to over-rich as it is to impoverished constitutions. Hence there is no individual, no living being, who is not instinctively impelled to this powerful general alterative agent.

When a vigorous horse has been kept in the stable for a long time, we see it when first brought out make leaps and turns, and show by its lively paces a great desire for movement. We then say that the animal is *frisky*. This great vivacity has not however as its sole object the manifestation of the joy it feels at being again at liberty: it expresses the *need for exercise* which the animal feels. Similarly it is under the influence of the need for exercise that the wild beasts in a menagerie

* Experiments of Brown-Séquard.

constantly prowl about their cages; that children coming out of the class-room leap and run about the recreation ground, and that dogs run after each other in the streets.

Every living being which has long been motionless experiences a need for action, and this fact is alone sufficient to prove the hygienic importance of muscular exercise.

The *need for exercise* is one of the numerous sensations which lead living beings to perform actions necessary for the preservation of life or of health. Prolonged immobility produces a need for muscular exercise, just as sustained work produces a need for repose.*

The need for repose is called *fatigue;* the need for exercise has not received a special name, but deserves one quite as much as *hunger*, *thirst*, etc.

Under the influence of deficient exercise, certain materials which should be used up each day by work, accumulate in the human machine, the wheels of which they encumber, and the working of which they clog. These materials are the *reserves* of which we have pointed out the origin and destination. It is necessary, for the perfect balance of nutrition, that the reserve materials should be used up as fast as they are formed. When they are not regularly destroyed and they tend to hinder, by their accumulation, the working of the organs, we feel ourselves impelled to bring our muscles into action, with the unconscious object of burning these materials in the work, and the need for exercise is produced.

But the superabundance of the reserve materials is not the only cause of the need for exercise; if insufficient exercise can lead to the accumulation of certain useless materials within the system, it also induces a diminution of the materials necessary to the balance of health, and thus leads to impoverishment of the constitution; so we see some persons whose life is too inactive, put on too

* The need for exercise is developed with more intensity in proportion to the lowness of the temperature; by severe and piercing cold we are much more driven to action than by great heat. In this case the need for exercise is derived from the instinct which leads us to produce heat by movement.

much fat and become plethoric, whilst others waste and become thin through insufficient movement.

Thus the need for exercise is felt as much by thin people who assimilate too little, as by fat people who do not dissimilate enough.

The need for exercise then responds to two physiological necessities, of which instinct gives us warning. It can come from an overcharge with reserve materials, and the urgent necessity there is that these materials should be burned; it may also arise from a general sluggishness of the functions and the need of a stimulus capable of arousing them to fresh activity.

The need for burning too abundant reserves, the need for drawing more oxygen into the systen, these are the two causes which join in producing the manifestation of the instinct which leads every living being to perform muscular work. But if the useful warning is misunderstood, if the need for exercise is neglected, two orders of phenomena occur.

In the first place the quantity of oxygen introduced into the system being insufficient, the blood becomes less rich, less vivifying; its contact does not give to the organs that precious stimulation, that salutary whipping, which makes their working more active and brings all their energy into play. The appetite fails through deficient stimulation of the digestive organs, through *paresis* of the stomach and intestines. The muscles lose their irritability, and respond more slowly to the stimulus of the will. In a word, all the functions languish and the organism becomes weaker.

On the other hand, the reserve materials, not being regularly burned, gradually accumulate, and their presence in excess in the system leads in the end to serious disturbances of health. There is nothing more frequent in persons of sedentary habits than diseases brought about by accumulation of these reserve materials. Defective dissimilation of fat produces *Obesity;* insufficient combustion of the nitrogenous materials leads to *Gout.*

These two disorders are not exclusively confined to the human species. Every one must have noticed how domestic animals, under the influence of deficient exercise, tend to grow fat; it is not perhaps as generally known that inaction may make them gouty. Larks kept in a cage often show on their feet deposits of uric acid exactly like the "tophi" seen in men subject to gout.

We know that life is an incessant combustion, and that vital heat results from continual chemical combinations. The air drawn into the lungs leaves its oxygen in the blood, and this is the chief if not the sole agent of the combustions. The combustions do not, as Lavoisier believed, occur in the lungs themselves, but in the very heart of the tissues. It is necessary then that the oxygen should constantly be carried to the combustible substances. And this gas is carried by the blood to the furthest ramifications of the circulatory network.

When an insufficient quantity of oxygen is supplied by respiration, the combustions are slow and incomplete, like those in a fire-place in which the draught is too feeble. If the fire languishes in a fire-place which draws badly, it is because it is supplied with less oxygen owing to the slowness of the air-current passing through it. Thus in the human body the lungs represent the fire-place, which supplies oxygen to the tissues, to be burned. If insufficient exercise be taken, respiration introduces too small a supply of oxygen into the system, and the vital combustions languish.

From the insufficient supply of oxygen results *incomplete oxidation* of the substances to be dissimilated. The nitrogenous tissues, for instance, instead of being completely burned to form *urea*, a product very rich in oxygen, are transformed into *uric acid* compounds, which are much less oxygenated. Now urea is a very soluble substance and is easily eliminated, and is moreover almost harmless to the system. Uric acid on the contrary is sparingly soluble, and consequently is eliminated with great difficulty; if it is formed in the blood in excessive quantity it is not completely eliminated; the kidneys which should remove it from the body leave too much of it in the blood, and a tendency to Gout is developed. Gout in fact is nothing but an overcharge of the blood with uric acid. Very various accidents may result from the saturation of the system with this nitrogenous compound which we might call the "gouty poison." When it is deposited in the joints it gives rise to an attack of gout; when it chokes up the eliminating tubes of the kidney it produces *Gravel.*

It is beyond the scope of this book to give a complete account of the diseases which arise from defective combustion. But it was necessary to take an example from the more common facts of pathology in order that we might make clear the mechanism by which deficient exercise produces disease.

III.

To get an exact idea of the effects of muscular work on the general process of nutrition, it is enough to know the opposite effects of insufficient exercise. Now we have seen that the results of insufficient exercise may be reduced to two; (1) excessive accumulation of reserve materials; (2) insufficient supply of oxygen. All the morbid conditions, slight or severe, due to deficient muscular work, are derived from these two essential disturbances in the balance of the system.

Want of oxygen produces a languor of all the vital functions by defective stimulation of the organs; hence insufficient assimilation of food and enfeeblement of the system. The superabundance of reserve materials leads to all the disturbances of health due to insufficient dissimilation, to sluggish nutrition.*

Exercise is of great importance as a regulator of nutrition. It is indispensable to the maintenance of health to heed the warning given to us by the system when it suffers from prolonged inaction, and to satisfy this need for exercise which induces every living being to put its muscles in action.

But it is very necessary to yield promptly to the

* See Professor Bouchard's book—"Le Ralentissement de la Nutrition."

solicitations of this instinct, for the sense of need for exercise tends very soon to disappear when its satisfaction is delayed. If not heeded it lessens day by day; if inaction is immoderately prolonged, it disappears entirely, and a time arrives when the organism which has too long led an inactive life shows a marked tendency to become more and more inactive. This is because too prolonged repose has brought about new organic conditions, uniting as it does all the circumstances which lead to the production of every kind of fatigue when work is attempted.

On the one hand, all the organs languish, and cannot be aroused from their torpor without a painful effort of the will; the muscles are benumbed and but little irritable; the heart, which rarely undergoes the agitations of exercise, is too impressionable, like all enfeebled organs, and the slightest muscular exertion causes palpitation; the lungs, accustomed to the respiratory movements suitable to the inconsiderable needs of an inactive life, have long been used to bring into action only a small proportion of their air-cells, the others being closed and collapsed during the respiratory act. The field for aëration of the blood being in this manner reduced, the slightest increase in the activity of the gaseous interchange renders the respiratory functions insufficient.

On the other hand, prolonged inaction predisposes the body to a ready intoxication after work, owing to the abundance of the reserve materials, a source of products of dissimilation and waste. When a fat man undertakes violent exercise, his fatty tissues undergo violent combustions, which are more exaggerated in proportion to the urgency and duration of the need for their dissimilation. These tissues, very rich in carbon, give rise to an abundant formation of carbonic acid, and breathlessness occurs with exaggerated intensity. If the man, instead of being fat, has in his body a great quantity of nitrogenous reserves, breathlessness will not be the dominant feature, and immediate fatigue will be but moderate; but consecutive fatigue will be extreme. We have described all the disturbances which arise from intoxication by the products of nitrogenous waste, and have shown that stiffness is in direct proportion to the quantity of these waste-products. Hence consecutive fatigue is to be feared by a man too rich in reserve materials, he has further to fear lest fatigue should provoke an attack of gout by producing a regular avalanche of uric acid compounds.

Thus it is that after too prolonged inaction, exercise, instead of being accompanied by a sensation of satisfaction, becomes a painful toil. The man unused to work foresees that a disagreeable physical sensation will attend the throwing off of his inertia; he "fears fatigue." Hence he finds himself caught in a vicious circle from which he cannot free himself. He acts no longer, because his organs, loaded by the accumulation of reserve materials, make work painful to him, and the accumulation becomes greater the longer he remains inactive. If he has not the courage to submit to the inevitable pain which accompanies every beginning of physical exercises, if he shuts himself up in his inaction, to which the presentiment he has of the discomforts of fatigue more and more inclines him, his condition becomes aggravated, and he inevitably falls into a state characterised either by an excessive richness of reserve materials, or by impoverishment of the system and languor of the vital functions.

Thus the sense of need for exercise corresponds to different organic conditions, to diametrically opposed organic states.

The general effects of exercise tend to modify all constitutions in a sense favourable to that perfect equilibrium of the functions which constitutes health. By the mere fact of the adaptation of the organs to the varied needs of muscular exercise, the irregularities of nutrition tend to disappear. By the very fact of regular performance of function, the Human Machine becomes more fitted to perform its functions well, and gains the conformation best adapted for the performance of work; now this conformation is also that which is most favourable to the regular performance of all vital actions.

Thus it is that muscular movement is useful in all disorders of nutrition, and that bodily exercise is a necessity for all constitutions.

But we must not conclude that the benefit of exercise is equal in all cases, whatever may be the quality of the work done. If muscular movement produces a series of identical general effects in all constitutions, the different exercises we have considered in the fourth part of this book have all of them their special effects.

We cannot enter here into details of application, and reserve for another volume the complete study of the *Therapeutics of Exercise*. It will be enough to recall, in finishing this chapter, how the special effects of exercise may vary according to its kind and its dosage.

We have seen that work has two opposite influences on nutrition: it increases the *gains*, and it also increases the *losses* of the system. The hygiene of work essentially consists in balancing these two opposed results; but certain conditions of exercise may make now one, now the other, predominate, and it is possible to obtain almost at will, by the aid of muscular work, either an increase or a diminution in the weight of the body.

An example borrowed from Dr. Worthington's book on "Obesity" will suffice to show how work can lead, according to the details of its application, to diametrically opposed results. On the Marne, between Alfort and Chateau-Thierry, two teams of horses worked on a towing path, drawing boats. The first team drew up stream, *walking*; the second down stream, but *trotting*. This course was, for each team, the only work of the day. As far as the quantity of work done each day was concerned, the horses which walked executed a greater number of kilogrammetres, since they went the same distance, but against the current; the horses coming down stream drew a lighter load and covered the same distance; but, in spite of the difference in the quantity of the work, the swiftness of their pace completely changed for them the results of the work; the horses which did their work at a trot got thinner, those which walked, gained weight.

CHAPTER II.

EXERCISES WHICH DEVELOP THE CHEST.

Importance of Oxygen in Nutrition—Advantages of a great Development of the Chest—How this Result can be obtained by Exercise—Received Opinions on this Subject—Our Reasons against them—By what Mechanism the Chest is Developed—*Forced* Breathing—Pressure from within outwards—Increased Breadth of the Shoulders not to be Confused with Increased Size of the Chest—Conditions which Develop the Chest—Amplitude of the Respiratory Movements—Opening out of the Pulmonary Air-cells—Increase of the Respiratory Need—The Chest of Mountaineers—Exercises which produce a "Thirst for Air"—Exercises suitable for Developing the Chest—An unexpected conclusion: Superiority of Exercises of the Legs to those of the Arms—Running and Skipping.

I.

THE quantity of air introduced into the system at each respiration is regulated by the capacity of the lungs. Now we have seen in the preceding chapter that the acquisition of a great quantity of oxygen is one of the most useful results of bodily exercises.

It is then of great importance to define the conditions in which muscular work is capable of increasing the size of the cavity in which the lungs are contained.

At first sight we should be inclined to believe that the exercises performed with the upper limbs, which are moved by the muscles of the shoulders and trunk, to be those most likely to raise the ribs; and in fact exercises of the arms are generally regarded as excellent for increasing the respiratory power.

It will be enough to quote and criticise a very conscientious study by Demény,* to show the fallacy of this opinion.

* *Georges Demény.* De l'Education Physique.

"We have determined," says this author, "that there are various degrees of exercise favourable to the dilation of the thorax.

"The attitudes in which the scapulæ, drawn back and fixed by the tonicity and by the contraction of the rhomboidei, trapezia, and latissimi dorsi muscles, serve as fixed points for the elevators of the ribs, these attitudes, of which the type is the soldier at attention, the body upright, *the belly retracted by the aspiration of the thoracic viscera*, produce a manifest dilation of the thorax.

"Still more a slight backward motion of the arms, rotation outwards, abduction, and most of all the vertical elevation of the arms, as in passive suspension with the arms at full length, raise the ribs to a maximum degree, and give to the costal cartilages a mobility which allows of great inspiratory movements, and opposes the fixation of the thorax in the position of expiration."

These conclusions are preceded by very interesting considerations on the muscles which are brought into action in these attitudes, and the author clearly demonstrates that inspiratory muscles are brought into action. Their two extremities are separated in these attitudes, and the muscular tone tends to draw the movable points of attachment, represented by the ribs, nearer to the fixed points of attachment represented by the scapula, the clavicle and the humerus.

Demény's conclusion is that more air enters the chest in the attitudes he describes, than in the condition of repose. It is certain that in these attitudes the ribs are very strongly raised, but the author condemns himself by remarking that the thoracic aspiration draws up the abdominal viscera under cover of the ribs, so that *the diaphragm is thrust upwards.*

If we try to define the respiratory advantages gained by this manœuvre, we see that it puts into forced action all the inspiratory muscles *except the diaphragm*, which remains in the position of *expiration*, for it is pushed up by the abdominal viscera. Now if a man, keeping his hands in his pockets, takes the trouble to take a very deep inspiration, he will be able to raise his ribs to the greatest possible limits, and further, he will find that his diaphragm will share in the movement, and *will push down the abdominal viscera*, instead of allowing itself to be thrust up by them into the chest. The vertical diameter of the thorax will thus be increased, while before it was diminished by *visceral aspiration*, and in the end, it will be found that the most ingenious gymnastic combinations are not as efficient in increasing the intra-thoracic space as are profound expirations made during repose.

The conclusion from this is, that the best athletic exercise for increasing the size of the chest is that which compels the deepest inspirations.

Before developing this idea we must explain the mechanism in virtue of which a temporary amplification of the thorax can in a short time produce a lasting increase in its capacity. But we must first remark that it is of no advantage in respiration to increase the thickness of the thoracic parietes, if the cavity remains small; it is the intra-thoracic space which must be amplified in order to increase the respiratory power.

Now there is only one way of increasing this space, and that is to increase the volume of its contents, the lungs.

It would be illusory to set any value on the elevation of the ribs, on a favourable direction of the costal articulations, on the strength of the inspiratory muscles, etc., if the lungs were not increased in size at the same time as the thoracic cavity is dilated. If the lungs become weakened, the upper ribs fall in, and the best formed chest becomes flat. An empty thoracic cavity is incompatible with raised ribs, and do what we will an empty chest assumes the position of inspiration.

We see this every day after the absorption of pleuritic effusions, when the lung tied down by false membranes is incapable of returning to its normal size, and perhaps is reduced in volume by one half or two thirds. However powerful the inspiratory muscles, whatever the direction of the costal articulations, the ribs cannot be raised, for a vacuum cannot exist in the pleural cavity.

Thus, in the thorax, the volume of the receptacle is determined by the size of the contents. If you wish to develop the chest, do not try to raise the ribs, but try to inflate all the air-cells of the lungs ; you cannot do it by any mechanical means, and the most clever combinations of muscular movements give but an incomplete result when unaccompanied by the movement—voluntary or instinctive—of forced inspiration.

The experiments of M. Demény certainly prove that the gymnastic attitudes he describes are the most efficient in raising the ribs ; but they also prove that the raising of the ribs, carried to an extreme, does not suffice to give a maximum size to the lungs, for when the ribs are raised, the diaphragm goes deeper into the thorax and the abdominal viscera rise. The respiratory field thus loses at the base of the chest what it gains at the apex.

The momentary amplification of the thorax during inspiration may indeed lead to energetic contraction of the inspiratory muscles ; but a definite increase in size, persisting during repose, can only be brought about through increased volume of the lungs.

How is it that the lungs can increase in size through athletic exercise? By a mechanism well known in physiology, by the filling out of certain air-cells ordinarily inactive, which only come into play during forced inspiration. The expansion of the pulmonary vesicles is complete in proportion to the quantity of air introduced. The atmospheric air drawn into the lungs by a very powerful inspiration seeks out the most obscure corners, and inflates the air-cells of certain regions which ordinarily have no part in the respiratory function.

A definite increase in the volume of the lungs is the consequence of frequent repetition of this supplemental respiration. The air-cells which are as a rule inactive, and which are reserved for cases of excessive respirato y strain, arise from their inaction ; their walls, which are usually collapsed, and even stuck together, separate and give entrance to the air which cannot find room in the confined space sufficient for ordinary breathing.

If the forced inspirations are often repeated, the air-cells, the action of which has thus been accidentally solicited, come in the end to associate regularly in the ordinary respiratory movements. They are then very quickly modified in the sense most favourable for efficient working, according to the law we have so often pointed out, of the adaptation of organs to the functions they perform.

Thus, forced respirations result in a modification of the structure of certain regions of the lung, and in making them work better. Under the influence of unusual exercise the vesicles increase in size and contain more air. More blood is also supplied to them. Their capillary network becomes richer, and their nutrition more active. Thus in the end they take up more room.

It is in this manner that the regular working of a great number of air-cells, ordinarily inactive, can rapidly increase the size of the lungs.

If we follow out the modifications produced by forced respirations, we see that the lungs thrust outwards the thoracic walls to make more room for themselves. During inspiration the ribs, by rising, favour the inflation of the lungs, but in this case it is the lungs which, having increased in size, thrust the ribs upwards and keep them raised even in the condition of repose. Hence an increase in the circumference, and a vaulted conformation of the thorax.

It is then *from within outwards* that the force capable of expanding the chest acts, and it is in reality to the lungs and not to the muscles that the chief share in the changes in form and size of the chest belong. The most powerful inspiratory muscles cannot raise the ribs, unless the lungs participate in the movement of expansion, and on the other hand, the lungs can raise the ribs without the aid of the muscles, for the chests of emphysematous patients remain vaulted in spite of their efforts to lower the ribs and complete the expiratory movement.

If we sum up the facts we have just enunciated, we shall be driven to the conclusion that, in order to raise the ribs and get rid of the vicious conformation of flat chest, we must not seek to act directly on the thoracic muscles, but to produce as extensive respiratory movements as possible.

There are two methods of amplifying respiration ; one consists in voluntarily expanding the thorax in all directions. This method is in the domain of "chamber-gymnastics"; it has been much extolled, and it may give good results. The other method comes more directly into the field of our studies. It consists in increasing by exercise the amplitude of the respiratory movements.

II.

The problem has now become clear and definite. We need, in order to develop the chest, to know what exercises are most fitted to produce a series of very extensive respiratory movements. Now the amplitude of respiration, as well as its frequency, is in direct ratio to the intensity of the respiratory need, and we know that the intensity of this need depends on the quantity of mechanical work performed in a given time.*

The exercises which cause an *accumulation* of work are then those most fitted for increasing the size of the thorax, and for demanding increased work from the lungs. And we know that this accumulation of work occurs especially in exercises of strength and speed.

Thus the mechanism of exercise, its performance by the aid of these muscles or of those, are of secondary importance in producing the result of which we are speaking. It matters little by what process the muscular force is expended, provided that there is great expenditure in a short period of time. It is indifferent whether the movements are very slow, each of them representing a great number of kilogrammetres, or whether they are extremely rapid, each movement representing but a moderate effort. It is merely necessary that the sum of work represented

* See Chapter IV. "Breathlessness."

by these movements, whether few or many, should be considerable in a short time.

Now the quantity of work which a given muscular group can perform in a given time is subordinated to the strength of this group. There are muscular groups which are too weak to expend much force in a short time. One arm may use its whole strength without its work representing, in the unit of time, a great number of kilogram-metres. So whatever form the exercise takes, if the arm alone is working, we shall not find that the breathing is much quickened. The exercise may induce local fatigue before the intensity of the respiratory need has increased. It may even happen that the work of both arms together does not, after a given time, amount to enough to demand more ample respirations.

In general, the exercises which are performed with the legs represent more work than those which are performed with the arms. The muscles of the upper limbs could not support, without extreme fatigue, an expenditure of force which will cause no effort to the lower limbs. It is not tiring to anyone to walk 500 metres in five minutes: what gymnast could traverse the same distance in the same time hanging by his hands from a stretched rope? The total mechanical work would be, however, the same; displacing the same weight through the same horizontal distance.

We must not then trust to the muscles of the arms to expand the chest. Muscular exercise can only lead to the development of the thorax in an indirect manner, and in no way by a direct effect comparable to the increase in size of a muscle which works. The muscle which contracts often becomes larger because its nutrition is more active. But the chest only expands when the surcharge of the blood with carbonic acid creates a need of a greater quantity of oxygen for hæmatosis.

It is to the more active respiratory need, to the "thirst for air," that the instinctive movement by which the ribs are more energetically raised is due, in order to draw into the lungs a greater quantity of air.

The thirst for air, carried too far, produces breathlessness, which is nothing else than a powerless struggle of the system seeking in vain to satisfy a need. When breathlessness is very moderate it causes very ample respiratory movements; but when it is excessive the breathing becomes very shallow as well as very rapid.

So that exercise has no longer any effect in expanding the chest, when breathlessness reaches an extreme degree.

To sum up, the most profitable way of dilating the lungs, developing the thorax and expanding the chest, consists in the performance of exercises capable of increasing the respiratory need, without pushing them so as to produce an extreme degree of breathlessness.

If we pass from physiological explanation to observation of facts, we see that practice gives a striking confirmation of theory.

Exercises of strength lead rapidly to an increase in the size of the thorax. It is the same with exercises of speed when they need very energetic movements. No exercise develops the chest as rapidly as does running, unless it be wrestling.

Mountaineers all have large chests, and the Indians who live on the high plateaux of the Cordillera in the Andes, have been noted for the extraordinary size of their chests. This great development in mountaineers is due to two causes which act in the same direction: frequent ascent of steep inclines, and constant residence at great heights at which the air is rarefied. The climbing of these slopes needs a great quantity of work, which causes increase of the respiratory need; respiration in a rarefied atmosphere obliges a man to take deeper breaths in order to supplement, by the quantity of air breathed, the insufficiency of its vivifying properties.

Singers, with no other exercise but singing, acquire great respiratory power and a remarkable increase in the dimensions of their chests.

Numerous observations prove that it is enough voluntarily to take a certain number of deep breaths every day, to produce, in a short time, an increase in the circumference of the chest which may amount to two or three centimetres.

If we wish to gain the same result from muscular exercise, we must choose a form of work which will increase the intensity of the respiratory effort, that is, an exercise which brings powerful muscular masses into action. We shall thus perform a great quantity of work in a short time without producing fatigue. Now the legs, which possess three times as much muscle as the arms, can perform thrice the quantity of work before being fatigued. The lower limbs are then more capable than the arms of awakening the respiratory need, which is proportional to the expenditure of force.

Thus it is an error to demand from gymnastic exercises practised with appliances, exercises of *suspension* or *support*, any development of the chest. The trapeze, the rings, the parallel bars, quicken respiration much less than running. These exercises cause an increase in the size of the muscles, and even of the bones of the regions which work, but they cause very little increase in the dimensions of the thorax.

Men who do much work with their arms have often a conformation which is very imposing at the first glance. They have sometimes broad shoulders; but if the arms have done the work alone, without the assistance of the muscles of the trunk, we easily see that the apparently large size of the thorax is due to an excessive development of the muscles about the shoulder joint, and not to raising of the ribs.

Thus we are on the wrong road when we look for too ingenious means for developing the chest; this result, precious above all, can be obtained without any complicated appliances, without any difficult process, and if we had to formulate concise advice on this subject we should say:—

When a young person has a narrow and flat chest, recommend running if it be a boy, or skipping if a girl.

CHAPTER III.

LOCAL EFFECTS OF EXERCISE.

Effects on neighbouring parts. Useful Effects: Compression of Vessels by the Contracting Muscles; Quickening of the Circulation as a result—Disappearance of Œdema during Exercise—Injurious Effects of Muscular Contraction: Excessive Compression of Internal Organs—Dangers of *Effort*—Effects of Work on Muscle—Useful Effects: Increase in Size—Injurious Effects; Wasting of the Organ through Excessive Work—*The Accidents of Work.* Muscular Ruptures—Tendency of Muscular Fibre to Shorten through Excessive Work—Semi-flexion of the Fore-arm in Gymnasts—Dangers of Muscular Contractures—How Deviations of the Spine are produced by Ill-planned Exercise.

MUSCULAR work produces local effects of two kinds. The first kind occurs in the muscles themselves, in the bones which are moved, and in the joints which are the centres of movement. The second occurs throughout the region in which the movement takes place, and concerns organs which take no direct part in the exercise. We shall study separately the direct effects of muscular contraction, and its effects on neighbouring parts.

I.

The chief effects observed in the regions which are the seat of repeated muscular movement are due to the compression which the muscle, in becoming shorter and thicker, exercises on neighbouring parts. This compression may either affect vessels containing fluids, such as the lymph and the blood, or more solid materials, as the intestinal contents, and the pressure may thus be transmitted to remote points. Hence result effects which are not strictly localised, and which serve as a connecting link between the local and the general effects of exercise.

In this manner the contraction of the abdominal muscles during exercise may influence the digestive functions by driving onwards the intestinal contents. An exercise which brings the abdominal muscles into action is thus favourable to defæcation, and can cause the disappearance of digestive disorders due to constipation.

Similarly, the compression which the muscles exercise on the capillary vessels gives a more active impulse to the blood-current, which is transmitted even to the heart, just as pressure on an india-rubber tube filled with water is transmitted to the elastic reservoir with which this tube communicates. In this manner the local contraction of a muscle can influence the general circulation. We know that stagnation of blood, in motionless limbs, can produce œdematous swelling, and we also know that such limbs can regain their normal size under the influence of exercise which causes contraction of the muscles, and mechanical acceleration of the blood-current in the capillaries.

The effects of muscular compression on the neighbouring parts are not always useful: exaggerated contraction can lead to accidents. Thus, too powerful contraction of the abdominal muscles can make the intestines, by great pressure, distend a natural orifice and become engaged there. It is thus that herniæ are produced in the inguinal or crural canal through the passage of an intestinal coil subjected to too great pressure. This accident is most commonly produced during the act of effort, which demands, as we have explained, a very energetic contraction of the abdominal muscles.

Still more serious accidents may happen during very powerful contraction. An essential condition of effort is the compression of the distended lungs, which serve to support the ribs. An energetic compression, proportionate to the intensity of the muscular work, is exercised during the effort on the great thoracic vessels and even on the heart. It may happen that the pressure exercised on the vessels is sufficiently strong to cause a back tide of blood in the capillaries of the lungs or brain, and to bring about laceration of these vessels, and pulmonary or cerebral hæmorrhage.

Rupture of the great veins of the spine has been observed from the effect of too violent an effort. In this case there occurs a hæmorrhage in the spinal cord which causes *paraplegia*, that is to say, paralysis of the parts of the body below the lesion. We may frequently see a horse, harnessed to too heavy a cart, give an energetic pull, and fall with its hindquarters paralysed. Through too violent an effort the animal has broken—not its back, as is commonly said—but a vessel in the spinal cord, and paraplegia has ensued.

Ruptures of the heart have even been recorded in consequence of very violent efforts. A porter at Bordeaux had made a wager that he would lift a full hogshead. In the superhuman effort he made to raise this enormous burthen, his heart was ruptured and he dropped down dead.

These mechanical effects of exercise are, as we said above, on the borderland between the general and the local effects of exercise. We are now going to describe those which are strictly local.

II.

Muscular contraction may be the cause of useful effects, and may also occasion accidents and various lesions. Among the disagreeable effects of exercise, some are the inevitable result of muscular contraction; others occur accidentally, either through a vicious method of performing the work, or owing to defective resistance in the organs which perform it.

Numerous cases have been recorded of rupture of muscles during the performance of muscular actions. These ruptures are always produced when a muscular fibre contracts with an energy which exceeds its own power of resistance. They are often the consequence of a badly co-ordinated movement. If, for instance, only one muscle is employed in the performance of an action for which a muscular group is needed, it will break just as a cord breaks when employed to lift a weight which is too heavy for it. Or the defective co-ordination consists in this, that the part to be moved is solicited by a sudden effort to pass from immobility to motion, instead of doing so gradually. Thus unforeseen movements are a frequent cause of muscular ruptures when they are performed with great energy or speed.

Sometimes an awkward contraction tends to shorten a muscle just when a mechanical cause is tending to stretch its fibres. The muscle, subject to two opposing influences, is torn. We owe to our friend Dr. J. Lemaistre the observation of a man who, in the gymnasium, broke a great part of his pectoral muscle. He was a young soldier performing a circle on the rings, under the dread of the brutal menaces of his drill-sergeant. Impelled by the fear of being punished if his attempt were not bold enough, and restrained by the fear of a movement which was new to him, the gymnast, after violently launching his body so as to make a revolution from before backwards, endeavoured to check himself, at a moment when his body was moving with great speed. His body was at this moment as far as possible from his arms, these being above his head. In this position of forced adduction, the fibres of the pectoral—an adductor muscle—were as much stretched as possible. Then an effort at contraction, increasing the already excessive tension, produced their rupture. The inferior two thirds of the muscle were torn through their whole thickness.

These effects of exercise, whatever interest they may have for the surgeon, need not occupy us further, for their mechanism is sufficiently obvious, and their production is quite accidental. We shall pass on at once to other phenomena intimately connected with the physiological process of muscular contraction, and which are the inevitable results of work.

III.

Among the most striking effects of muscular exercise, are the changes undergone by the muscles themselves under the influence of work. The muscles increase in size, and their structure is at the same time changed; they lose the fat which infiltrates their fibres, and tend to be reduced to their own proper elements, the muscular fibres, the density of which, being greater than that of other tissues, gives a characteristic firmness to the region which works. Further, the surrounding fat is burned up, as well as that which formed a constituent part of the organ. The cellular tissue in the midst of which the muscles were imbedded, is burned to feed the combustions, and the whole region undergoes a change of form characterised by the appearance of prominences and hollows; the muscles *stand out*. We may thus, merely by inspecting a man given to violent exercise or laborious toil, determine what parts of his body are chiefly concerned in the muscular work.

The increase in size of the muscles under the influence of work is due to the greater activity of the circulation during contraction. When a limb works, the blood flows to it, drawn by a physiological force which is difficult to explain, but the effects of which are felt in all organs which work, and during the performance of all functions. The process in virtue of which there is an increased supply of blood to a muscle during work, has for its object to provide this organ with the materials necessary for combustion. Muscle in fact cannot produce work without producing heat; but when it does this, it is at the expense of certain substances brought to it by the blood, and it only burns up its own materials when the supply from without is deficient. So we only see a muscle diminished in size by work in cases of organic exhaustion, when the impoverished constitution cannot supply blood rich enough in combustible materials.

Thanks to the unceasing supply of materials from the blood, the muscle does not use up its own substance unless the contraction be exaggerated or unduly prolonged. In cases of persistent overwork the muscles end by losing in size and feeding on themselves, as we see in certain professional runners whose legs are extremely small, owing to the manner in which they have been abused. The muscle which performs excessive work consumes itself in the end, the materials supplied by the blood are no longer sufficient to feed the combustions. Similarly a furnace consumes at first the wood which is supplied to it, but in the end, if the heat be too great, burns itself and oxidises the iron bars by which it is confined.

Muscle uses for its combustions the materials placed at its disposal, and it is for this reason that the surrounding fat is the first to disappear, and the right arm, for example, working alone, may lose its fatty tissue, and present, through the thin skin very pronounced muscular prominences, while the left arm which has remained inactive, still preserves a rounded and plump form due to the infiltration of the subcutaneous cellular tissue with exuberant fatty materials.

Thus work, besides producing general effects on nutrition, begins by changing the local structure of the region which is chiefly at work. Hence it is important, from an æsthetic point of view, to demand an equal amount of work from all the regions of the body, if we wish to avoid remarkable irregularities of external conformation.

The increase in size of a muscle is easily explained. Contraction draws to it a greater quantity of blood, and the increased flow continues even when the work is over. This more considerable afflux of blood causes more active nutrition through the abundance of materials in which the muscular fibres are bathed, and which place at its disposal more nutritive elements.

But increase in size is not the only change observed in a muscle as a result of work ; we may notice also a change of shape corresponding to the movement it performs.

This is one of the most interesting of the local effects of work, for it is intimately connected with the mechanism of the deformities which certain exercise may produce. A muscle which is more constantly in action than other muscles, or in other words, a muscle which contracts more often than its antagonist, undergoes in the end a certain degree of shortening. If, for example, the two extremities of a flexor muscle are very often approximated by contraction, and its action is not counterbalanced by an equally frequent and energetic contraction of the extensor which opposes it, its fibres tend to preserve the form which they so often assume, and the muscle becomes shorter.

We often observe, in gymnasts, this partial contraction of the muscles, and consequently the predominance of a particular attitude. Those who abuse the exercises needing the flexion of the fore-arm on the arm acquire an excessive development of the biceps, and this muscle tends to becomes shorter as it becomes thicker; the movement of extension thus becomes limited, and the fore-arm cannot be placed in the same straight line as the arm. Hence arises a deformity which is unimportant in the example given, but of a kind which may become serious if it involves certain regions of the body, the direction of which must be regular under pain of defect in harmony of contour and in elegance of position.

Let us suppose that this muscular contracture which is so frequent in the arms of men who practise much on the trapeze, occurs in the muscles of the dorsal region: the same vicious effects which we have just described in the direction of the arms, now influence the direction of the vertebral column. If the flexor muscles of the vertebræ act more than the extensors, they tend to shorten, while their antagonists preserve their normal size, and the spine is curved forwards. Hence an unavoidable stoop. If the lateral muscles of the spine have received the preference in exercise, it is in them that we observe shortening of the fibres. The spine will be drawn to the right or to the left according as the muscles of one side have become more developed than those of the other. There thus occur lateral deviations, or, to use the technical term, *scolioses.*

We shall see, in speaking of the exercises which produce deformity, how frequent are scolioses in exercises which are confined to one side of the body, fencing, for example.

These scolioses are at first purely muscular, and can be rectified, either by giving up the exercise which has immoderately developed the muscles of one side, or by practising an exercise which will develop the muscles of the opposite side after a manner which will equalise the action of the antagonists, and obtain an equilibrium of opposing forces which will produce a straight spine.

But these means will be insufficient if applied too late, for it may happen that the predominance of the muscles of one side, and the deviations which result from it, lead to consecutive disturbances in the nutrition of the vertebræ, and to malformation of these bones.

In fact, the vertebral column is constructed of a number of very short bones, piled one on top of the other, and each capable of moving upon the one which supports it. If a vertebra is drawn to the right, for instance, the movement which it performs throws its weight on to its right edge and tends to raise its left half. All the pressure which it exercises on the bone which supports it, is then localised to the right ; but this pressure which is now borne by a very limited part of the vertebra, represents a considerable weight, that in fact of the whole body above the particular vertebra. This pressure hinders the process of nutrition of the bone, which tends to atrophy at the part pressed upon. On the contrary, the left part of the vertebræ undergoes no arrest of development, for it receives less weight than in the normal condition : it keeps its ordinary size, and the bone definitely assumes an angular shape ; its left half, which has undergone no abnormal pressure, remains thick, while the right half, which has been pressed upon, has become thin. Its shape exactly resembles that of the keystone of an arch, and this shape is repeated in all the vertebræ which undergo the same deforming influences. Hence a curvature of the whole dorsal spine, with its concavity to the right ; a curvature difficult to remedy, for it is no longer due to simple muscular action, but to material deformity of bones.

Deformities of the spine are the dangers of gymnastics. As useful as are bodily exercises in remedying deviation of the figure when they are employed with discernment, they are equally capable of producing them when unmethodically applied.

CHAPTER IV.

EXERCISES WHICH PRODUCE DEFORMITY.

Gymnastics and Æsthetics—A rooted prejudice; the Beauty of Form of Gymnasts—Deformities due to Gymnastics with Apparatus—Mechanism of these—Too much Exercise of the Arms—Attitudes of Support—*Breasting*—The Horizontal Bar—The Parallel Bars—*Circling*—The Trapeze—The Round Back of Gymnasts—Fencing—" Fencers' Scoliosis "—Comparative Observations on Right-Handed and Left-Handed Fencers—Our conclusions are opposed to those of former authors—Opinion of Bouvier and Boulland—Mechanism of these Deformities—Different attitudes of the Fencer during the different Stages of a Fencing-Bout—Guard, Attack, Parry, and Thrust—Dumb-Bells—Riding—Different Effects of Riding in a Race, and of the riding of the Schools—The Back of a Jockey, and the Figure of a Cavalry Officer.

I.

WHEN we attend a gymnastic display, and study at leisure the conformation of the young people who take part in it, we have a certain feeling of disappointment—What! is this then the harmony of form, the pureness of contour, which our gymnasts should find, like the old Greeks, in the practice of physical exercise?—Examine the antique statues of "Achilles," of the "Fighting Gladiator," and of the "Discobolus," and you cannot help saying that if these heroes were moulded by gymnastics, they must have been gymnastics quite unlike ours. Let us admit that no one has less the appearance of a demi-god than a performer on the trapeze.

It is difficult to resist the tide of formed opinion, which, for half a century, has represented the gymnasts as types of beauty, and we admire them on trust with our eyes shut. Let us then open our eyes and study a man who has assiduously practised on the rings, the horizontal bar, and other gymnastic apparatus.

The most striking things about a professional gymnast are the exaggerated development of the bust, and the small size of the lower half of the body. The shoulders are very broad, the hips narrow, the legs slender. The part of the body whose office it is to support should naturally be very muscular, and it is a first anomaly to see that, on the contrary, the upper half of the body exceeds the lower in size and vigour.

This anomaly is easily explained if we call to mind the mechanism of these exercises. They all need a veritable transposition of the action of the limbs, and make the arms play the part of the legs. They all need the support of the body by the shoulders, whether the arms *suspend* the body below the bar of the trapeze, or *support* it above the same. The shoulders must then in these exercises gain a development fitting them to do the work of the hips.

Besides the defective proportion we have pointed out, the professional gymnast shows a very characteristic deformity: he has a *round back.*

If we look sideways at a man who for some years has assiduously exercised on the trapeze and the parallel and horizontal bars, we see that the line of the back from the neck to the loins has a very pronounced convexity. This is an exaggeration of the natural dorsal curvature, and sometimes attains the dimensions of a true deformity in persons who practise exclusively such exercises as those above mentioned.

This is not all. The shoulders are also the seat of a characteristic deformity. The scapula, drawn forwards by its articular head, undergoes at the same time a movement of rotation which causes the inferior angle to rise and to project backwards. This makes a protuberance in the back comparable to that which, in extremely emaciated phthisical patients, produces the *alar chest*, with this difference that, in gymnasts, the bony prominences are accompanied by great muscular prominences, while in cachectic persons the angle of the bone seems ready to break through the skin.

In front, the line which forms the profile of the chest is flat, and even re-entrant. A pronounced prominence exists in the region of the nipple, but it is due to an exaggerated development of the pectoral muscles rather than to arching of the ribs. The thorax is, however, increased in size in gymnasts, but chiefly, as we shall see, in those who exercise their legs. In gymnasts who use their arms chiefly, the apparent size of the chest is largely due to the development of the muscles of the shoulder, back, and chest. The antero-posterior diameter of the thorax is certainly not diminished in these persons, it is even increased, but the increase takes place behind only, through the roundness of the back. The chest is not really re-entrant, but it looks so, owing to the forward tendency of the shoulders.

Such are the deformities observed usually in our gymnasts—not in all, but in those who practise orthodox gymnastics to excess: we may say the *old style* of gymnastics, for there is happily a reactionary tendency against it. This deformity is due to abuse of the exercises demanding *suspension* and *support* of the body by the hands. Now these are the two fundamental positions of gymnastics performed with the aid of apparatus.

When the body is moved in order to pass from suspension to support by the arms, this change is effected by two methods, *breasting and circling*.

In the breasting movement, the body is first suspended by the fully extended arms to two rings or to a horizontal bar, then it is drawn up by a contraction of the biceps, which brings the shoulders to the level of the wrists. At this moment the difficulty begins. It is necessary that the elbows, which are lower than the hands, should be raised above them, in such a manner that the body, instead of being suspended, comes to be supported by the arms.

To pass from suspension to support, the gymnast must raise himself above a bar of wood if he is on a trapeze, or above an imaginary line if he is on the rings. In both cases the centre of gravity of his body must pass *behind* this line in order eventually to attain a position above it.

If we observe the different movements, we see the muscles of the back of the neck contract energetically with an effort which seems *to thrust the neck down between the shoulders.* The whole body is drawn together, and the dorsal region of the spine strongly curved in order to bring the shoulders as far as possible in front of the bar and thus lighten the work of the arms, at the same time as the pelvis is raised as much as possible, to lift the whole weight of the body and raise the centre of gravity. The gymnast has at this moment the most ungraceful appearance it is possible to imagine. Now we know that the body tends to preserve the imprint of an often repeated attitude.

This drawn attitude of the upper part of the body, with exaggerated flexion of the upper six or eight dorsal vertebræ, is characteristic of all the breasting movements.

It also occurs in the *circling* movement, which needs the revolution of the body round the bar of a trapeze, or round the imaginary line between the rings. All these exercises need a forced flexion of the dorsal part of the spine, and tend to produce a round back.

Other gymnastic exercises seem, at first sight, calculated to counterbalance the effect of those the disadvantages of which we have just described. If the trapeze and the horizontal bar bring into action the flexors of the spine, we may say that on the parallel bars, on the contrary, the extensors are especially employed. This is true enough, and yet these exercises have no tendency to correct the arched appearance of the back produced by the trapeze.

In fact, the parallel bars, like all the apparatus which need the support of the body on the hands, tend to throw the shoulders forwards, in such a manner that, without increasing the curvature of the spine, they render it more apparent. When the body is supported by the arms, which transmit the weight to the shoulders, it is necessary that the numerous muscles surrounding the scapula, the clavicle, and the head of the humerus, should contract energetically, in order to make of these bones a solid and resistent whole, capable of assuming the office of the pelvis. The muscles, on which falls the major part of this work of consolidation of an essentially mobile region, are the pectorals, for their action is to draw the shoulders *forwards* and *inwards*, and this is the position always assumed by the head of the humerus in exercises on the parallel bars.

In a man moving along the parallel bars supported by his extended arms, the trunk hanging down by its own weight, it is easy to see that a line traversing the shoulders is much in advance of one passing through the same points in a man standing upright at attention. It is the energetic and sustained contraction of the pectorals which, during the whole period of support on the arms, gives to the articular head of the scapula this forward direction. Further, the distance between the bars being always greater than the width of the shoulders, the arms are thrust at once from below upwards, and from *without inwards* by the force they transmit to the scapulo-humeral articulation.

In other words, the parallel bars have a tendency, to thrust the shoulders *inwards*, to *raise* them, and to carry them *forwards*.

We need not here insist on the physiological mechanism which tends to render an often repeated attitude permanent. We will merely recall that a muscle which contracts often and energetically, tends definitely to shorten, and consequently to draw its origin and insertion nearer together. Thus it is that after sustained and repeated exercise the pectoral muscle tends to draw its more movable point of attachment, which is the neck of the humerus, nearer to its more fixed point of attachment, which is the front of the chest, or in other words, to draw the shoulders forwards and inwards.

Finally, the thrust of the humerus from below upwards, tends to leave its imprint on the conformation of the gymnast, either by the deformity it produces in the clavicle itself, exaggerating the curves of this bone, and consequently shortening it, or in the articular cavities by changing their depth and direction.

The analysis of the movements explains then what a glance is sufficient to determine ; that gymnastic exercises performed with the aid of apparatus deform those who abuse them.

They tend to draw the body together and give it a curved appearance: (1) by developing to an exaggerated degree the muscles of the shoulders and back; (2) by exaggerating the dorsal curvature of the spine in the upper half of its extent.

They have no tendency to diminish the actual size of the thorax, but they make the chest appear sunken by carrying the shoulders forwards, inwards, and upwards.

This simple exposition will doubtless have more value than a long pleading to make it clear that the trapeze will not be a regenerator of beauty of form. And yet for a long time to come people will religiously bow down before the anti-physiological traditions of *gymnastics with apparatus* which we owe to Colonel Amoros.

II.

Gymnastic exercises are not the only ones which produce deformity. Another athletic exercise which is much practised now-a-days, *fencing*, produces also very characteristic, although less pronounced deformities.

We have collected on this subject a series of observations which were presented in January 1886 to the Medical Society at Limoges, and the conclusions from which are diametrically opposed to those which had hitherto been obtained in the matter. We shall here describe the phenomena we ourselves observed, and the physiological interpretation we have given of them.

Everyone who has fenced much shows in a more or less pronounced degree a lateral curvature of the spine. As to the direction of this curvature, this *scoliosis*, we may say that all right-handed fencers tend to have scoliosis with the concavity to the right, and all left-handed ones scoliosis with the concavity to the left. These tendencies are very unequally marked. Hardly indicated in some cases, they may become serious deformities in others. We need hardly point out that the vertebral column of an adult, solidly built, in a vigorous man who fences at long intervals, could perfectly resist the tendency, and take no vicious direction, while the maximum deformity would be produced in a subject, liable to rickets or softening of the bones, who had begun to fence when quite a child, and continued assiduously till grown up. Between these two extremes there are many degrees, but we must say that, generally, a methodical examination is necessary to establish the existence of deformity.

The deformity, even when very pronounced, is usually imperceptible at the first glance. The practice of fencing develops in fact, more than any other exercise, agility and precision of movement; it gives a certain ease and grace in the carriage which compensate for, and mask after a fashion, the slight deviation of the trunk.

On close examination, however, of those who frequent the fencing school, we find the characteristic signs of scoliosis. Among these there is one for which surgeons usually look first, because it is the most striking: this is the deviation of the line formed by the spinous processes of the dorsal vertebræ. This sign is not often present in scoliosis due to fencing, for in these cases the deformity is usually slight, and the sign of which we speak is only met with where the curvature is very pronounced. We have observed it, however, in a youth of sixteen years of a feeble constitution, who fenced to excess, and who had strengthened his system at the expense of the straightness of his spine.

There are other signs of deviation which we meet much more often in fencers. One of the commonest is *lowering* of the shoulder. Here our observations are absolutely contradictory to the opinion of other authors.

In a work by Bouvier and Boulland * we read "Fencing may help to remedy a commencing scoliosis, by *raising* the shoulder *on the side which holds the foil.*" This sentence contains a great error, the practical consequences of which may be serious. The shoulder of the arm which holds the foil in fencing is not raised; on the contrary, *it is lowered.* Considering the weight of the authority we have quoted, we must support our contrary opinion both by observation of facts and by a rational study of the different movements of fencing.

* Dictionnaire de médecine et de chirurgie pratique, art. "Rachis."

As to facts, our observations concerned twenty experienced fencers, among whom were eight fencing masters and three left-handed men. We wish first to state that the observations made on the left-handed men gave absolutely inverse results to those on the right-handed; and this is a sufficiently conclusive counter-proof. In all the cases observed, the shoulder has so frequently been lower *on the side of the working arm*, that this deformity has become for us the professional stamp of the fencing master.

To measure properly the degree of difference in height, it is enough to put the subject of examination upright against a wall, and to lower successively to the right and to the left a T-square held edgewise, until it touches the prominence of the shoulder produced by the *acromion*. On each side we rule here a horizontal line, and we can then measure the difference in level between the two. We need hardly point out that it is necessary, before measuring, to ascertain that the hips of the subject are exactly at the same height, and that the different height of the shoulders is not due to inequality in the length of the legs. By this method we have found the shoulders lowered by as much as two and a half centimetres in persons who are vigorous and in other respects well built.

Often the deformity is seen at a glance. We have seen fencers whose linen vest showed a great transverse fold over the right pectoral muscle, while it was smooth and stretched over the left side of the chest: a proof that the right side of the trunk was shorter than the left, the shoulder being lowered and nearer to the hip.

Finally, there is another sign of dorsal scoliosis which we have rarely found wanting: this is a flattening of one side of the chest corresponding to a vaulting of the other side. In right-handed fencers, the flattening is at the right external part of the thorax, and the vaulting external and to the left; in left-handed men the other way about. The vaulting is due to a great prominence of the rib curves which are pushed outwards by the convexity of this side of the spine; it is usually accompanied by enlargement of the intercostal spaces. On the side of the depression, on the contrary, the ribs have retreated or fallen in, being drawn inwards by the vertebral column to which they are attached, and which on this side is concave. The ribs which are depressed are also approximated, and thus the intercostal spaces are narrowed. In very pronounced cases, there is not merely a flattening, but an actual hollow on the side of the sword-arm. In slight cases the difference is still sufficiently noticeable for it to be necessary to pad the right side of a fencer's coat. Many tailors are well aware of this detail, which has its own value.

It would be possible to turn to the advantage of the fencer, this tendency to deformity of the thoracic parietes in cases in which there is from other causes an opposite deformity. One of the best fencers in the barracks at Limoges, a left-handed fencing master, suffered some years ago from a right pleurisy. After this illness the right side of his chest was depressed, the pleurisy having caused, as usual, retraction of the thoracic parietes. Since then, fencing always with his left hand, he has unconsciously remedied the right-sided deformity, for now, instead of a hollow here, there is a slight convexity.

Thus fencing, always practised with the same hand, tends to produce a deviation of the dorsal spine, the concavity of which corresponds to the hand which holds the foil. This is a lateral curvature, a scoliosis. It can present various degrees, and is more pronounced in proportion to the slighter power of resistance of the subject, to his youth, and to the amount he has fenced. This scoliosis gives the usual signs of lateral curvature, amongst which three are easy to detect. One of these only occurs in pronounced cases: this is the deviation from the vertical of the line formed by the spinous processes. The other two are nearly constant and give a stamp to all men who fence much. They are: the lowering of the shoulder on the side of the sword-arm, with flattening of the chest on the same side, and vaulting on the opposite.

Such are the results of observation; let us now seek to give a rational explanation of them by considering the mechanism of fencing.

When we analyse the movements of a man fencing, we see that they all agree in imposing on the body an attitude similar to the vicious curvature we have described. Now we know that an attitude often assumed, a curvature which the spine assumes every day, tends to become permanent. It is thus that deviations of the figure are established by habitually vicious carriage, or by the special attitudes of certain professions.

A complete summary of the different movements of fencing is presented by the mimic combat known as *the assault*. All the stages of the assault may be reduced to three: *the guard*, *the attack*, *the parry*; the thrust needs no special description, it is merely an attack rapidly following a parry.

In *the guard*, the right-handed fencer raises his left shoulder to carry his arm above his head; his right shoulder is on the contrary lowered, in carrying his hand to the level of his right breast. His face is turned towards his opponent, but his body, to show less front, is turned sideways. Thus when the fencer leans, his body is not bent *forwards*, but *to the side*, in the direction of his opponent, and consequently in the direction of his sword-arm. They always lean over, academic principles notwithstanding, and two fencing masters in the assault lean over quite as much as their pupils. A man leans more in proportion to the attention with which he is watching his opponent to seize the moment for attack. A man then draws himself together like an animal crouching for a spring, and the body bends more and more before being extended. It is at this moment, in this forced attitude, that the vertebral column is most fatigued and has the greatest tendency to curvature.

In *the attack*, the fencer *lunges*, that is, the trunk is carried forwards and violently bent towards the opponent in the endeavour to reach him. The vertebral column, in this lateral displacement, may be compared to the arm of a lever, the extremity of which is charged with the weight of the head and shoulders, a weight which adds to the shock of flexion in compressing the sides of the vertebral bodies (right side in right-handed, left in left-handed men). This pressure often repeated, and always on the same points, comes in the end to hinder the nutrition of the vertebræ. If these have little power of resistance, and if the violence is often repeated, there results a subsidence, a settlement of the bones on the side which is compressed, while the other side keeps its normal size. The whole column undergoes this process of unilateral subsidence and consequent deviation from the vertical.

In *the parry*, the body does not move, the fore-arm and the wrist are alone in action; but the fencer always preserves the position of lateral flexion which we described in the guard, for it is necessary that the body should be ready at any moment to thrust.

Thus in all the phases of fencing, the body acts in, and is fatigued by, maintaining a position which forces the trunk to incline constantly to the side of the sword-arm. The vertebral column may be compared to a bow which is stretched and loosened, forming a curve, the concavity of which corresponds to the hand which does the work. This curvature, being often repeated and long continued, what is there to surprise us, if the body preserves its stamp?

Reasoning is then in agreement with facts in leading us to the following conclusions:—

If we wish to employ fencing with a therapeutic end in a feeble person, at an age when deviations of the spine are to be feared, we must recommend that both hands should be equally exercised, not only in order to avoid an unequal development of the muscles of one side of the body (which hitherto has been the chief consideration), but also, and chiefly, in order to avoid the production of deformity. If we employ fencing with an orthopædic aim, in order to try and remedy a scoliosis, we must not confine the exercise, as is recommended in the above quotation, to the side on which is the convexity of the curve; we must do exactly the opposite of this. If we have to raise a drooping *right* shoulder, the foil must be held in the *left hand*, and conversely.

We are unwilling to conclude this study without speaking of a very common practice at fencing-schools, which, in the endeavour to remedy the evil effects of fencing, really rather exaggerates them. With the object of exercising the side of the body which has not been at work, we see a fencer, after a bout in which he has used his right hand, set methodically to work with a dumb-bell in his left hand, not considering the very different effects of these two exercises. Dumb-bells, in contra-distinction to fencing, raise the shoulder of the side which works. In fact, by a compensatory movement which does not occur in fencing, during the whole time that the left arm is using the dumb-bell, the body, in order to balance itself, leans towards the right, and resumes the exact position which the man wishes to avoid.

There is only one way of avoiding the deviation which occurs in a man who fences with one hand only; this is to use alternately the right hand and the left.

Riding may be classed amongst the exercises which produce deformity, but the deformities produced vary according to different modes of riding.

In professional horsemen there exists a curvature of the lower limbs, which is more pronounced in proportion to the greater malleability of the limbs at the period when the exercise began. The legs tend to become concave. It is by being as it were moulded around the horse's trunk that the legs and thighs of the horseman become arched.

Another deformity may be pointed out as occurring in persons who ride in races; this is an arching of the back. The jockey leans forward to lighten as much as possible the horse's hindquarters. But, besides this attitude which curves the dorsal region of the spine, there is a more active cause of deformity. The arms must support the horse's mouth, and thus support a weight often exceeding 20 kilogrammes. To sustain this pull the jockey supports himself by his stirrups and knees. The body is thus under the influence of two forces, which tend to draw nearer together the two extremities of the dorsal arch, and thus to exaggerate its curvature.

The horsemanship of the riding-school and that of ordinary out-door riding seldom follow the same methods as race riding, and tend to give the body a perfectly balanced and consequently a perfectly vertical position. The horseman must be in a position most favourable to firmness of seat, that is, he must bend neither forwards nor backwards, neither to the right nor to the left, and he is forbidden to gain any support from his reins. His vertebral column must always be ready to move in all directions when necessary to maintain equilibrium, and for this the vertebræ must remain very freely movable on each other. The pieces which build up the vertebral column must not then undergo any excessive pressure; drawing together of the loins or back must, above all, be avoided, under pain of deficient *flexibility*.

Observation has shown us the great difference between the horse soldier and the jockey from the point of view of form. Old jockeys are drawn together, have high shoulders and a round back. Cavalry officers preserve, on the contrary, a remarkable elegance of figure even in advanced age.

It is impossible for us to analyse all the exercises which produce deformity. The types we have described sufficiently point out the method to be followed in judging of the influence of muscular work on the form of the body.

We may say generally that an exercise will produce more or less marked bodily deformity, whenever it is performed under the following conditions:—

(1) Concentration of muscular effort in a very localised region, the other parts of the body not sharing in the work.

(2) Necessity of maintaining during the exercise an attitude in which the axis of the body deviates from its normal direction.

(3) Frequent and prolonged performance of movements which man does not naturally practise, and to which his conformation is not adapted.

CHAPTER V.

EXERCISES WHICH DO NOT PRODUCE DEFORMITY.

The best Gymnastic Exercises—Ground Exercises—An Exercise too little regarded; French Boxing or *Chausson*—Fair division of work in this Exercise; Necessity for Perfect Equilibrium; Boldness of the Movements—*The Turning Kick*—Swimming and Climbing—Rowing—Two Varieties of Boating Exercise; the Oar and the Paddle—Superiority of the Oar—Rowing and Sculling—General conditions of Exercises which do not produce Deformity; these conditions are especially Negative—Natural tendency of the Body to Regular Development—Exercise must not oppose this tendency—Suppleness a condition of Elegance of Figure—Superiority of Exercises of Skill to Exercises of Strength—Rope-dancers; Jugglers and Balancers—The habit of carrying Burthens on the Head—The Women of Teneriffe.

I.

THE conclusions we enunciated in the last chapter may serve to guide us in pointing out the conditions in which exercise must be practised in order to maintain the regular form of the body.

The exercises which produce bodily deformity are, in the first place, those which do not make all parts of the body work equally. If we are, before all things, anxious to preserve regularity of form, we must adopt exercises in which all parts of the body regularly perform work in proportion to the strength of their muscles.

In the gymnasium we call *ground* exercises those which are performed in the upright posture, and which consist in successive movements of flexion, extension, etc., of the legs, the arms, the trunk, the pelvis, and the neck. These are evidently, from an æsthetic point of view, the best of all exercises. Every limb does work in proportion to the strength of its muscles, for it moves only its own weight. Further, there is a perfectly measured contraction of all antagonistic muscles, and no tendency to predominant contraction of flexors rather than extensors, or *vice versâ*, and in consequence no tendency to draw the bones into abnormal directions. Finally, the body being supported on the legs during these exercises, the vertebral column has no tendency to assume a vicious attitude for the maintenance of an abnormal equilibrium.

These exercises would then be the best of all if they were a little more interesting to those who practise them. But they are very unattractive, as they suppress all initiative on the part of the pupil, and only need an attentive and passive obedience to orders.

There is happily another gymnastic exercise which combines with regularity in the expenditure of force a peculiar attraction, because it implies a contest of skill, agility and readiness: this is *French boxing*. This exercise is learned in a series of lessons of which each is performed alternately by the right and the left side of the body. In this manner the right leg and the right arm repeat exactly, when their turn comes, all the movements which have just been performed by the left arm and the left leg.

French boxing, in which blows are given with the feet as well as with the fist, needs every moment attitudes of great boldness.

When a kick has to be given as high as the face, the trunk must be strongly inclined to the side to counterbalance the displacement of the centre of gravity, and this attitude would be vicious if it were always in the same direction. But the right leg, which has delivered a kick, has hardly returned to the ground when the left leg must take its turn, and repeat the attack, either directly forwards, or by the pirouette known as the *turning kick*. With a rapidity which astonishes the spectator, the body must change from one leg to the other with a sufficiently stable equilibrium to propel the foot in a precise direction with a force which sometimes exceeds 50 kilogrammetres. In order that the centre of gravity may be displaced with such marvellous ease, the vertebral column, which plays the part of a balancing-pole, must preserve an extreme mobility. The inter-vertebral joints must allow of very extensive movements, which are incompatible either with contracture of the spinal muscles, or with anchylosis between any of the vertebræ, or, finally, with any vicious direction of the articular surfaces. And these are the three chief causes of deviations of the figure.

French boxing, or *chausson*, is, then, preferable to fencing for the regular development of the body of a young man, and for preventing vicious carriage.

Swimming, like chausson, needs a regular action of all the muscles. The body must progress in this exercise by a movement of extension which, beginning in the legs, spreads to the thighs, the vertebral column, and the arms.

Climbing has a great resemblance to swimming. In both these exercises progression is brought about by alternate movements of flexion and extension of the body and limbs. Between these two methods of progression there seems to be at first sight only a difference of direction; in swimming it is horizontal, in climbing from below upwards. But there is a capital difference as regards the mechanism of the work; in the swimmer, the arms and shoulders move in the same horizontal plane; in the climber, on the contrary, the arms are much in advance of the chest, and their movements of flexion, the hands being fixed, tend to draw the shoulders upwards, forwards, and inwards.

We have had no opportunity of observing the professional climbers who spend their lives in the State forests in climbing large trees for the purpose of removing the branches. But, considering the nature of the work they perform, the conformation of their shoulders should resemble that of the gymnasts who make too much use of the trapeze. In the exercise of swimming there is, on the contrary, no cause of deformity, and swimmers have, therefore, generally a very regular development.

There are certain exercises which seem at first sight to be performed by a very localised group of muscles, but which a more attentive analysis shows to be generalised throughout the body. Thus a man who rings a heavy bell does not only work with his hands which hold the rope, but with his arms which bend, with his trunk which leans forward, even with his feet, which contract in order to adhere more firmly to the ground.

Rowing is reputed to increase the size of the biceps, and this sport is generally classed with exercises of the arms. This is a mistake, for the work of the rower is far from being localised in his upper limbs. The muscular effort which moves on the boat is largely situated in the extensors of the vertebral column. The oarsman *pulls* above all with his loins. Further, when the boat is to be propelled with great speed, as in racing, the legs work at least as much as the arms.

As we are writing these lines we are suffering from an attack of muscular stiffness produced by resuming the exercise of rowing after a year's interval. In the muscles of the arms we have merely a slight sensation of discomfort, but those of the loins and thighs are really painful, having been vigorously in action.

We must make a strong distinction between exercise with the oar and that with the *paddle*. In the latter exercise the canoeist derives a fixed support from the seat, and his legs do not help him at all. They usually lie in the bottom of the boat inactive and extended. As to the trunk, it participates in the work, not by movements of flexion and extension, but by lateral displacements, now to the right, now to the left. Further, the canoeist, when making his most powerful efforts, is not leaning backwards, like the oarsman, but curved forwards.

This position is imposed by the necessity of giving to the movement of the trunk a direction opposed to that in which the water is displaced by the motor of the boat. Now in paddling, the water is displaced from before backwards, whilst in rowing it is displaced from behind forwards.

If we attend a boat race and compare the scullers with the canoeists, we are struck by the difference.

The canoeing movement is certainly very graceful. The body leans in regular rhythm to the right and to the left, and the head at each displacement is inclined in the opposite direction to the trunk, by a series of lateral inflexions of the cervical vertebræ. From these two opposed but compensatory movements, results a wave-like movement, which, added to the rapid gliding of the frail bark, forms a seductive picture. But the canoeist's back is curved like that of the jockey, and his legs remain inactive. Hence, in our opinion, the inferiority of canoeing from the hygienic point of view. It leaves the lower limbs absolutely motionless, and it tends to produce a round back.

In rowing, the oarsman also leans forwards at intervals in order to carry his oar backwards, but this is at a stage in the exercise when no force is required and, therefore, no pressure is exercised on the vertebræ. The really energetic muscular action, the one which determines the progression of the boat, is performed by bending the body backwards; at this moment of the effort the head is high and erect, and if the movement is very powerful, the face is upturned. The really active movement in rowing consists in *extension* of the dorsal spine. No movement is more fit than this to remedy a round back.

It will be well to point out the difference between "sculling" and "rowing." In the latter case there is one oar held in both hands, which forces the oarsman to lean to the side of his oar. In sculling there is needed an equal and symmetrical effort of both hands. Hence, to preserve the straightness of the body, sculling is much superior to rowing.

II.

We cannot review here all the exercises which are able to favour regular development. But we should like to try to define certain points which must be kept in mind when we wish to appreciate the influence of movements on bodily form.

First, the body left to itself, without being subjected to any external influences capable of producing deformity, tends naturally to develop in a regular direction. The causes which tend to produce deviation may be of internal origin, such as affections of bones or joints, retraction of tendons or of muscles, and paralyses. But the most common deformities arise from external causes, such as pressures, shocks, works or habits leading to a vicious carriage. Amongst the external agents capable of producing bodily deformity, ill-chosen or ill-directed exercise is a very frequent cause.

The vertebral column is the axis of the body. When it is normal in direction, the body is upright and the attitude is elegant. Most of the deviations of the spine have a muscular source, and arise from the predominant action of the muscles which draw the vertebræ in a given direction over those which should balance the action of these by drawing the spine in the opposite direction. Muscular exercise tends to develop the muscles and the bones: it is enough, with an æsthetic end in view, that this development should be regular, that no region of the body should acquire an exaggerated size capable of destroying harmony of proportion, and that no portion of the skeleton should assume a vicious direction.

Neglect of all exercise sometimes coincides with deviations of the body, but these are almost always due to an habitually vicious carriage, such as is observed in persons of sedentary life. The schoolboy kept in class from morning till evening, the artisan kept all day in the workshop, often present deviations of the figure; but the vicious position of the body needed for writing is the true cause of the lateral curvature of the spine which is common in school-children; similarly it is to the bent attitude when working with the needle that we must attribute the round back so common in tailors.

Certain deformities of the figure may be due even to deficiency of exercise, to the excessive immobility of the individual and to the extreme feebleness of the muscles hence resulting. The vertebræ being very freely movable on each other, cannot be consolidated and acquire the resistance of a rigid and homogeneous column, without being strongly pressed together, and maintained in intimate contact by the contraction of the surrounding muscles. If these muscles are too feeble, the weight of the shoulders and head causes the vertebræ to glide one upon the other, in the direction in which its weight tends to carry the body, that is forwards.

When muscular force is completely removed, as for instance in the dead body, there is a tendency to fall forwards; and if the dead body, held upright, is supported by the waist, we see the head lean down towards the chest, the shoulders fall forwards, and the back arched by an exaggerated flexion of the spine.

This stooping attitude, due to complete absence of muscular action, is an exaggeration of that observed in persons whose muscles are extremely enfeebled and atrophied by inaction. The round back is in these persons always accompanied by a receding chest, first because muscular inaction leads to diminution in the size of the thorax, secondly, because in a side view of the body, very pronounced convexity of the back tends by comparison to cause the line of the sternum to appear flat, and even concave. We observe this characteristic deformity in all cases in which young persons have led too sedentary a life, deprived of air and movement.

Muscular exercise, in whatever form, gives marvellous results in these deformities in which we cannot properly speak of a deviation to be remedied, but rather of a weakened part to be supported. The vertebral column promptly finds energetic support from the spinal muscles as soon as a man begins to perform violent movements, for every work needing a certain expenditure of force demands action from these muscles for the purpose of fixing the vertebral column, the centre and pivot in all movements of the trunk and limbs.

But aside from these cases of excessive debility, it is not from increased strength of the muscles that we must demand the means of restoring perfect uprightness to the figure. The persons who are most remarkable for elegance and grace are often very *supple* rather than very vigorous.

Suppleness of figure comes from the great ease with which the vertebræ can glide in all directions over each other. From this great mobility results the facility with which the various pieces of the dorsal spine accommodate themselves to the different attitudes of the body, and to the rapidity with which the trunk is balanced in all the displacements which it undergoes. So that the greatest possible grace of figure may be observed in clowns.

Certain exercises which demand very slight expenditure of muscular force have a remarkable tendency to make the back very straight: these are exercises which need balancing. A rope-dancer cannot keep upright on his slender support if he allows the axis of his body to fall out of the vertical, and this axis is represented by the vertebral column. All the movements of the acrobat tend to give to the muscles which move the vertebræ the degree of contraction necessary that the bony rod they form should have a perfectly vertical direction.

The rope dancer preserves when on the ground the position which his well-disciplined muscles are accustomed to give to the bones on which they act.

Balancing jugglers are, like rope-dancers and *india-rubber men*, types of perfect physical straightness; and if we compare them, in the circus, to the gymnasts whose specialty is the trapeze, we are struck by the superiority of the former in elegance of figure.

We have seen nothing more charming than a little balancing girl who, at the circus, climbed to the top of a pyramid built of bottles, and poised herself like a bird on the neck of the highest without displacing any of them. It was marvellous to see the child, when she had built the fragile structure, first make sure of the balance standing upright, then, putting her foot on its frail support raise herself, holding in her hand the neck of the last bottle, without the trunk deviating from the vertical by a millimetre. It was then necessary, from the stooping posture, to gain the upright one, and it was only by a mathematical precision in the contraction of the vertebral muscles that the extension of the legs and thighs could be affected without upsetting the whole structure.

The young girl who performed this extraordinary feat had gained, by practising it, a most graceful figure, and we were struck to see the contrast between her and a "gymnastic woman" in the same circus, whose back was rounded and whose shoulders were deformed by practice on the rings and trapeze.

Straightness of the spine is not due to the strength of the muscles of the loins and back, but rather to their perfectly harmonious action. If the muscles which bend the spine to the left exceed in vigour their antagonists which bend it to the right, the dorsal part of the spine yields to the stronger traction and there is a tendency to left *scoliosis*, however great the strength of the subject. If on the contrary there be perfect equality of strength between the muscles of the two sides, there will be harmonious action between them, and the figure will be straight.

All the exercises which demand perfectly harmonious action from the extensors and flexors of the vertebræ tend to make the figure perfectly straight. All those, on the contrary, in which there is predominant action in one half of the body break the harmony of the muscular forces.

A burthen constantly carried on one shoulder deforms the figure: the spine deviates to the opposite side of the body, the muscles of which are obliged to contract vigorously in order to draw the trunk to their side and counterpoise the weight. If their contraction is very prolonged and very frequent, they undergo, like all muscles the action of which is too prolonged, a shortening which keeps the spine in a position in which it has too frequently been placed. The vertebral column deviates and the shoulder which bears the burthen rises. Warehousemen who carry heavy bales, the railway navvies who carry sleepers, have the left shoulder usually higher than the right, for this is almost always the one which does the work. The "carrying" shoulder becomes higher.

If the burthen is carried on the head, two things may happen: either the load is excessive, and the extensors of the spine support it with difficulty. The vertebræ then yield to the pressure, and the curves of the spine are exaggerated. A round back is the result.

It is not the same when the load is not too heavy, and it is, as is usually the case, balanced on the top of the head. The vertebral column does not then perform a work of strength, but a work of precision, and the porter has to give to the vertebral column a direction which agrees perfectly with that of the weight. The axis of the body must then become vertical, and there must be no deviation of figure, under pain of displacement of the burthen.

We can find no better orthopædic exercise for a child with a vicious carriage than the carrying of light burthens on the head. If there are no changes in the vertebræ, if the deviation of the spine to be prevented or remedied is due solely to defective harmony in the action of the muscles of the back, this balancing exercise will be the best that can be found to remedy the nascent deformity.

Numerous observers have pointed out the elegance and regularity of figure in country-women who carry vessels of water on their heads; and how on the contrary there is deformity in those parts of the country in which the pitcher is carried on the shoulder.

The women of Teneriffe, according to a traveller who visited that island, are remarkable for the elegance of their figures; their skill is also surprising in balancing on their heads different light objects.

PART VI.

THE OFFICE OF THE BRAIN IN EXERCISE.

OVERWORK IN SCHOOLS—MENTAL AND PHYSICAL EXERCISE — EXCITO-MOTOR WORK — WORK OF LATENT STIMULATION — THE WORK OF CO-ORDINATION IN EXERCISE—AUTOMATISM IN EXERCISE.

CHAPTER I.

"OVERWORK IN SCHOOLS."

The Scholastic Regimen—Report of the French Academy of Medicine. "Mental Overwork" and *Sedentary Life*—Proposed Remedies; A more Simple course of Study, and more Physical Exercise—How these Reforms must be applied. Their Mutual Dependence—Difficulty of Simplifying the Course of Study. Dangers of more Physical Exercise without Diminution of Mental Work—Are Bodily Exercises Recreation for the Brain—Unrecognised Importance of care in the Choice of all Exercise for the Needs of Cerebral Hygiene.

A HYGIENIC question of the greatest interest has for some years attracted the attention of the public and the profession. We are alarmed by the dangers of excessive work of children in schools and academies, and the highest authorities have pointed out the sad results of *mental overwork.*

The French Academy of Medicine, officially invited to give counsel both on the extent of the evil and on the nature of the remedies to be applied, came, after an animated discussion, to the following conclusions:—

"Without concerning itself with the course of study, *of which however it desires a simplification*, the Academy insists specially on the following points: "A longer time of sleep for the younger children: for all the scholars a shorter time in class and preparation, *that is a shorter time spent in sedentary occupations*, and a proportionate increase of the time for recreation and exercise.

"*The imperious necessity* of making all the scholars perform daily exercises of physical training proportional to their age (walking, running, leaping, formations, developments, regular and prescribed movements, gymnastics with apparatus, fencing, games of strength, etc.)"*

The French Academy of Medicine points out in the existing scholastic regimen two different faults: excessive mental work, for it desires a more simple course of study —and insufficient muscular exercise, for it advises increased attention to physical exercise.

But if we consider the actual terms of the resolutions, the learned assembly does not appear to consider the two proposed reforms as of equal urgency. It insists on the "imperious necessity" of "a shorter time spent in sedentary occupations," while it rather vaguely expresses a "desire" to see a more simple course of study, without giving any definite counsel about the mental work of the scholars.

It seems that the members of the learned assembly have especially wished to decide with their full authority on the question of *sedentary life*, which is more directly within the province of medicine, and have preferred to leave to other judges the care of deciding whether the children really perform excessive mental work.

We may then hope that a new enquiry, directed by specialists, will allow us to form a judgment on this question of mental overwork with as much clearness as the French Academy of Medicine has decided in the matter of physical exercise.

But many months have already elapsed since the publication of the Academy's report, and no step has been taken, no enquiry has been officially ordered. The question of mental overwork after having, quite rightly, excited everybody, seems to be passing into oblivion. It is surrounded by silence, as if everything had been said.

Must we then consider the report of the Academy of Medicine as a sufficient guide? If it were, we should be tempted immediately to apply the reform which it declares to be most urgent, and to greatly increase the amount of bodily exercise, while reserving for a later reform the diminution of mental work, which is not so

* Comptes rendus de l'Académie de Médecine. July 15, 1887.

strongly recommended, and the initiation of which presents moreover much more serious difficulties.

In fact there is nothing easier than to impose upon children daily exercises of training, nothing seems more difficult than to diminish the lessons.

Intellectual contest is now the commonest form of the *struggle for existence*, and if a child, letting his brain rest, demand from it merely moderate exertion, he risks being beaten in the race by rivals who are more regardful of success in the struggle than of the laws of hygiene.

Is it then possible to apply the remedy pointed out by the Academy as an urgent necessity, without first making the reform on which it does not so strongly insist? Are we to increase the muscular exercise of the children even in cases in which we have not yet "simplified the course of study"? Will it be advantageous, finally, to make children, who are suffering from excessive mental fatigue, perform a "daily regimen of physical training"?

The academic report has not foreseen this question, and here is an unfortunate want. It is not an indifferent matter whether the two reforms suggested are mutually indispensable, and whether the prescriptions recommending exercises of strength and skill are addressed merely to children who lead too sedentary a life, or if they also apply to those children who do an excessive amount of mental work. An explicit commentary was so much the more needed, because already the general opinion, in advance of the decision of the judges, had pronounced in favour of the application of gymnastic exercises of all kinds in the treatment of mental overwork. All those who have appreciated the beneficial effects usually produced by physical exercise, seem impatient to see, while waiting for other reforms, gymnastic teaching take a larger place in educational establishments.

If we believe what most people say, bodily exercises will have a double effect, and will extend their benefits to the wearied mind of the child as well as to his enfeebled body. Muscular exercise will be a salutary counterpoise, able to re-establish the balance of the system which has been upset by excessive mental effort.

The physiological effects of the most common bodily exercises are still but little known, for they are seldom practised by men who study, and very few doctors have had the opportunity of verifying on themselves the most interesting results. Amongst the effects there are many which are purely *subjective*—a certain phenomena of fatigue, for instance—and the shades of which, very characteristic to those who have experienced them, may remain a dead letter to the ordinary observer in whom they have never occurred.

Thus, doubtless, is to be explained this widely circulated error, accepted without examination by most unscientific persons, and even by some doctors, who attribute to physical exercise the office of a derivative from mental fatigue.

Muscular exercise can assuredly remedy the faults of scholastic education which consist in an excessive *sedentary life*, but it is not a remedy applicable to mental overwork. There is, we believe, between the measures necessary in the treatment of these two faults of education a kind of antagonism and contradiction, which makes the solution of the problem a very delicate one.

We have at the same time to give work to the inactive muscles of the child, and repose to his overtaxed brain.

Now we hope to show that in certain exercises which the Academy recommends, in "the regular and prescribed movements, in gymnastics with apparatus, and in fencing," the intellectual faculties are occupied, and the brain has to work just as much as the muscles.

If then it is proved that a child is suffering from mental overwork, how can we dream of prescribing these exercises for him?

But if the too sedentary life of the scholar imperiously needs an increased amount of bodily work, and if we cannot hope, in order to increase the time for exercise, to diminish the hours of study,* we must at least adopt, amongst the various ways of exercising the body, those which need least the association of the brain in the muscular work.

No one has at present attempted to examine from such a standpoint whether it is necessary to exercise discrimination in choice in this matter. No one has asked if the gymnastic methods so much in honour in these days, are those most capable of giving to the muscles of the child the desired activity, without imposing fresh fatigue on his already overworked brain.

The object of the following chapters will be to establish, on a physiological basis, the rules which must guide us in the choice of an exercise, when we have to deal with a person whose life is too sedentary, and who is exhausted by continuous mental toil.

* M. Edouard Maneuvrier in his remarkable work on "*l'Éducation de la Bourgeoisie*," L. Cerf, 1888, proposes a complete plan of scholastic reform, according to which it will be possible to reduce to six hours the daily work of the child.

How many years shall we have to wait before so urgently needed a reform is put in practice?

CHAPTER II.

MENTAL WORK AND PHYSICAL EXERCISE.

The Muscle which Works and the Brain which Thinks—Similarity of the Physiological Phenomena—Heating of the Brain—Experiments of Dr. Lombard—Flow of Blood to the Brain during Mental Exertion—The Balance of Mosso—The consequences of Work of the Mental and of the Physical Order—Combustions and Products of Dissimilation—Auto-Intoxications through Overwork. Similarity of effects in the Physical and in the Psychical Order—Effects of Brain Work on the Composition of the Urine; they are Identical with those of Muscular Work—An Attack of Gout following Mental Fatigue like one following Physical Fatigue—The Case of Sydenham.

I.

LEAVING all philosophical doctrines on one side, and moreover without any need for committing ourselves to the materialistic hypothesis, we can show that there are very close analogies between mental work and physical exercise. These are two modes of the manifestation of vital energy which are very different in their form, but subject to the same physiological laws.

The conditions of work are the same for the brain which thinks and for the muscle which contracts: in both of these organs, when their activity comes into play, we observe a considerable increase in the blood-supply, and a greater production of heat.

If we measure a limb which has just been performing violent exercise we ascertain that there is a considerable increase in its size. This is because its vessels are distended by an increased quantity of blood.

It has even been noticed that the brain, when at work, becomes the seat of a more considerable flow of blood. Some physiologists have had an opportunity of studying the circulation of the blood in the cerebral vessels of patients in whom a portion of the skull had been removed by injury. Through this species of window to the organ of thought they have been able to see the brain swell with blood whenever mental work was performed, and the congestion disappear as soon as the intellectual effort was over.

An ingenious experiment has even made it possible to determine in a very striking manner that the quantity of blood drawn to the brain by mental work is more or less abundant according to the greater or less intensity of the intellectual effort. Mosso, an Italian physiologist, has constructed a balance on which a man can lie at full length. When a man is the subject of experiment the apparatus is so counterpoised that the part which supports the head and that which supports the feet are in exactly the same horizontal plane. The sensibility of the balance is sufficiently acute for a very light weight, added to one side or the other, to destroy its equilibrium. If the person under observation lies down perfectly motionless, and in absolute mental repose, the two extremities of the balance remain at exactly the same level. But if his mind becomes occupied with ideas needing an effort of attention, if an endeavour is made to solve a difficult problem, if a call is made on the memory or the judgment ; if in short the active psychical faculties come into play, the equilibrium of the balance is immediately destroyed, and the end which supports the head sinks.

The blood flows in more abundance through the cerebral vessels by the very fact of mental effort ; the brain suddenly becomes heavier, and this increase in weight gives the exact measure of the increase in blood-supply. We may in this manner determine that the lowering of the head is more marked according as the psychical faculties are more strained.

There is another analogy which is no less striking, between the work of the brain and that of the muscles. In both these organs greater activity of function is accompanied by greater production of heat.

If we thrust a thermo-electric needle into a muscle we find that the temperature of the muscle rises when it contracts. This heat, detected by the thermometer, is but a small part of that which has been produced in the motor organ, and the greater part of which has been transformed into movement.

We know in fact that the human motor is subject to the law of the transformation of forces, and to the same conditions as ordinary heat-engines: movement cannot be produced without consumption of heat. The perfect analogy between the human system and other heat-engines has long been known. The quantity of heat expended in the production of a muscular effort of known intensity has been exactly measured, and has been found to be nearly equal to that used by a steam-engine for the same expenditure of force.

Brain-work can evidently have no common measure with the mechanical work performed by a machine or by a muscle; but physiology has shown that the brain, like a muscle, needs for its activity, a certain expenditure of heat. Mental exertion is, like muscular exertion, accompanied by a rise of the temperature of the working organ.

This truth is not a merely imaginative one. Many years ago scientific experiments were performed to show the influence of brain-work on the temperature of the head. The first studies in this subject were made by Dr. Lombard of Boston in 1869. The positive results he obtained were confirmed by the labours of Schiff and quoted by Dr. Luys in his work the *Brain and its Functions*. It is now admitted on all hands that the brain becomes warmed during thought.

Whether the will uses under the form of mental work, or under the form of muscular exercise, the energy contained in the human system, the expenditure must always be liquidated by means of a liberation of heat. Under the influence of certain chemical combinations which go on within the organic tissues, and which are called *combustions*, the heat contained in a latent state within the molecules of the body is set free, and is then absorbed by the cerebral or the muscular action, as the heat of the fire is absorbed by the steam-engine.

These are the two most striking analogies which meet the physiologist when he compares bodily with mental work; in the labourer and in the thinker alike, there is an increased flow of blood towards the organ which works, and a greater liberation of heat within the anatomical elements which are thrown into activity.

II.

If we carry the analysis further, we find that there are other points of resemblance between the results of intellectual work and those of physical exercise.

In the first place, in the brain which thinks, just as in the muscle which contracts, the combustions being more active, there results a more active destruction of certain living materials which feed the combustions. It is in the same way that a locomotive which goes faster must increase its consumption of coals. There is a certain loss in the system as a result of mental work just as in the case of bodily exercise.

But this is not all.

The combustions do not cause the complete disappearance of the substances on which they feed, they change them in nature as the flame of a fire changes the coal and wood which it burns. The burning wood gives rise to products of combustion which may be found when the fire has gone out, which are cinders and soot Similarly the system after work contains products of combustion, called products of *dissimilation* because they no longer resemble the tissues of the organism of which they once formed a part.

The products of dissimilation—here is one of the most interesting points in the history of work—are injurious to life, and must be discharged from the system under pain of producing serious disturbances. Hence there is in the human body a series of *excretory* or *eliminating* organs, charged with the cleansing it, if we may use the expression, of all these impurities.

But if the formation of the waste-products of combustion is very considerable, as after intense work, it may happen that the eliminating organs are insufficient, and that the products of dissimilation accumulate in excessive quantity, and may profoundly disturb the great vital functions.

Now, according to theories which are gaining currency, and in support of which we have brought some sufficiently striking facts, certain forms of fatigue are due to the presence in the blood of an excess of the products of dissimilation which have accumulated owing to the combustions of work.

When fatigue is carried too far, it takes the name of *overwork.*

Muscular overwork has various forms, but, amongst other disturbances it may produce febrile conditions analogous to typhus or typhoid fever. In the opinion of all physicians in these days, the fevers of overwork which are observed alike in animals and in men, are due to a kind of poisoning of the body by its own elements, to an *auto-intoxication* of the system by the products of dissimilation which have accumulated in too great abundance as a consequence of excessive work.

But mental overwork also leads, according to several members of the Academy of Medicine (sitting of May 7, 1887), to febrile states of a typhoid character. This similarity of effects clearly indicates similarity of causes, and shows that we must attribute to an accumulation of the products of dissimilation the fevers of overwork derived from excessive study, as well as those which are observed to follow the abuse of bodily exercise.

What are the products of dissimilation which result from brain-work? We cannot exactly say, for we do not even know the exact composition of all the organic products which are formed during muscular work, a subject which has received much more attention than brain-work. We merely know, according to the most recent labours of Gautier, that certain poisons analogous to those of putrefaction are formed under the influence of the chemical actions by which vital heat is produced. What relation have these poisons, which are of the nature of *alkaloids*, to mental work? What even is their correlation with muscular work? These are questions on which light has not yet been thrown.

In the actual state of science we can only recognise these poisons by their effects, and the living organism is the reagent which determines their presence by the disturbances which they produce. In any case, the singular resemblance between the disturbances of health which occur after excessive mental work and after over-work of the muscles, authorises us to conclude that the causes are analogous.

Physicians have long recognised the injurious influence which overwork has on the diseases to which man is subject. The same aggravating action is attributed to mental overwork as to physical overwork on the course of acute or chronic affections. The most insignificant internal affections, as well as the simplest external injuries, may assume a very serious character in a man who has performed muscular work at once too violent and toc long sustained, as well as in one whose brain has performed mental efforts too intense and whose intellectual strain has been too prolonged. A pneumonia assumes an infective character in a young soldier overworked by forced marches, and equally so in a boy who has worked excessively in preparing for an examination. In both cases the seeds of disease fall on a field vitiated by the products of dissimilation.

Thus, while waiting for science to furnish a full and satisfactory theory of mental overwork, the facts of observation show us that there is a striking analogy between the results of excessive physical exercise and those of abuse of mental work.

There is as strong an analogy in the slighter degrees of fatigue as in the grave cases of overwork.

There is a material phenomenon very easy to observe, which has long attracted the attention of physiologists, and which accompanies excessive muscular work: we refer to turbidity of the urine. This turbidity is due to presence in excess in the urine of products of incomplete combustion, urates and uric acid. Now the same turbidity which is observed in the urine after a forced march very often follows great intellectual strain; we have been able to observe it in ourselves after finishing a chapter needing laborious study.

After muscular exercise the products of nitrogenous waste of the muscles are eliminated in the urine in the form of uric acid. Is the same the case after brain work, and are they the imperfectly burned nitrogenous molecules of the nervous substance which are eliminated from the system? We are at present unable to give a satisfactory answer to this question; but we can put forward as a fact, as certain as it is curious, the similarity of composition between the urinary deposits after physical exercise and after mental fatigue. In both cases an excess of urates is eliminated.

This identity in chemical composition is not the only analogy presented by the waste-products formed by physical work on the one hand and by exaggerated intellectual activity on the other. The excessive production of these two kinds of waste-products can produce identical disturbances of health.

It has been often pointed out in those with a gouty diathesis that an acute attack may follow excessive physical fatigue, and physicians attribute such an explosion to the accumulation of uric acid in the blood.

Now it has been proved that great mental strain, such as is caused by a course of excessive brain-work, produces, like bodily exercise, an increase of uric acid in the blood, and determines by so doing an attack of gout. If, in the physical order, a day's hunting, for instance, is often followed in the gouty by a violent attack, many cases have also been quoted in which a like accident occurs in consequence of excessive mental work. A very celebrated case is that of Sydenham, author of a valuable treatise on gout, who suffered from his first attack immediately after finishing his book.

Thus the facts of daily observation, equally with physiological deductions, authorise us to conclude that there is a close analogy between the effects of mental fatigue and those of muscular fatigue. This first conclusion should be already enough to render us very circumspect in the application of physical exercise to persons suffering from mental overwork.

But if we descend to details, if we make a summary analysis of the chief exercises in general use in our own time, we shall find that the analogy between mental work and bodily exercise becomes more and more striking. In the difficult movements of gymnastics, in riding, and in fencing, we shall see that the office of the brain and the nerves is as important as that of the muscles.

CHAPTER III.

EXCITO-MOTOR WORK.

Necessary association of the Nerve-Cell and the Muscular Fibre in Movements—Origin of Motor Stimuli—Nerve-Centres—The Spinal Cord a Centre of Unconscious Movements, the Brain a Centre of Voluntary Movements—Office of the Grey Matter of the Brain—The Dog of Professor Goltz—A counter-proof: the Observation of Dr. Luys—Muscular Work and Nervous Work in Voluntary Movements—Frequent Disproportion between the Effort of Will and the Muscular Exertion—Conditions which make the Relation vary between the Expenditure of Nervous Energy and the Mechanical Work of the Muscles—Diminution of Muscular Irritability—Muscular Fatigue.

I.

THE intimate relation which exists between the brain, the organ of thought, and muscle, the instrument of movement, is not as a rule sufficiently recognised. We wish to show here how the cerebral cell is intimately associated with the activity of the muscular fibre, and how the intellectual faculties are far from remaining inactive during the performance of various gymnastic movements which are nowadays in high favour.

To understand the importance of the part which work of the brain may play in a bodily exercise we must first get an exact idea of the organic apparatus by the aid of which movements are performed. This apparatus is essentially made up by: 1 Nerve-centres in which the motor stimuli are elaborated; 2 Conducting organs charged with the transmission of these stimuli: the motor nerves; 3 Organs whose office it is to respond to the stimuli emanating from the nerve-centres, and to perform movements: the muscles.

To these organic agents of movement we must add another, as unknown in its essence as it is indispensable for the performance of conscious muscular actions: the Will.

The Will orders and the muscles execute: but it is important to understand that the principal agent of movement has no direct relation with its subaltern. The will needs, for the transmission of its orders to the muscle, the whole complicated chain of nerve-centres and nerves. When we wish to move the foot, the order of the will sets out from the grey matter of the brain, passes down the spinal cord, and along the nerves of the leg and thigh. It is only after it has traversed this long succession of cells and nerve-fibres, that the vibration produced by the impulse of the will finally reaches the muscular fibres and determines their contraction. If in this course the nervous impulse finds an interruption in the continuity of the conducting tissues; if the spinal cord or the motor nerve are cut, the stimulus stops at the point of lesion, and fails to reach its destination: the muscle does not act notwithstanding the exertion of the will, for it never hears the call. Thus are explained the paralyses of movement which follow lesions of the spinal cord or of the motor nerves.

The will has then no direct action on muscle—nor has it any such action on the motor nerves, nor on the spinal cord.

But, on the other hand, muscle has no power of its own and cannot act spontaneously. The force contained in its fibres is latent, and resembles that of gunpowder. The gunpowder will not detonate without a spark; the muscle will not contract without a nervous *stimulus.* A work of nervous stimulation must then precede the work of the muscle.

Experimentally we may replace the nervous agent, the natural stimulus of muscle, by artificial stimuli, of which the one in commonest use in physiology is electricity. The phenomena which occur on electrifying the organs of movement are quite similar to those of voluntary contraction, and we have here a valuable analogy which allows us to study precisely the work of the muscles. We shall have to appeal to this remarkable analogy for the explanation of certain phenomena of bodily exercises.

In the living man the stimuli which cause the muscles to act come from the nerve-centres, that is from certain parts of the nervous substance which are endowed with a peculiar energy, and which have no need to borrow their power from any other part of the system. There exist two nerve-centres for the muscles of animal life: these are the Spinal cord and the Brain.

The Spinal cord is the centre for *reflex* stimuli and unconscious actions: we shall speak of its office further on. The Brain is the organ in which the stimuli sent by the will to the muscles arise. It is solely from this organ that the orders transmitted to the muscles by the nerve-fibres set out.

The will acts only through the brain, and especially on the thin layer of grey matter which forms its outer surface and which is the essential organ of thought as well as the indispensable instrument of motor stimuli.

Curious experiments have shown that the removal of the grey matter of the brain leads to the abolition of all voluntary action, without however necessarily causing death. Professor Goltz in 1881, brought from Strasburg to the congress in London a dog which he had been able to keep alive after having removed all the brain-substance. The animal was no longer capable of making any voluntary movement. Like an automaton, it walked straight forwards without ever turning aside, without seeking to avoid obstacles placed in its way, against which it struck, though its visual faculties were intact. Its muscles had not lost the faculty of action, but they were no longer directed by the will, and were no longer under the influence of external stimuli; they only performed reflex movements, or actions which habit had rendered automatic.

By the side of this experiment of Goltz showing the abolition of voluntary movements when the cerebral cortex has been removed, we may quote another observation which is no less curious, and which shows by a sort of counterproof that the grey matter of the brain atrophies when its movements are abolished.

"I have been able to demonstrate," says Luys,* "that in persons who had undergone amputations at a distant date, subjects who had been long deprived of an upper limb, for instance, there existed certain long disused portions of the brain, coincident, very distinctly localized atrophies. I have, moreover, demonstrated that the atrophied regions of the brain are not the same in the case of the amputation of a leg, and in that of the amputation of the upper limbs."

To understand the value of this observation we must recall the fact that inactivity of an organ is always followed by its atrophy. If then the disappearance of certain muscular movements through the removal of a limb leads to the "silence," and in consequence to the atrophy, of certain regions of the brain, this is clearly because the functions of that organ are intimately associated with those of the muscles; *the brain works when the body acts.*

II.

Thus it is within the grey matter of the brain that the nervous work which precedes, provokes and accompanies all voluntary muscular actions is produced.

If we have succeeded in expressing our ideas clearly, the reader will now understand that every voluntary movement involves a double expenditure of force, or in other words, a double work: a work of the muscle which contracts, and of the brain which excites the contraction.

The work due to the muscular contraction is apparent, outwardly visible, and may be measured by the dynamometer.

The work due to the excitement of the motor cells is a hidden work, which cannot be determined *de visu* and can have no common measure with muscular work, because its nature is not mechanical, but *physiological.*

* *Luys.* The Brain and its Functions, p. 53. Kegan Paul, Trench & Co.

We can represent it, by comparison, in a sufficiently satisfactory manner, thanks to the analogy between nervous and electrical phenomena. If we suppose a muscle thrown into action by electricity, the chemical changes which go on in the battery might represent the physiological working in the grey matter of the brain under the influence of the will, and which lead to the muscular contractions through the mediation of the motor nerves, just as the electricity of the battery calls forth the contraction through the mediation of metallic conductors.

Thus, the nervous work which precedes every voluntary movement has its seat in the grey matter of the brain, and a cerebral effort corresponds to each muscular effort. The cerebral effort is itself a result of the action exercised on the nerve-elements by that force of unknown nature called the will. Without concerning ourselves about the nature of this force which brings into play the activity of the motor nerve-cell, we shall designate its action during muscular work the *Effort of Will.*

The Effort of Will is necessary in order to excite a muscular contraction, but *the energy with which a muscle contracts is not always proportional to the intensity of the voluntary stimulus.*

This is a point of great importance, and we wish to discuss it here, for it has conclusions which are of great importance in the practice of physical exercise. Many circumstances can need an increase of the nervous work without a corresponding increase in the mechanical work performed by the muscle; often a very powerful effort of will is followed by an insignificant muscular contraction.

This difference between the intensity of the nervous work and that of the muscular work which it calls forth is very striking in the phenomena of fatigue. Everyone must have noticed that a fatigued muscle needs, to make it go on working, a more intense effort of the will than one which has been at rest. What an amount of energy of will must be expended to hold out after five minutes at arm's length, a weight which was at first held without effort! The muscular work has not increased, for the weight is always the same, but the nervous work is doubled because the fatigued muscle has become less *irritable* and must, if it is to contract, be more strongly stimulated by the nerve. Hence the necessity that the will should produce a more violent vibration in the nerve-centres, a more intense disturbance, the effects of which are translated, when the work is over, by a kind of enfeeblement, of temporary prostration, which always follows great expenditure of nerve-force, equally in the psychical and the physical order.

It is easy, with the aid of electricity, to imitate experimentally all the phenomena of muscular contraction, and to render evident the disproportion produced by fatigue between the quantity of force expended by the fatigued muscle and the intensity of the stimulus which it receives. If we stimulate a muscle by means of a current of graduated intensity and fit to one of the extremities of this muscle a dynamometer indicating the force with which it contracts, we observe that after a series of contractions the muscle becomes weaker although the intensity of the current has not diminished. In proportion as the work is prolonged the response of the muscle to each stimulus becomes more and more feeble, and finally ceases altogether. If we now gradually increase the intensity of the current we see the contractility of the fibre gradually reappear, and the dynamometer indicate a stronger and stronger contraction which at last becomes as strong as it was at first. But the current is now stronger, and a contraction of the energy of that which was at first produced by a current represented by the figure 1 may now need for its production a current represented by the figure 2.

The necessity of drawing from a muscle all the vigour it possesses is not the only circumstance of physical exercise which needs supplementary nervous work. We shall see in the following chapters under how many different forms work of the brain is added to work of the muscles in the course of exercises of the *Body*.

CHAPTER IV.

WORK OF LATENT STIMULATION.

A Cat lying-in-wait for a Mouse—Lying-in-wait in Animals. Nervous Work which this Action needs—Identity of Certain Phases of Bodily Exercise with the Phenomenon of lying-in-wait—A Fencing Bout—Physiological analysis of the "Direct Blow"—Fencers who have "Quickness"—Readiness of Blow—Latent Stimulation of Muscle and Diminution of the Latent Period—Explanation deduced from the Discovery of Helmholtz—The Office of the Brain in Fencing—How the Fencer betrays his Intentions—Advice of Bazancourt. Effects of Work of Latent Stimulation—Nervous Fatigue and Intellectual Fatigue—Nervous Fatigue; its Effects on Nutrition—Why Cats do not become Fat.

HAVE you ever watched a sleeping cat suddenly awakened by the nibbling of a mouse? It starts up and pricks up its ears. Look at it lying in wait: not a muscle moves. In its absolute immobility it seems still to sleep; but its bristling whiskers and sparkling eyes announce that a more intense life animates its outwardly inert body; all its limbs are stretched like springs, and its muscles, under the influence of powerful nervous stimulation, only need a last push to throw them into violent action.

When the mouse appears its capture is instantaneous: with the rapidity of lightning the animal has sprung and given a deadly blow with its claws.

To obtain this sudden transition from immobility to action, the cat had prepared its muscles, distributing to each a supply of nervous energy, keeping them as it were awake in an intermediate state between repose and action. In physiology we give the name of *latent stimulation* to this preparation which the muscle must undergo to become more fitted for instantaneous obedience to the orders of the will.

Latent stimulation of the muscles is an expenditure of force which eludes all mechanical estimation, for it is not outwardly translated by work in *kilogrammetres*; but it is a physiological action which does not pass unnoticed by the nervous system, and which must be taken into consideration in the analysis of a bodily exercise. When a cat lies in wait for a mouse, the fatigue of the chase does not consist in the bound which the animal makes to seize its prey, but in the nervous tension which precedes this movement.

We have an opportunity of studying, in numerous hunting animals besides the cat, this very interesting action of *lying-in-wait*. In hunting dogs training and inheritance have caused the disappearance of the second part of this act, which is its natural termination. A thoroughbred *pointer* never gets beyond the stage of lying in wait, and never bounds upon its prey, but its muscles do not escape that latent stimulation, which, in principle, has the object of rendering them more ready for action, and which, in shooting dogs, has been developed into a peculiar attitude indicating to the sportsman the presence of game.

Many exercises, and these common ones, need a preliminary preparation of the movements which recalls in a surprising manner the phenomena of "lying in wait"; these are exercises in which quickness assumes the character of *suddenness*. Whenever the muscles must pass instantaneously from immobility to action, and that at the precise moment when there is the best opportunity for the movement, a very intense nervous work must precede the muscular action; the brain must submit the muscle to a preparation without which the organ of movement would not be ready to obey *without loss of time.*

To elucidate this point we need a rather subtle analysis which will be best performed with the aid of an example.

In a fencing-bout two fencers will sometimes watch each other closely for several minutes without making any movement. All at once this immobility gives place to an exceedingly rapid movement: one of the fencers has seen *daylight,* that is a space of a few millimetres which the other had discovered by an imperceptible displacement of his hand, and the foil, moving with all possible speed at the very moment this opportunity was given, strikes him full in the chest. This is one of the most valued thrusts in fencing, and those who perform it successfully are reputed to have *readiness* in attack.

What happens in this very short space of time necessary for the delivery of a direct blow? The fencer has uncovered himself, his opponent judges that he can reach him; in a moment the muscles contract and the weapon reaches its mark.

There is nothing more easy in appearance than this movement of stretching the arm out straight, while the legs violently thrust the body in the direction of the blow. But this simple blow which needs neither cunning feints nor delicacy of touch, and which only consists in a straightforward extension of arm, is really one of the most difficult attacks of fencing. Like a cat lying in wait for a mouse, the fencer who is watching his opponent must seize for attack the precise instant when the opportunity occurs, or his chance will be lost. A man must be a fencer himself in order to understand the value of an infinitesimal fraction of a second when he has to make a thrust the very moment a chance is given him: the conception of the blow and its delivery must both occur in the duration of a flash of lightning.

We call the sudden extension of the leg which throws forward the fencer's body, and the quick movement of the arm which directs his foil against his opponent, a *lunge.* Now this movement cannot take place without an almost instantaneous obedience of the muscles to the will. We call the aptitude of a fencer for passing instantaneously at the right moment from absolute immobility to the most rapid movement, his *quickness.* Fencers who are deficient in quickness can calculate a blow, and can recognise the precise instant when it ought to be delivered, but the arm and leg do not obey quickly enough. The blow may have been conceived in time, but it is delivered too late. "Quickness" of the muscles and instantaneous movements need a considerable nervous expenditure, of which certain physiological facts give us an explanation.

A muscle does not *instantaneously* obey the order of the will. This discovery was made clear by Helmholtz in 1850. This physiologist showed that when a given point of a motor nerve receives an electric stimulus an appreciable interval occurs between the moment of stimulation and that of contraction. This *retardation* in the muscle is partly due to the time occupied by the stimulus in traversing the nerve; but taking into account the duration of this, which can be exactly measured, we find that there remains an appreciable fraction of time in which the muscle which has already received the stimulus has not yet begun to contract. Helmholtz gave the name of *latent period* to this silent time in which the motor organ, having already heard the call of the will, has not yet responded by a movement.

Now, various circumstances can alter the duration of the *latent period*, and render more or less speedy the obedience of the muscle to the stimulus which it receives. The most efficacious condition for shortening the latent period is increase of the strength of the stimulus.

Let us suppose that the motor organ is stimulated by an electric current. The latent period being two hundredths of a second with a current of known intensity, its duration will be reduced to one hundredth of a second if we double the intensity of the current.

If the muscle is stimulated by the Will, the same law will be applicable to the duration of the latent period, and this will be shorter in proportion as the strength of the voluntary stimulus is greater, this increase of the stimulus being represented by a more violent disturbance in the nerve-cells and fibres. The Effort of Will will then be more intense according to the *suddenness* with which the movement has to be performed, whatever the speed of the actual movement and the intensity of the muscular effort which determines it.

But we will penetrate further into the study of this curious phenomenon of the "latent period." The muscle at rest may be compared to a sleeping servant, who must be awakened before he can obey the orders of his master. We have seen that too feeble a stimulus leaves him inert—still asleep as one may say—on the contrary, a powerful shock wakes him up at once, and obtains from him a prompt obedience. The same diligence in the performance of the order could be obtained if we began by waking him by means of a preliminary call ; he would then hold himself in readiness to execute the slightest order.

Now, the experiments of the laboratory have shown us that by subjecting a muscle to a series of very slight electric stimuli we can throw it into a peculiar condition which is not yet action, but which is no longer repose, and which disposes it to contract *without loss of time* on receiving an energetic stimulus.

We call *latent stimulation* this condition in which the muscle has become more irritable, more ready to obey, like a thoroughly alert and attentive servant only waiting for a sign from his master to execute his orders.

In a fencer watching for the moment of attack, all his limbs are in this physiological state which is one neither of repose nor of movement. But this kind of active immobility can only be obtained at the price of a continuous nervous expenditure, an incessant stimulation emanating from the grey matter of the brain.

While the fencer on the watch has all the appearance of complete repose, his brain and nerves are in a condition of excessive tension. Like a Leyden jar being charged, his muscles are making, in a manner, a store of nervous energy, in order that at the right moment the will may suddenly determine the explosion of movement.

Such is the nervous expenditure necessary for a simple direct blow delivered with readiness.

This expenditure attains sometimes greater proportions still in certain phases of a fencing-bout in which the performance is necessary, not of a simple and elementary movement, such as the extension of the arm in a straight line, but a series of combined muscular actions, such as a difficult parry followed by a thrust. In these cases several complicated movements must at a given moment follow each other rapidly and fuse into a single muscular action equally precise and sudden. Such a performance in fencing then assumes all the characters of an intellectual operation.

After having "crossed swords" with his opponent, when the fencer thinks he has calculated his game, it often happens that he invites an attack with the intention of replying to it by a certain thrust in which he excels. He makes a feint of exposing himself, and if the too-confident opponent attacks in the opening offered, a rapid parry turns his foil aside, and an unavoidable thrust follows. The fencer was ready, he had the parry and thrust *in his hand.* The movement was co-ordinated in advance, and a series of muscular contractions, often very complicated, follow in perfect order, with an irreproachable precision, and a lightning-like rapidity.

This work of *preliminary co-ordination* needs a great expenditure of nerve-force. Any one who has ever handled a foil will remember how excessive is the tension of the nervous system in a man waiting for the right moment in which to deliver a thrust which he has long premeditated. To understand this, a man must himself have experienced the internal effort which keeps his muscles constantly under stimulation strong enough to make them more ready to obey, but not strong enough to throw them into action till the right moment. And the chance which must not be allowed to escape only lasts a fraction of a second!

Is not this "head" work which keeps till the opportune moment the mind of the fencer occupied with the idea of the complicated movement which he wishes to make, and which makes visible in his imagination the lines which his foil is about to describe?

Between the moment when he has co-ordinated his parry and thrust and that in which he finds the opportunity of executing them, he has made many movements, has practised many feints in the endeavour to ensnare his opponent ; but in the midst of these movements, to which he has to give a sustained attention, he has always kept his parry and thrust *in his hand*, awaiting a favourable opportunity.

He is like a man wishing to use a telling phrase, who waits for an opportune moment, follows the conversation, and directs it, and while speaking never ceases to have the words he wishes to use on the tip of his tongue.

But the most lively repartee loses its effect if it just misses its point; similarly the most cunning thrust cannot succeed unless it is delivered at the right moment. If the attention of the fencer is relaxed for a single instant ; if the muscles which have to deliver the blow cease for a fraction of a second to receive a latent stimulation from the brain, the fencer no longer has his movement "in his hand." And if, at this moment, he has an opportunity of delivering the thrust he has prepared, he finds that his muscles are no longer ready to obey instantaneously the order of the Will, the movement has not the suddenness and readiness which are needed to ensure its success.

It is only at the price of most fatiguing efforts that a fencer can thus keep his muscles alert, and ready for action, all the time that he is hindering them from acting till the right moment comes.

The Baron de Bazancourt * has pointed out a way of divining the favourite parry and thrust of an adversary, the one he has *in his hand*. He advises the pretence of a very lively attack by extending the arm and thrusting the body vigorously forwards, keeping up such a defence as not to be exposed to a thrust. The result of this false attack is to call forth an instinctive manifestation of the movement which the opponent had prepared. The muscles of the arm, which for some minutes were undergoing an intense work of latent co-ordination, spring into action, through an involuntary movement to turn away the point of the adversary's sword, although this

* *Bazancourt.* Les Secrets de l'Epée.

never reaches its destination. His foil describes in the air a rapid evolution which makes it possible to see what movement the fencer had in his mind.

The complicated movement which is thus involuntarily produced was prepared in the muscles of the arm, as the phrase which an actor has to use is stereotyped in his brain ready to be spoken. Just as the fencer who is too impressionable will allow the inopportune escape of the long premeditated movement, so an excited actor does not always await the end of the speech he has to answer before beginning the reply with which his mind is occupied.

The work of latent co-ordination which we have endeavoured to analyse recurs in all the exercises which imply a contest, fencing, single-stick, boxing; and to get an exact idea of the expenditure of force in such exercises we must not merely think of the energy of the muscular movements, but must also take into account the expenditure of nervous energy.

By the side of the muscular force used in producing the movement we must further write down the nervous force expended in shortening the time from the moment when the movement is *willed* to that when it is performed; besides the *motor stimulation* which is outwardly translated by a muscular contraction, we must take note of the *latent stimulation* which leaves the muscle in a condition of apparent repose, but which prepares it to respond instantaneously to the call of the will.

If we wish to express this conclusion in a manner which is less scientific but more impressive, we may say that these exercises are performed rather by the nerves than by the muscles.

Hence result the very peculiar effects of these exercises on the nervous system.

Every one must have noticed that after a difficult fencing-bout the fatigue he experiences seems disproportioned to the quantity of work he has performed. The fencers who seek for "readiness of blow" make no very violent movements; their play is sober: they watch more than they act. But they are much more tired by their attentive immobility than novices who gesticulate and jump about, performing all kinds of fantastic movements.

In fencing, the expenditure of force consists less in the performance of muscular actions than in their preparation.

Fencing is therefore the type of the exercises which fatigue the nerves more than the muscles.

If beginners say that they at first experienced pains all over the body, this is because stiffness is inevitable after any unusual exercise. But an experienced fencer never feels the bruising of the muscles which always follows exercises of strength. On the other hand, he cannot escape, after a difficult bout, a kind of temporary collapse, a characteristic prostration which we may call *nervous fatigue.*

The sensation of nervous fatigue is very different from that experienced after great labours which merely need an expenditure of material force, and after exercises which make the muscles work rather than the nerves. This sensation, which when once experienced is not forgotten, is difficult to describe, as are all fine sensations. If we try to give an idea of it by comparing it to a well-known sensation, we may say that it resembles the psychical prostration which follows any sustained effort of the will, as when, for instance, we have long striven against submitting to the will of another, or when we have energetically directed our attention to the solution of a difficult problem.

Nervous fatigue shows variations under different circumstances and in different constitutions. It is usually characterised by a kind of prostration and temporary depression, but it may also show itself by a transient excitability similar to that which is observed in certain enfeebled persons, and which doctors call a *condition of irritable weakness.*

This peculiar form of fatigue which follows exercises demanding much nervous work, is due to the disturbances undergone by the nerve-cells which preside over voluntary motion, just as intellectual fatigue is due to increased activity of the cells which are concerned in mental work.

Now, these two classes of cells are situated in the grey matter of the brain. It is then in reality the brain which supports the fatigue following exercises needing a great expenditure of nervous energy.

For this reason, fencing is unsuitable to men who study, and equally so to children who work their brains to excess, and it is the last exercise we should advise for very excitable temperaments, unless we have to provide food for unoccupied brains, for unquiet spirits whose activity consumes themselves, failing better occupation. In such cases fencing may become a precious derivative, by absorbing, as would mental work, the excessive nervous force which was tormenting the inactive mind.

Fencing, like all exercises which produce disturbances in the nervous system, is a most valuable exercise to persons who wish to get thinner. Among the most important functions of the nervous system is that of regulating nutrition; so we see all fatigue borne by the nerves, all excessive expenditure of nerve-force lead to diminished energy of the process of nutrition and favour the opposite process, thereby causing loss of weight.

Psychical disturbances, sustained emotions, through the waste of nervous energy which they occasion, hinder the nutritive functions, and lead to loss of weight. It is by an identical mechanism that the same result is produced after exercises needing a great expenditure of nervous energy. It is curious to see how animals whose mode of life necessitates movements similar to those of fencing have the privilege of escaping obesity.

Have you ever enquired how it is that cats can combine with their proverbial idleness such great agility? Muscular inaction leads just as much in other kinds of animals as in the human species to obesity; the dog which does not hunt, the horse kept in the stable, become fat and sluggish. Wild animals even, if kept in a cage, where they are forced into the repose of domestic life, very rapidly lose their slenderness of figure and their ease of movement.

Why does the cat escape the ordinary law, and why, in spite of the fact that it rarely moves, does it seldom become fat as does a dog or horse under similar circumstances? It is because its immobility is not that of inaction, and its nerves are working while its muscles seem at rest. Like a fencer waiting the moment to attack, the cat is constantly ready to spring. It is always watching something; a rat, a fly, or a joint of meat. A drawing-room cat only makes three or four springs in the course of a day, but each of them has been preceded by two or three hours of *latent* work. When we believe that the animal is engaged in a happy dream, it is meditating a capture, calculating the distance of its spring, and holding its muscles in readiness for anything that may happen. Hence it is never taken by surprise. If a little bird escapes from its cage, it is caught and eaten in three seconds. The cat has been watching it for a week; when it seemed asleep, it was lying-in-wait.

CHAPTER V.

THE WORK OF CO-ORDINATION IN EXERCISE.

Difficult Exercises—Skill in Exercises—Circling the Trapeze—Apprenticeship of Movements—Precision in Muscular Actions—Office of the Brain and of the Psychical Faculties in the Co-ordination of Movements—A Dancing-lesson—Muscular Education—Economy of Muscular Force and of Nervous Expenditure with equal Mechanical Work—Improvement of the Muscular Sense—St. Vitus's Dance—Hygienic Use and Importance of Difficult Exercises—Persons who should Refrain from them—Error usually Committed in the Choice of an Exercise.

THE will is not the only faculty of a psychical order which is concerned in the performance of movements; its office is limited to determining the muscular action and stimulating the muscle; but other factors must come into play to regulate, direct, and measure muscular actions.

Every movement needs the intervention of a great number of muscles, and each muscle must contract with a definite force in order that the whole work may lead to a precise movement. We call work of *co-ordination* the operation whose object it is to choose the muscles which must participate in the movement, to regulate the respective efforts of each of them, by distributing exactly that quantity of nervous energy which is necessary to produce a contraction neither too weak nor too strong. This work is performed by the brain.

We call those exercises *difficult* which need rather a clever co-ordination of movements than a great quantity of work. Riding, fencing, gymnastics with apparatus, are difficult exercises and need more skill than strength.

I.

Seeing with what ease the most complicated actions of ordinary life are performed, we should be inclined to believe that each muscle had its function fixed in advance, and was so connected with the will, that it would be enough to wish to displace a part of the body in a certain direction, in order immediately to find the muscular group on which the duty would devolve. We forget that the most ordinary actions, those which are performed with the greatest ease, have been laboriously learned, and were at first awkward and difficult, before becoming as it were, natural and automatic, through long practice.

Difficult exercises generally need attitudes to which a man is unaccustomed, new movements which his limbs have never before practised. A new apprenticeship is necessary to learn the new muscular combinations. Certain muscular groups which have long been used to act together must be disunited in certain gymnastic movements, whilst in the same effort other groups must be united which have never before been associated. A man who tries to walk on his hands is obliged to seek attitudes which are entirely new to him, and to make in his exercise combinations of movements and balances to which his body has never before been adapted. Whatever a man's strength, he will not succeed at first. All the energy he throws into his muscular efforts cannot make up for his want of practice, for, in the case given, skill is more needed than strength.

In every new movement, in every unknown attitude needed in difficult exercises, the nerve-centres have to exercise a kind of selection of the muscles, bringing into action those which favour the movement and suppressing those which oppose it. The bones on which the muscles act must also be displaced in a direction perfectly adapted to the performance of the required action. for a suitable inclination of these levers will favour the action, while an unsuitable one may render it impossible. Finally, all the parts in action, the limbs, the spine, or the pelvis, must execute with precision certain displacements relatively to each other whose resultant is an attitude favourable to the performance of the exercise.

When we endeavour for the first time to perform a hitherto unknown movement, it seems at first that our muscles, so docile in the ordinary actions of life, have become rebellious to the orders of the will. When the muscles finally obey, the bony levers in their turn seem to refuse to move in the desired direction, and the body, notwithstanding our most violent efforts, will not assume the attitude we wish.

There is a well-known gymnastic movement called *circling the trapeze.* Children who have once learned it can perform it with the greatest ease, and it needs a very slight expenditure of strength. It consists in hanging from the bar of the trapeze by the hands, and then making the legs and body pass right over the top of the bar, continuing the movement of revolution until the body has returned to its former position.

We may defy the most robust and most active man to perform this movement the first time he tries.

When he has seized the bar in his hands, the novice who attempts to imitate his teacher finds himself greatly embarrassed. He does not know how to give to his trunk the movement necessary to make his legs pass round the bar. At this moment, amidst his muscular efforts, the would-be gymnast is evidently making cerebral efforts: first he tries one muscle, then another. If he examines his own sensations he will find that he is performing work of a psychological order; his nerve-centres are seeking the solution of a problem which may be thus formulated: What muscles must he contract to make his trunk change from the vertical to the horizontal position? The answer to this question is not usually found till after many trials; but it is almost a surprise when the problem is solved, and the movement is at length performed. We do not feel that we have made a greater effort, but that we have made an effort of a different kind to the previous ones. The will, after trying unsuccessfully several muscular groups, has at length been able to group together those which were really suitable for the production of the desired effect.

He is like a man who, having long sought the mechanism for opening a secret door, at length puts his finger on the right knob and relaxes the catch.

The analysis which we have just made has allowed us to see one of the kinds of work of co-ordination: the performance of a new movement. But the work of the nerve-centres in difficult exercises does not end here. Besides the apprenticeship of movements which are unknown, there is the improvement of already known movements.

Many exercises need very great precision of movements. We have no longer to choose the muscles which shall act; but we have exactly to determine the intensity of their contraction, in order that the limb they move may neither fall short of, nor overshoot, its mark. We must adapt the intensity of the muscular effort to the distance to be traversed; or else the direction of the movement has to be more precisely determined than even its distance.

All the exercises of skill need this work of adaptation of movements to determined distances or directions. Fencing, boxing, single-stick, quarter-staff, need a perfect weighing of the forces *composing* the movement, for the *resultant*, that is to say, the final direction of the arm or the leg, must be exact within a few millimetres.

We call work of *co-ordination* the operation the aim of which is thus to regulate the intensity of the respective efforts of each muscular group, distributing to each muscle the quantity of nervous energy necessary to obtain a contraction which is neither too weak nor too strong.

This work differs greatly from muscular work properly so-called, and rather resembles an intellectual operation than a material action. It needs that most of the psychical faculties and the most delicate parts of the nerve-centres should come into play. We cannot estimate this by the dynamometer, but we must take it into account if we wish exactly to appreciate the force expended by the worker.

An example chosen from among the commoner phenomena of gymnastics may show us the diversity of the intellectual faculties brought into play in the work of co-ordination.

A clown is about to jump from the ground on to a narrow platform of considerable height. Watch him preparing his movement. He remains motionless for an instant, as if hesitating; his lower limbs are alternately flexed and extended several times, rehearsing the violent movement he is about to make. He is calculating the effort necessary to reach the platform without passing beyond it. The greater the precision needed in the leap, the more apparent is this kind of preliminary repetition, which is the translation, to the eyes of the spectator, of the work going on inside the acrobat. Measuring the distance with his eye, he is estimating the effort necessary to traverse it, and is determining the degree of contraction which he must give to his muscles.

The sensibility of the muscles and of neighbouring parts, such as the nerves and the skin, give to the leaper an exact idea of the intensity of the contraction he is preparing, the memory of an effort which he has often made to traverse a like distance, allows him, by comparison, to judge of the effort he is about to make; and it is only after this rapid calculation that he makes his spring.

Thus every co-ordinated movement needs the action of three chief faculties: Sensibility, which indicates to us the intensity of the muscular work; Judgment, which enables us to appreciate its probable effect; and Will, which decides on the movement and determines its performance.

Generally, muscular actions are co-ordinated during their performance. We observe this in slow movements. But whenever a movement must be very prompt and very sudden, it must be co-ordinated in advance.

Before performing an action needing at once promptitude and precision, the muscles must undergo a preparation. They receive from the nerve-centres a latent stimulation too feeble to make them contract, but sufficient to keep them, as we may say, on the alert. It is a warning given in order that the motor organ, like a vigilant sentinel, may do its duty at the first signal.

It is only at the price of this constant intervention of nervous energy that instantaneous movements can be performed with just measure and perfect precision. If a muscular action were at once very sudden and entirely unforeseen, it would have a character of *disorder*, and would be ill-adapted as regards intensity and co-ordination, to the circumstances which called it forth.

A horse frightened by an unexpected explosion wishes to make a bound to run away, but its muscles are unprepared, its limbs cannot instantaneously assume the desired direction, and instead of springing, the animal falls down.

We may describe in one word the character of difficult exercises from a physiological point of view, by saying that they need above all work of co-ordination. This has for immediate effect an economy in the expenditure of force, through regulating the work of the muscles, through demanding from each of them the exact quantity of work which it ought to perform in the exercise, through suppressing useless contractions, through giving to the bony levers the most favourable direction for the performance of the movement.

The faculty of co-ordination, like all physiological faculties, rapidly improves with practice, and there results great ease of work in a man accustomed to difficult exercises. With an equal expenditure of force a clever gymnast will do more work than an awkward one, or if he wishes, will do the same work with the expenditure of less force.

A man who excels in exercises of skill is a machine whose yield has increased; the work lost is in him reduced to a minimum.

Ease of movement is a quite natural consequence of the practice of different exercises. A movement is easy when nothing hinders or opposes it. The skilled gymnast especially excels in suppressing every muscular contraction which is not directly favourable to the performance of the movement. In the movements of an awkward man, many muscles have their action paralysed by the inopportune intervention of antagonists. Much of the force which he expends must be employed in overcoming the resistance which his own muscles oppose to his movements. An inexperienced swimmer expends force enough to move a heavy boat, but he only swims a few metres before he is exhausted. His disordered efforts come from a useless contest between the extensor muscles which should perform the movement, and the flexor muscles which awkwardly hinder it.

A man must himself have practised these exercises to understand the important place of the faculty of co-ordination. If there is apprenticeship of unknown movements, there is also improvement of known movements; there is method in walking, method in running, method in raising weights with the expenditure of as little force as possible; a slight movement of the shoulder or elbow, a curving or straightening of the spine are movements which, though imperceptible to the spectator, may sometimes diminish the work by one half. There is only one way of understanding all these refinements of movement, and that is to perform them in person. We then understand that in the most insignificant muscular actions there are numerous variations which onlookers cannot recognize. By practice we are able to choose amongst these difficult proceedings and we naturally adopt the one which represents the greatest economy of force.

It is thus that in the end we can perform, without fatigue, exercises which at first seemed most fatiguing.

The dominant feature of these difficult exercises, that which it is important to bear in mind in the therapeutic application of exercise, is that their difficulty diminishes in proportion as they are practised. So their effects are very different when they are performed by novices, or by men already broken in to the exercises we advise. Certain athletic exercises which need at the outset a great expenditure of nerve-force, are performed, after a certain time, with marvellous ease.

Riding is an exercise which shakes and wearies the beginner: it is very moderate exercise for an experienced horseman. Rowing needs a certain apprenticeship, the longer because it is often practised in frail boats in which it is difficult to balance, such as the skiff and the canoe; but after practising for some time, nothing is needed but plenty of muscle. The same man who at first was exhausted by half-an-hour at the oar, will in six weeks' time row a whole day without fatigue.

The lessened fatigue in exercises which are diligently practised, comes, in the first place, from a more intelligent use of the muscles, from which the skilled athlete gets much work with but slight expenditure of force. There is another reason for feeling less fatigue, because less effort is required from the nervous system for the coordination of better known movements. Work which at first needed the constant intervention of the conscious faculties is later performed without any apparent cooperation of the will; it has become automatic. We must not compare the effects of an exercise a man is learning with those of one which he knows. Dancing is an amusement: learning to dance is mental as well as physical work.

We have before our eyes the picture of a dancing lesson taken by one of our best friends, a distinguished oculist, who, at the age of thirty years, wished to learn the polka. It was most curious to see how the contraction of his face indicated an extreme tension of all his faculties. He was isolated by his thoughts from all his assistants, concentrating the whole power of his will on his legs which refused to follow the rhythm. It was a true combat amongst his undisciplined muscles, and his forehead was bathed in sweat. Never, he afterwards informed us, had a cataract operation caused him a like cerebral effort.

II.

The first benefit derived from the practice of difficult exercises is, then, in the education of movements. Everyone has noticed how rapidly gymnastics diminish the awkwardness and clumsiness of the man who practises them. The recruit who has been used to rough agricultural labours becomes rapidly more *polished*. His muscles, hitherto used to slow obedience, in order to perform their easy movements with more strength, are obliged to obey with precision and rapidity. They undergo a discipline to which they are strangers, and perform an apprenticeship which makes their action more prompt and easy.

If we consider the details of the application of difficult exercises, we meet certain patients for whom they are strongly indicated: these are children suffering from chorea. In this disease the patient has lost control of his muscles. Involuntary movements disturb him from morning till night, in spite of all his efforts to remain motionless, and on the other hand his voluntary movements are beyond direction and control. The patients upset things they touch, they wriggle and twist when they try to walk, and have, in a word, neither precision nor moderation in their muscular actions.

Chorea, or St. Vitus's dance, gives us the opportunity of studying persons whose power of co-ordinating movements has disappeared. To re-establish discipline in their insane muscles there is nothing better than these exercises, every movement of which needs a severe control on the part of the nerve-centres.

But, except in certain very special cases, difficult exercises have little medicinal application. They may be a useful pastime, and may become a wholesome passion able to protect a young man from dangerous temptations: they can give to a man a feeling of self-confidence, for they are useful in defence of the person;

they may finally turn a lout into an agile and supple man, but they will never make a weak man into a strong one.

Every exercise tends to modify the system in a sense favourable to its own performance, and to create types best fitted to accomplish it. This is a consequence of the physiological law in virtue of which function makes structure. It is enough to know the type of structure which is most suitable to success in any exercise to conclude that the practice of such an exercise will have a tendency to modify in the direction of such a type the constitution of the individual who gives himself up to it. Exercises of strength tend to render a man more massive, those of speed to render him lighter. We may find between animals and men analogies of structure which correspond in a striking manner to analogies of work. The porter and the wrestler are built like the ox and the cart-horse ; the prize-fighter resembles the bull-dog. If we enquire the results of difficult exercises, we find a striking resemblance between a man who practises them very much and the animal which excels in them ; the acrobat is very like a monkey.

This is the most striking result of difficult exercises: they tend to make movements freer, and the performance of work more easy. But just because of the economy of force which results from the skill acquired, they cause less than others an association of the great functions of the economy in the muscular work. By economising the force expended, they tend to diminish the expenditure of heat, to reduce as much as possible the intensity of the combustions and the production of carbonic acid which results from them. In this manner the respiratory need is but little increased, and there is no tendency to the production of breathlessness. For the same reasons, the circulation of the blood is not quickened nearly so much in exercises of skill as in exercises of strength and of speed. Difficult exercises influence very little the activity of respiration and circulation.

On the other hand, these exercises have peculiar effects on the nervous system which are to be explained by the very active intervention of the functions of innervation in the coordination of movements.

If we consider them from a purely hygienic standpoint, we may say that difficult exercises are far less useful than exercises of endurance or exercises of speed. The cases in which the physician will prefer to prescribe work of coordination rather than work of strength are very rare.

Increased fineness of the muscular sense, and great dexterity of movements may have their value in certain circumstances of life. It is no doubt sometimes of great practical value to know how to use a sword ; it is precious in case of fire to be able to climb a long slender cord like a monkey : it is agreeable to have on all our movements a stamp of ease which makes all bodily attitudes graceful. But hygiene has a very different point of view. The body needs for complete development that the most important parts of the human machine should act vigorously. Now, exercises which develop dexterity tend to throw the greater part of the work on the most delicate parts of the human system. They lead to economy in the expenditure of muscular force, thanks to supplementary work at the expense of the nerves and the brain.

In difficult exercises all the psychical faculties associate in the work of the muscles. Hence arise the most characteristic conditions of difficult exercises : they need brain-work. Judgment, memory, comparison, will, such are the psychical factors which preside over their performance. The cerebrum, the cerebellum, the sensory nerves, are organs whose very active concurrence is indispensable.

Persons whose brains have already been heavily taxed by mental work are not then those to whom difficult exercises are suited.

How indeed, can we expect that the nerve-centres will gain repose, and the cerebral excitement be calmed under the influence of an exercise which brings the encephalon and the whole nervous system into action? This is however a frequent error. Difficult exercises make up three-fourths of athletics. All the exercises performed with apparatus need a prolonged apprenticeship. The trapeze, the rings, and the horizontal bar are the terror of certain novices who torture—not their muscles, but their brain—in order to succeed in performing a difficult movement, which in the end, when they have learned the trick, needs little work.

Too much nervous work and too little muscular work! This is the reproach which clings to most of the exercises which need a long apprenticeship, and which are those most practised.

CHAPTER VI.

AUTOMATISM IN EXERCISE.

Movements Performed without the Intervention of the Brain—Decapitated Animals—A Curious Spectacle Invented by the Emperor Commodus—Organs which Perform their Functions Automatically—Unconscious Movements—Office of the Spinal Cord—Conditions of Automatism in Exercise—Influence of Rhythm; Movements with a Cadence—*Dancing* Tunes—Influence of Apprenticeship—Necessity for Absence of Effort in Automatic Movements—Regularity of Automatic Actions—A Personal Observation: Automatism in Rowing—Persistence of Automatic Actions—"Memory" of the Spinal Cord—How Different Paces are Created—Tenacity of Early Muscular Habits—Quickness in Fencing—Race Horses Trained too Slowly—Effects of Automatism in Exercise—Economy of Voluntary Nervous Energy—The Brain supplemented by the Spinal Cord—Repose of the Psychical Faculties—Superiority of Automatic Exercises in Cases of Cerebral Fatigue.

WE have tried to show in the preceding chapter how the brain and the psychical faculties can play an important part in bodily exercises. It remains for us to show here that muscular work may sometimes, on the contrary, be performed independently of the brain and without the intervention of the will.

We must first recall the fact that the brain is not indispensable to the performance of certain movements. The spinal cord suffices in certain cases to throw the muscles into action, for it is a *nerve-centre*, and consequently a focus of independent motor activity. But the movements due to the unaided action of the spinal cord have a peculiar character: they are involuntary. The will in fact has a direct action only on the cells of the brain, and cannot influence the independent activity of the spinal cord. This latter is only excited by *reflex action.*

In reflex movements the will is no longer the stimulus of the muscle: the latter contracts under the influence of a sensory impression.

Let us suppose that an afferent nerve is aroused by a powerful sensation. The excitement is conducted by the nerve-fibre to a central cell in the spinal cord, from which a motor nerve arises. This cell is at once the termination of the sensory nerve and the origin of the motor nerve. It may happen that the sensory impression, instead of travelling towards the head to awaken the conscious faculties, stops in the motor cell of the spinal cord. The latter then sends it on as a motor stimulus to a muscle. The impression is *reflected* in the motor cell of the spinal cord, as the sonorous waves of the voice are reflected from a wall and give rise to an *echo.* We may say without straining the analogy that a reflex movement is the echo of a sensory impression.

In general, reflex movements are very simple and seem to be regulated by the intensity and duration of the stimulus which excites them—as often as we pinch the foot of a decapitated frog, so often is there a slight flexion of the limb—but it may happen that reflex movements are more complicated, and that a single stimulus gives rise to a whole series of muscular actions. It then seems that a simple impression awakens in the spinal cord the memory of a great number of movements which have often been performed; just as a single word will awaken in the brain the memory of a whole series of ideas. Thus the contact of the foot with the ground will produce the whole series of the movements of walking. The living being can then walk, and even run, without his brain taking any part in the muscular action.

A fact of Roman history, reported by Mosso in his book on "Fear" gives us a curious proof of the automatic power of the spinal cord. The emperor Commodus gave to the people of Rome a spectacle which was much appreciated. He let loose in the circus ostriches which were excited to run, and, when they were at full speed, their heads were cut off with spears with a semilunar end. The decapitated animals did not fall at once, but continued their course to the barriers of the circus.

What we observe in a decapitated animal running, gives us a faithful picture of what is going on in an absent-minded man whose legs automatically perform the movements of walking, while his brain is otherwise occupied than in the action he is performing. In automatic movements what happens is that a series of reflex actions are substituted for actions which were at first voluntary. The brain, after having combined a movement, and determined its rapidity and rhythm, seems at the end of a certain time, to delegate its powers to the spinal cord ; it little by little loses its interest in the performance of the action, and only comes into play when some new and peculiar circumstance demands a change in the direction, the energy, or the speed of the movements.

I.

Automatism is the faculty, possessed by certain nervous elements, of putting the muscles in action without the intervention of the will. Many organs of the body have the power of working automatically ; the heart for instance has movements over which we have no control ; the frequency of its beats is independent of our will.

Automatism is not however always absolute, and many organs can, according to circumstances, obey the orders we give them, or on the other hand, move without our being aware of the fact. Thus we breathe involuntarily even when asleep, but we can at will quicken, slacken, or suspend the respiratory movements.

The movements of the muscles of animal life may present, like those of organic life, an automatic character. The limbs and the body move when we are asleep without the intervention of the will, and in the waking state numerous complicated actions are performed unconsciously. A man much occupied in thought will get up without thinking, walk to and fro without noticing it, and perform absently numerous movements of which he has no remembrance. These are automatic actions.

The movements of walking are, of all muscular actions, those which most easily become automatic. Everyone must have noticed how easy it is for the brain to be otherwise engaged and to take no part in the work of the legs when we are walking; we can discourse, reflect, and even compose verses while walking. It will, however, be difficult to help thinking of the muscles in action when circling the trapeze, or fencing. The more difficult an exercise, the more marked the intervention of the will, and the more mental concentration is needed in its performance. But the exercises which were most difficult at first, come in the end to be performed automatically by practice. All the horsemen who pass by, rising so gracefully in their stirrups at each step of the horse, perform this movement without giving it the least attention, and surrendering their bodies to an entirely automatic movement. If you wish to know how their brains were exercised when they were learning to rise in their stirrups, watch a novice out for a Sunday ride stiffly perched upon his hired hack, endeavouring in vain to "identify" himself with the movement which jolts him, and bearing witness, by the contraction of his face, to the profound mental strain to which he is subject.

The first condition needed for an exercise to become automatic and to be performed without any effort of attention, is that it should be perfectly known, and that its apprenticeship should long ago have terminated.

That an exercise may be performed without the intervention of the conscious faculties, several other conditions are necessary, and in the first place the absence of *effort*. We know that effort is a contraction of the whole body, whose object it is to compress energetically all the bones of the skeleton, in order to form of these various movable pieces a rigid whole, able to give a solid point of application to the muscles in action. It is impossible to preserve perfect freedom of mind when making an effort. The muscles, obliged to contract with all possible energy, seem to turn to their advantage cerebral nervous energy.

A man who puts his whole strength into a movement of any kind feels himself completely absorbed in his effort, and loses temporarily the consciousness of what is going on around him. If some one speaks to you at the moment when you are trying to measure your utmost strength with a dynamometer, you only preserve a confused recollection of the words which fall upon your ears, your conscious faculties were otherwise occupied and were distracted by the effort: so true is it, that mental actions and muscular actions, although so different in their essence, are often performed with the aid of the same instrument. It seems that the brain, an instrument of muscular as well as of mental work, is engrossed by the muscles when the latter have to employ their whole strength; hence thought has not free play, and cannot be as clear as usual. This taking possession of the brain by the muscles explains the usual want of intelligence of athletes and of men who do heavy work. The brain of a man who has made too many muscular efforts is a blunted tool which is no longer fitted for mental work.

There are then two essential conditions that muscular work may become automatic; these are long practice in the exercise performed, and moderation in the muscular effort it demands.

There are many other circumstances which favour automatism, and allow work to be performed without the intervention of the will. The subject has not been as yet methodically studied, nor has any one hitherto endeavoured to deduce from this curious phenomenon of automatism, the practical conclusion which would be valuable in considering the hygienic application of muscular exercise.

There is a fact of observation which is difficult to explain, but the truth of which every one will admit; this is that regularity of movements tends to make work automatic. In a man who has for some time been walking at a uniform pace, the conscious faculties no longer preside over the movement, the brain is no longer in command, the muscles obey a series of reflex stimuli which start from the sensation produced by the alternate setting down and raising of the foot. The more regular the reproduction of the sensation which determines the reflex action, the more exact is the work of the automotor mechanism which determines progression. Every one has noticed the influence of rhythm on movements. There are musical airs which "carry us away"; their well-marked cadence regulates the movements.

The sensation which strikes the ear becomes the starting-point of reflex actions which lead to alternate movements of the legs.

Walking, which we may consider to be the type of automatic exercises, needs however a cerebral effort as soon as it is performed under circumstances which make it irregular. Every walker must have noticed how fatiguing it is when we have to "choose our steps." When we pass from a fissured and rocky path to a well-made high road, we feel great satisfaction, and the work diminishes by one half. However, if we analyse the exercise, we see that walking on the smooth surface does not lessen the muscular work, but that it no longer needs the superintendence of the brain. On the rough road the brain must watch with a vigilant attention every movement of the legs. According to the irregularities of the road, we have to lengthen or shorten our pace, to place the foot precisely on a stone which offers a solid support, to avoid a jagged projection or a puddle of water. It is nothing but walking, and walking probably more slowly than on smooth ground, but it is no longer unconscious exercise, and the brain must not leave the muscles to their own guidance under pain of a false step and a fall. On the high road the conscious faculties may be dormant as far as the exercise is concerned; here to the work of the muscles is superadded a work of direction and control on the part of the brain. It is to this additional work that the excessive fatigue is due. Walking, in becoming irregular, has lost its automatic character, and needs, for an equal quantity of muscular work, a greater expenditure of voluntary nervous energy.

How are we to explain this mysterious influence of regular alternation of movements on their automatic performance? No physiological explanation has hitherto been given, but numerous practical applications are daily made. The importance of cadence and rhythm in facilitating movements, and in diminishing fatigue by relieving the brain of the care of directing the muscles, has always been understood. Music and dancing have always been associated. In military manœuvres the drum relieves the foot soldier from the necessity of attending to the movements of his legs; he keeps step in spite of himself.

If rhythm and cadence tend to produce automatism in movement, it is curious to notice how the impulse once given to the limbs is regularly and uniformly repeated throughout a long period of time. When the performance of the muscular action has once been handed over to the automatic powers of the system, this action tends to remain always at the same measure, to be performed with the same speed. If the exercise is prolonged, the last movements are exactly like the first.

I have quite recently been able to observe on myself this remarkable tendency of unconscious movements to remain regular in the absence of all cerebral guidance. Setting out from Limoges with a friend in a rowing boat, we descended the Vienne to the Loire, and down the Loire to its mouth. Rowing was a sufficiently familiar exercise to us to be performed without any tension of the brain, and as far as I was concerned my mind was completely freed from any attention to changes of stroke, the guidance of the boat being confided to my friend, an experienced oarsman.

We were double sculling. Many times during the twelve hours of each day's work I completely forgot the boat and the Vienne; many times my wandering imagination carried me a hundred leagues away from my companion, the rhythm of my stroke being always, however, in perfect unison with his. Our sculls always carried back, and then pulled forwards through the water, struck the surface of the water the same number of times per minute, always plunged to the same depth, always the same height above the water in the backward movement of the sculls.

I several times tried to ascertain if this perfect agreement were not due to the more sustained attention of my companion who could have, sculling bow, made his movements follow mine, increasing or diminishing the frequency of his stroke according to mine. But closer examination showed that it was really the constant uniformity of our movements which ensured their agreement. In fact many times we separately counted the frequency of our strokes, and while we were attending to them, during serious conversation, animated discussion, or profound reverie, the result of our obervations was always the same: nineteen strokes per minute.

Thus, after a certain time, this exercise of rowing, which had been very laborious to learn, had become as it were, stereotyped in the motor organs, and was performed automatically. Further, during the whole voyage, the pace we had adopted at the outset was maintained without change. Every morning of the nine days which the journey lasted, the muscles resumed their regular movement of the evening before, contracting nineteen times per minute with the regularity of a clock, without any intervention of the conscious faculties. Our "stroke" had become automatic.

Thus the brain, the organ of thought, can cease to preside over a movement without the latter losing its regularity and precision. When a movement has often been repeated it seems that the spinal cord retains its form and mode of performance, as the brain retains the sound of the articulation of words. How can a complicated movement, like that of rowing, be thus impressed on the spinal cord? It is difficult to say: but who can say how words, phrases, entire pages, are written in the brain, and how is it that we are able to repeat, without a single mistake, long passages of verse learned more than thirty years before?

We must then be content to accept the well-established fact, and to draw from it legitimate conclusions. We cannot refuse to admit that the spinal cord has a memory. This organ, which is primitively a conductor of movements initiated by the brain, remembers these movements and can repeat them under certain conditions, without the will intervening otherwise than to open and to close the series of movements. The memory of the spinal cord has for its result the persistence in an automatic condition of a movement often practised.

But the spinal cord does not merely keep the remembrance of the frequency of an often-repeated action; it also preserves faithfully the memory of the measure, the rhythm and the speed with which it is performed. It is from this persistence of impressions in the nervous system due to an often-repeated action, that the habitually slow or fast gait of each individual results.

We become accustomed alike to slowness and to vivacity of movements, and often both the speed and the heaviness of tread are the result of a habit contracted in childhood of which we do not find it easy to free ourselves.

Automatism marks with an indelible seal the first muscular actions performed, as memory stamps in a young brain the first phrases learned by heart.

When a horse has begun to gallop slowly it is difficult afterwards to urge it to more rapid movement. In the great racing stables they use very young boys, who can ride sufficiently well, in training horses. With this light burthen the horse can be urged, at the first gallop, to a pace which would be impossible if it had a man on its back, instead of a child. Trainers attach great importance to these early habits of movement, and we have heard a most experienced racing-man deplore the impossibility of procuring in the country these boys as light as monkeys. Under them the horse acquires the habit of a gallop which discomforts and discourages, at the very outset of the race, horses which have been trained to a slower movement.

Fencers, says Bazancourt, will never have quickness in fencing if they wait too long to regulate their movements, for this makes their hands slow.

It needs an effort of will to oppose an action which has become unconscious and to change an acquired pace. If the muscles are abandoned to their mechanical impulse, they always return to the rhythm which is provided for them automatically. The horse early accustomed to a slow movement makes a supplementary expenditure of nervous energy when we wish to hasten its normal gallop; and we must not attribute the increased fatigue solely to the increased work needed to gallop faster. In fact the animal would also experience this nervous discomfort due to the effort needed for an unusual co-ordination of movement, if compelled to slacken its gallop much below the normal.

In this manner we can explain the fatigue experienced by a man used to walk fast, when he is obliged to accommodate his pace to that of a slow walker. The discomfort felt either on exceeding or falling below our ordinary pace are alike due to the intervention of an effort of new co-ordination in order to adapt to an abnormal rhythm the movements which are ordinarily performed mechanically, without the intervention of the guiding faculties.

II.

When a man performs an automatic movement he makes a call upon the memory of his spinal cord and distracts his attention from the work. When, on the contrary, the movement is new to him, or difficult, or demands a violent effort, the conscious faculties are obliged to enter into energetic action; the muscular sense gives precise indications of the degree of contraction which must be given to the muscles; the faculties which preside over comparison and judgment appreciate what must be added to or substracted from the muscular effort, to give perfect precision to the movement; finally, the will comes into play to give the definite impulse to muscular activity. These are so many factors which increase the expenditure of nervous energy without making the muscle perform any more work.

Automatism in movements economises work of the brain, as memory economises mental work. There are formulæ which shorten mathematical work, by enabling us to dispense with several elementary operations. Similarly, by a series of automatic movements we are able to dispense with the attentive coordination of each muscular action of which the spinal cord has preserved, so to speak, the formula.

If we now enter upon the practical application of the physiological facts we have just been discussing, we see at the first glance the great hygienic superiority of exercises which can be performed automatically. Economy of nervous energy, complete repose of the brain, absolute inaction of the psychical faculties, such are the conditions in which automatic exercise is performed. The work of the human system is then performed by the coarser parts of the machine, and fatigue is first felt by the subordinate agents of movement. The nerve-centres, having taken no part in the work, do not suffer from the discomforts which follow it. Fatigue, after automatic exercises, is purely muscular: it rather affects the body and limbs than the head and the nerves.

Hence it is not difficult to understand the immense advantage presented by automatic exercises when we seek in muscular work a derivative for brains fatigued by intellectual overwork.

We have so far endeavoured to establish scientifically, on a physiological basis, the peculiar characters which differentiate the exercises in which the brain is not concerned from those which need an effort of will and a work of co-ordination. It remains for us to fortify our theoretical deductions by the observation of facts, and for this it is necessary to appeal to the experiences of all those who have practised bodily exercises.

There is nothing which recalls the fatigue produced by learning a difficult exercise so much as that which accompanies the laborious solution of a difficult problem. There is the same strained effort of attention during the work, there is the same cerebral prostration afterwards. In both cases the fatigued man refers the seat of his discomfort to his head. This is because in both cases the brain has been at work.

A man must be a poor observer if he has failed to notice the instinctive repugnance which is felt for difficult exercises by all persons suffering from mental overwork.

Look at a schoolboy before a master teaching him the first elements of fencing. His sullen and cross expression, indicating fatigue and weariness, seems to say: "This is worse than construing!" Let the same boy out of school into the fields and you will see him start like an arrow, his legs carrying him away in a lively run. He will in a few minutes do ten times as much work as he would in fencing practice, but this work is an affair of the legs: his head is not concerned in it. He will come back very hot and breathless, bathed in sweat, but his mind will be freed and his brain rested.

Remember your own college days. Who were the young men who were most ardent in physical exercises, the greatest lovers of the trapeze, the prize winners in the gymnasium? Those whose intellectual faculties had escaped overwork on account of their idleness, those whose cerebral nervous force was not expended over books, which were indeed open before them, but which they did not read.

If opposed observations are quoted they refer to persons equally well endowed in the matter of brain and muscle, and who have as much ease in mental work as fitness for bodily exercises. These are rare exceptions.

There is a general tendency to blame the indolence and physical apathy manifested by students whose more serious studies demand a greater strain of the intellectual faculties. They are told it would be better for them if they used otherwise than in conversations and reveries, the time which is given, grudgingly enough, for the recreation of their overtasked brains. Their masters scold them, and stimulate them to arise from this *far niente* to perform some violent exercise. All the apparatus in the gymnasium are at their disposal: why do they not make use of them?

In spite of the master's exhortations, the pupil whose head has done much work feels little disposed to bring his limbs into action, and he avoids with an instinctive repugnance the trapeze and the horizontal bar. Is this then, as is often said, because he disdains an exercise too childish for the dignity of his fifteen years? Is it not rather because he fails to find in muscular fatigue the pretended derivative able to bring rest to his spirit?

For us, if the child suffering from mental overwork does not feel any desire for bodily exercise, it is because his instinct is sounder than the opinion of his masters: it is because the gymnastics to which he is urged would need an effort, not only of his muscles, but of his brain, already wearied by study.

The importance of care in the choice of an exercise from the point of view of cerebral hygiene has not hitherto been recognized, and people have not thought of availing themselves of the great advantage to be derived from *easy exercises*.

This advantage may be summed up in two words; they produce *muscular* fatigue without leading to *nervous* fatigue. They quicken the blood current, make the breathing more active, regulate the digestive functions, without at the same time needing that excessive activity of the cerebral functions which always accompanies difficult exercises.

No one has hitherto, however, thought of using these precious advantages. No one even takes into account the conditions which may make the degree of difficulty of an exercise vary. No difference is made, in the hygienic application of bodily exercises, between those which are new, and those which a man has long practised; the cerebral work demanded during the period of apprenticeship of an unknown movement is not taken into account.

After a certain period of study, difficult exercises have been learned, and may then become automatic. Their effects will then be very different. Is it not quite a different thing to *amuse* oneself with dancing, from *occupying* oneself with learning dancing? Dancing, riding, rowing, even running, when they have long been practised, need no more brain work than walking, which is above all an automatic exercise.

But for certain bodily exercises the period of apprenticeship is indefinitely prolonged, and the movements need an unceasing guidance on the part of the nerve-centres and the conscious faculties, because these movements cannot be constantly identical, and unforeseen emergencies occur. Fencing can never become an automatic exercise, notwithstanding the tendency exhibited by certain parries and thrusts to become habitual actions and to be performed instinctively; the movements cannot always be performed in the same manner and follow always the same order, for they are subordinated to those of the opponent. Riding becomes an automatic exercise if it is always practised on the same horse, to which the rider accommodates his movements. It needs on the other hand the activity of the brain, and demands a very attentive work of coordination, in cases in which very difficult horses are ridden, which differ very much in character and obedience.

We cannot then regard automatism as a character which will serve to mark off a particular group of exercises. It is rather a mode of performance which most known exercises may assume, when these exercises are performed under conditions which we have endeavoured to determine in this chapter.

To sum up, muscular automatism is a function devolved on the more dependent parts of the nervous system, with the object of economising the work of the brain, considered as the guiding force of the human machine.

Hitherto people have not sufficiently considered, in the various gymnastic exercises, the importance of this economy from the standpoint of hygiene of the nervous system. They have not yet established the very different indications for exercises which make the nerve-centres do much work, and for those which demand but little action of the brain.

These indications are however very formal and clear, and may thus be shortly expressed :—

Whenever the therapeutical application of exercise has for its aim a lively stimulation of the nerve-centres and the performance of brain work, difficult exercises are to be preferred to automatic exercises.

Easy, instinctive exercises, or those which have become familiar through long practice, those in a word which can be performed automatically without needing any sustained effort of attention, are suitable, on the contrary, for persons whose brains must be spared while their muscles are being fatigued.

Prescribe fencing, gymnastics with apparatus, and lessons in a riding school to all those idle persons whose brain languishes for want of work. The effort of will and the work of coordination which these exercises demand will give a salutary stimulus to the torpid cerebral cells. But for a child overworked at school, for a person whose nerve-centres are congested owing to persistent mental effort in preparing for an examination, for such we must prescribe long walks, the easily learned exercise of rowing, and, failing better, the old game of leap-frog and prisoner's base, running games, anything in fact rather than difficult exercises and acrobatic gymnastics.

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