Hilda Ridpath

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FATIGUE

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BY

A. MOSSO

Professor of Physiology in the University of Turin

TRANSLATED BY

MARGARET DRUMMOND M.A

AND

W. B. DRUMMOND M.B. C.M. F.R.C.P.E

Extra Physician, Royal Hospital for Sick Children, Edinburgh
Author of "The Child, His Nature and Nurture"

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TRANSLATORS' PREFACE

PROFESSOR MOSSO needs no introduction to the English speaking public, his work on Fear being already well known through a translation by E. Lough, and F. Kiesow, published in 1896. His study of Fatigue, which is now for the first time translated, deals with a subject of even more general interest and of special importance to educationists.

Although from the nature of things one of the oldest of the arts, only of recent years has education attained the status of a science, and even, yet, many of its maxims are frankly empirical. Based upon psychology and physiology it suffers from all their errors and defects and prospers with their prosperity; hence the application of modern methods of scientific research to the problems of psychology and physiology may be expected to result in important additions to the theory of education. All natural sciences have gone through a period of youth in which their sphere was not clearly defined, their terms were vague and their results uncertain; all of them may be said to have attained their majority when experiment came to the aid of observation, and more particularly when the phenomena considered were compelled to submit themselves to measurement. So elusive are the phenomena that form the subject matter of psychology and much of that of physiology that they might well have been thought beyond the sphere of measurement. Yet of late years, thanks mainly to the impulse given by the wonderful patience and ingenuity of the Leipzig school of psychologists (Weber, Wundt, Fechner, etc.), scores of instruments have been invented to record and measure the vital and mental processes. Of these one of the most interesting and important is Professor Mosso's ergograph or fatigue-recorder, with which instrument he performed the experiments described in the text, on which most of his conclusions are based. Those interested in education have not been slow to see how this instrument may aid them in their special study, and with it various observations have been made on school children with the object of ascertaining the degree of fatigue attending different studies, the time of day at which they can be most profitably pursued, and the best division of the school day as regards play and work.

Professor Mosso's experiments were on adult subjects only, yet his results will be found both suggestive and illuminating by the practical teacher ; the book will not only give him much that is new, but it will give him the experimental proof and the physiological basis of many of the empirical maxims of his science.

Without pretending even to summarize the main contributions of the work to our educational theory, we may perhaps be allowed to call attention to a few points.

The convincing series of experiments in Chapter X, demonstrating the relation between cerebral and muscular fatigue with the suggested explanation, should have a far reaching influence on school curricula. One of the most obvious practical conclusions would be that games or any form of athletic exercise should not be pressed upon children during examination time or any period of special intellectual strain.

Again the experiments recorded in Chapter VII show in a very striking way that what teachers have learned by experience—viz. that short periods of work alternated with play give the best results—has a sound physiological basis.

That a quiet situation is essential for a school is now generally recognised in theory—though unfortunately not always in practice—and the experiment given on page 205, showing how the time of perception is lengthened by noise, gives the proposition the certainty of a mathematical demonstration.

The Herbartian School of Educationists have done good service in laying stress on *Preparation* in the giving of a lesson, and in their practice good teachers have always acknowledged the wisdom of getting the minds of the class in tune at the beginning by the judicious calling up of previously acquired knowledge. On pages 300–1, Professor Mosso gives us the physiological explanation which should enable us to walk with opened eyes on this path on which hitherto a blind instinct, or at most an acquaintance with the working of our own mind, has been our guide.

Such are a few of the practical questions touched upon, but every teacher who takes a scientific view of his work will recognise that the subject here treated has a bearing on all the most important questions of school organization and management, and will find frequent opportunity in his daily round of testing and applying the theories here advanced.

In conclusion it remains only to state that in making the translation we have adhered to the original as closely as possible ; in the case of quotations we have, wherever practicable, consulted the works cited, and taken the passages from them directly. We have to thank Professor Mosso for his kindness in permitting the translation, and in revising the proof sheets ; and we only hope that its readers may find the translation as interesting as we have found the original.

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CHAPTER I

THE MIGRATION OF BIRDS. CARRIER PIGEONS

ONE spring, towards the end of March, I happened to be in Rome, and, hearing that the migration of the quails had begun, I went down to Palo on the sea coast in order to ascertain whether these birds, after their journey from Africa, showed any of the phenomena of fatigue. The day after my arrival I rose when it was still dark, took my gun, and walked along the shore towards Fiumicino. Here and there on the beach were to be seen fires lit by bird catchers in order to attract any quails arriving during the night. Just before dawn I heard shots, and some quails appeared flying very quickly in little groups of four or five. Immediately they alighted I tried to approach as near as possible. They crouched down and waited on the alert. Often they let me come within a few paces; then fled swiftly along the ground. It is said that quails sometimes allow themselves to be caught by the hand, but I cannot affirm this from personal experience, nor can any sportsman whom I have consulted.

By this time it was a lovely morning. A fresh north wind blew towards the sea, but, in spite of the contrary wind, the quails continued to arrive in greater and greater numbers. I believe I never saw them fly more quickly. Meeting a peasant, I walked with him along the boundary walls shutting in the Roman farms. He told me that at the time of the migration he made a round every day in order to pick up the dead quails, and that just along these walls at the foot of the telegraph posts he always found some.

The poor birds, in the eagerness with which they seek the land, do not even see the trees, or at least have not power to slacken or arrest their flight, and dash themselves against trunks and branches with such force that they kill themselves. I accompanied the old man in order to see the number and the condition of the dead quails. We went towards a tower dating from the Middle Ages which was built on the beach near a clump of trees. "That," said the peasant, pointing to the tower, "is one of the places where I find most." And indeed we found three in the moat, of which two were already stiff, while one was still warm. Taking them in my hand and blowing up the feathers, I perceived that they were not wasted. There was still fat under the skin in several parts of the body, and the pectoral muscles were in good condition.

The poor creatures are so exhausted by the journey that their strength is just sufficient for flight. When from a great distance they perceive the dark line of land, they are attracted by the white spots representing houses, and steer for them with such eagerness and impetuosity that they reach them, so to speak, before they have recognized them. I shall show by and by that in great muscular effort and extreme fatigue cerebral anaemia is produced, and that this anaemia may diminish the power of vision. Near a house I met several people, who assured me that many quails dashed their heads against it, because they had not the strength to raise themselves the extra yard necessary to clear the roof.

The quail flies nearly nineteen yards per second, or thirty-eight miles per hour—that is to say, about the rate of an ordinary train.

The journey from Africa to Italy is much easier than at first appears, seeing that from Africa Sicily is visible with the naked eye. The distance from Cape Bon to Marsala is about eighty-four miles. A quail, flying at the rate of 1,115 yards per minute, would require for this journey two hours twenty-one minutes. The distance from Cape Bon to Rome is about 341 miles, and a quail flying in a straight line could accomplish this in nine hours. Thus the shortness of time required for the passage explains why the birds are not much wasted when they arrive.

A Roman sportsman once told me that he used to try sowing in his garden the seeds he found in the crops of quails, and that every year he was interested to find African plants springing up, of some of which he had kept the flowers.

The quail is not a social animal. It leads for the most part a solitary life. Not even at the time of its love affairs does it show any family affection, the male abandoning the female as soon as she begins to sit. Quails do not travel in flocks like swallows or ducks, but each one sets forth on its journey without regard to the others. When they have to struggle against a strong wind at sea, they persevere as long as they can ; then, when they are exhausted, they yield to its violence and end by falling senseless upon rocks or on the deck of some ship. Storms, according to Brehm,[1] plunge them into such terror and confusion that, even after the squall has passed and the wind become favourable, they remain motionless for several days on the spot where they alighted, before summoning up resolution to continue their journey. If a squall does not overtake them, quails cross the Mediterranean without great fatigue, and it often happens that the sportsman finds no quails in a district where he expects them to be plentiful, owing to the fact that the first arrivals have continued their journey, whilst change in the weather has delayed the others.

I have never seen any of them after their arrival resume their flight in order to settle on one of the neighbouring hills. Brehm thus describes the arrival of the quails in Africa : " By keeping watch at a point on the north coast of Africa during the time of the true migration of the quails, one can often be present at their arrival. A dark cloud is seen, low down, fluttering above the water ; it approaches rapidly, getting lower and lower all the time, so as finally to alight just at the extreme edge of the sea. It is the crowd of quails, nearly dead with fatigue. Just at first the poor creatures lie for some minutes as if stunned and incapable of motion ; but this state does

[1] Brehm, *Thierleben, Dritte Auflage*, 1891, vol. v. p. 557.

not last long. A movement begins to appear. One of the first arrivals leaps up and runs quickly along the sand in search of a better place to hide itself. A considerable time elapses before a quail can make up its mind once more to make use of its exhausted thoracic muscles and begin to fly: as a general rule it seeks safety in running, and does not take wing for the first few days after its arrival except in case of absolute necessity. I myself have no doubt but that, from the moment the bird has *terra firma* under it once more, it accomplishes the rest of its journey mainly by running."

De Filippi states that he has seen pigeons in the open sea resting on the waves with outspread wings, and in these birds this was certainly a sign of overpowering fatigue.

Brehm tells us that he has heard trustworthy sailors declare that the quail also, when extraordinarily fatigued, settles on the water and rests for some time, then takes flight once more and continues its route. I have somewhere read that among the birds which are the strongest on the wing, some have been observed at sea bearing on their backs a tired little one, which has thus found safety in a desperate situation.

A well-known testimony to the fatigue of quails is found in the Bible. The Book of Exodus tells how the Hebrews were fed on quails in the desert. The ease with which they let themselves be caught shows how much they were exhausted by their journey.

There are birds which travel more than 9,000 miles every spring from South Africa, Polynesia, and Australia, in order to reach the polar regions ; and in autumn return to their winter quarters in the same way. Every year the martin travels from the North Cape to the Cape of Good Hope, and vice versa.

The migrations of the cranes and storks we see repeated every year ; but how they find their way across mountains and over seas, how from Africa storks and swallows return to their old nesting place, how the instinct which guides them is developed : these are things which we do not yet know.

Of late years some valuable books have been written on the subject. I may mention those of Palmén,[1] Weismann,[2] and Seebohm.[3] Nowadays ornithologists are no longer content to say with reference to migratory birds that they exhibit a marvellous instinct. Palmén shows that the oldest and strongest birds guide the migrating flocks, and that the greater number of those which go astray and lose themselves are young ones of the last brood, or mothers which stop and turn aside to look for their strayed little ones. The adult males rarely lose their way unless they are struck by a storm.

Palmén has published a map showing the highways of migration. The milestones of these long routes are certain places where the birds can rest and find abundant food. That the birds, when they are hatched, can have any innate knowledge of these places, Palmén regards as quite out of the question.

[1] I. A. Palmén, *Ueber die Zugstrassen der Vögel*, 1876, Leipsig.

[2] Weismann, *Ueber das Wandern der Vögel*, Berlin, 1878.

[3] Seebohm, *The Geographical Distribution of the Charadriidae.*

The instinct which the birds possess requires to be educated. Scarcely have they come from the nest when they begin to study their immediate environment. Then they go off in search of food, and the rapture of motion spurs them on as far as they dare trust their memory. Thus their sense of locality and of direction develops rapidly.

When autumn comes they begin their journey south, and if a bird born that year in its impatience goes before its parents and sometimes succeeds in finding the right way, on the other hand it more frequently perishes. This is why, as a rule, migratory birds travel in flocks. It is thus that the young ones learn from the old the formation of the ground, the mountains, the rivers, and the valleys, which are the principal highways of migration. What seems to us a marvellous and blind instinct is only a knowledge of places handed down from one generation of birds to another.

II

In order better to study the phenomena of fatigue and the changes in the organism of birds caused by a long journey, I have had a house for carrier pigeons fitted up in my laboratory. The Minister of War has kindly helped me in my task by presenting me with the pigeons. I take this opportunity of expressing my gratitude to the Government both for this assistance and for the facilities offered me when I was studying the marching of soldiers.

Pigeons do not become good carriers until they have been educated. Not until the third year of their education do they attain their maximum strength and skill, and the greatest perfection in their sense of direction. A pigeon can travel up to the age of twelve years, but after its sixth year its power of resisting fatigue diminishes more and more. Numerous books have already been published on the subject of carrier pigeons—those of Lenzen, Schomann, Chapuis, Puy de Podio, and Gigot may be mentioned—while in 1887 an excellent work appeared in Italy by Captain Malagoli, superintendent of the service of military pigeons. In Belgium three periodicals appear devoted to the subject of carrier pigeons.

I started my pigeon house in 1885 with fifty young pigeons which had never before left their birthplace. These pigeons were sent to me from the military pigeon house at Alessandria, and were of Belgian breed, which is superior to all others in instinct, as well as in strength and speed.

A most important matter in the education of carrier pigeons is to make their stay in the pigeon house pleasant to them. Great care must be taken that they are not disturbed, that they have the kind of food they prefer, and all the comforts and conveniences they can desire. They will thus return more readily to their home, when they find themselves far from it. The instinct which guides them is a kind of homesickness and the firm belief that nowhere else will they be so well off.

When the pigeons are to leave the cot for the first time, a rainy day is chosen; towards evening the window is opened, and the pigeons are forced to go out in front of the house or on to the adjoining roofs. On this first expedition they are timid, and look round them with an air of distrust. They elongate their necks, and appear to be studying the neighbourhood. A few dart timidly on to the roof of the nearest house, then quickly return to the cot. On a repetition of this trial some pigeon, more intelligent than the others, will remain in the air describing great circles, just like a child who feels the impulse to run and play. To teach my pigeons to recognise their home from a distance I had them carried in a covered basket to a place about half a mile from the laboratory. When set free the pigeons rose in the air, described a circle, and then made swiftly for the dove cot. Another day we took them to Moncalieri, then to Asti, then to Alessandria, and thus gradually accustomed them to travel over the whole of northern Italy as far as Bologna and Ancona. We could have trained them to travel over a larger district, but a distance of 300 miles was more than sufficient for my studies on fatigue; and moreover, at every trial many pigeons were lost, as during the first year their sense of direction is poor.

I shall now give an account of some of my experiments.

On July 8, 1890, by the first train, at 5 a.m., we took ten pigeons, each four months old, to Asti. These pigeons had never made a journey, and knew only the roof of the dove cot and the adjoining houses. On the evening before, we had painted their wings red, in order to recognise them easily from a distance, and we painted blue the wings of ten old pigeons which had before travelled from Bologna to Turin.

At 7 o'clock precisely the two baskets were opened at Asti station, which is thirty-one miles from Turin. Immediately on leaving the basket the old pigeons took the direction of the town, which forms a right angle with that of Turin. The young pigeons followed them, but we saw at once that they were remaining in the rear. Above the town they described a circle, and then disappeared. In an hour and a quarter three of the old birds had reached the laboratory. At twenty minutes past nine the trained pigeons had all arrived. Towards noon not one of the young ones had been sighted. At ten minutes past one two arrived together, and a little later a third. It was easily seen that they were very tired, for they alighted on the roof and remained motionless while the old birds, which had made the same journey, were lively, and kept flying round in great circles and cooing.

By ten o'clock only three of the young pigeons had returned. This shows that their instinct is not of much use to them, if they are not trained. Moreover, it could not be very difficult for them to get their direction from the Alps and the hill of Superga, which can be seen from Asti.

Another day I sent ten pigeons, four months old, to Alessandria, fifty-two miles from Turin. Of these not one returned, although the Alps, which surround Piedmont like an amphitheatre, are clearly seen from Alessandria also, whence it should be quite easy to recognize a town like Turin.

It must, therefore, be admitted that adult pigeons alone possess the instinct of direction. It is not true that pigeons can find their bearings only in the country where they have been trained. There are cases known of pigeons bought in Belgium and carried to Italy or Spain in closed baskets, which have succeeded in escaping from the hands of their breeders and have returned to their home. In 1886 nine pigeons brought from the United States were set free in London; three succeeded in crossing the ocean and returning to their home.

The military pigeons which fly between Rome and Sardinia cross the sea in about five hours, and it is certainly one of our most brilliant achievements thus to make our military pigeon houses emulate those of other nations.

Worthy of all admiration is the courage of those birds which, full of faith in the guidance of their instinct, thus set forth to cross a sea without visible shore. It is impossible to see Sardinia from Rome, as the distance between Mount Mario and Mount Limbara is 186 miles. In order to see these two points simultaneously the birds would have to reach a height of about 1,650 yards above sea level. Now it is certain that pigeons never rise more than five or six hundred yards. Hence, when they start on their journey from Rome to Sardinia, they must trust entirely to their instinct of direction, for they can see before them nothing but water.

The legends and history of pigeons are full of poetry. Babylon and Jerusalem were celebrated for their pigeons. At Rome the bird was sacred to

Venus; and the dove was accepted in the Christian religion as the mystic symbol of love. Once a pigeon has chosen a mate, he does not leave her all through life. An osier basket shaped like a helmet or large pear is given them for their nuptials, and in this abode begins the life idyll, so often described by poets.

When I see them in their nest, there come into my mind the beautiful lines of Petronius, which I have written over the doorway of the military dove cot in my laboratory—

> Militis in galea nidum fecere columbae:
> Adparet Marti quam sit amica Venus.

It is indeed a charming sight to see them cooing, circling round one another, raising and lowering their wings, spreading their tails and caressing one another. Very soon the cares of the family begin; from ten o'clock in the morning till four in the afternoon the male bird sits on the eggs, and the female for the rest of the day. Year after year the same pair still make their home in the same nest. My pigeons rear forty or fifty families in the same place; each has its number and its little house fixed to the wall; nor is there any fear of its deserting or changing its cot, so great is the power, so indestructible the bond of its first love. When either females or males are taken from their nests, their eggs, or their young, most imperatively do they feel the necessity of returning to their families. When they are taken a long distance, the fatigue and toil which they endure in order to find their home once more is incredible. One might think they had become blind and had ceased to recognise danger; they care no more for their lives, they are infatuated with love. In search of their own cot they traverse the sea, pass through clouds, brave the thunder, go from one town to another, weakened and starved, faring wretchedly on what they can pick up in the fields; from roof to roof they wander, until at length, after uneasy days and weeks spent in this arduous quest, they arrive panting at their home, station themselves on the nearest roof opposite their own window, and fall down as they gaze, as if their strength suddenly failed and they succumbed to fatigue and exhaustion.

III

When the quail flies it makes a peculiar noise, which the Tuscans call "frulla"—an expression derived from the noise of a winder, or other rapidly turning machine. But it is only birds which move their wings very quickly that produce this sound. Swallows and pigeons fly after another fashion, without making any noise. Who that has seen the eagles on the Alps can ever forget their majestic flight and the slow beat of their wings? In general, it may be said that the smaller a bird is, the less suited it is for flight, and the more it must by rapidity of movement correct the disproportion existing between the weight of its body and the length of its wings.

To the physiologist the flight of birds is a most interesting phenomenon, "and also one of the most mysterious that Nature presents to our view." So says Marey, who is without doubt the greatest authority on the subject of movement. In his two books, *La Machine Animale* and *Le Vol des Oiseaux*, he has treated the questions of terrestrial and aerial locomotion in such masterly fashion that they will always remain models of popular science. No one has gone further than Marey in the analysis of the mechanism on which the flight of birds depends. His investigation of movement, the instruments he has constructed to register it, the novelty and ingenuity of his methods, his application of instantaneous photography to the exact study of very rapid motion, these things mark an epoch in science.

Comparative anatomy shows that a bird's wings are analogous to our arms and to the fore-legs of the mammalia. The muscles which move the wings cover the whole anterior part of the thorax, and are firmly attached to the sternum, which itself attains an enormous development, and which by means of a strong ridge running along it doubles the surface to which the muscular fibres are attached. In man the attachment of the pectoral muscles extends from the collar bone to below the breast. But, although better developed than in other animals, they are very small in comparison with those of birds, in which the weight of the two pectoral muscles is a sixth part of the total weight of the body. This is, however, necessary in the case of creatures whose element is air. Every one knows how fatiguing it is to walk on fine dry sand or on snow. Our feet sink in, and at every step part of our muscular force is used up in finding firm foothold, and in exercising pressure to enable us to carry our body forward. From this we can understand how much greater is the difficulty of moving in air. At every stroke of the wing the air slips from beneath; hence the wing must necessarily be large, and the strokes rapid, in order that the air may offer some resistance.

The rapidity with which birds fly is in truth prodigious. Flying Childers, the most celebrated racehorse that ever lived, in a run of about three miles covered only 15·63 yards per second. The greatest speed ever observed on the Paris racecourse, in a run of two and a half miles, was 15·08 yards per second. And we must remember that the best horse can keep up such a speed for six or seven minutes only, and that after long training. The speed of pigeons is twice as great, being 33 yards per second; for a tolerably long journey it is from 37 to 43 miles per hour. The swallow flies 49 yards per second; and it is fairly well proved that birds can remain on the wing for several days without rest.

That the strength of animals increases proportionately as their size decreases is a fact known to old writers. Haller, in his *Treatise on Physiology*, compares the strength of the London porters with that of a horse, and concludes that the former are proportionately the stronger.

Plateau has studied this subject,[1] and notes that an insect such as the common beetle can drag along a mass fourteen times as heavy as its own body: other insects can drag as much as forty-two times their own weight. The horse can pull twice or thrice its own weight only. According to Plateau,

[1] Plateau, *Comptes rendus*, t. lxi. p. 1155, and t. lxiii, p. 1133.

of two species of insects belonging to the same family, which differ in weight, the smaller and lighter is always proportionately the stronger. This does not depend on the fact that the smaller insect has relatively larger muscles, but on the fact that its muscular contractions are relatively more energetic. An ant can carry a burden twenty-three times as heavy as itself.

In no animal is muscular contraction so rapid or so frequent as in insects. When we hear an insect passing close to our ear, we can mark the great difference in their modes of flying. The butterfly, which moves its wings slowly, makes no noise, just as there are birds which fly quietly without making themselves heard.

The rhythmical vibration of the wings is one of the most important phenomena in the study of movement; and towards this physiologists have turned their attention in order to learn how many times a muscle can contract and relax in a second. The very shrill sound produced by gnats is due to the movement of their wings as they fly. The frequency of such movement is determined by comparing the sound produced by insects in their flight with the notes of the scale. Thus we find that the note of the common bee is *la*, that is, 440 vibrations per second. Then there are differences between the male and the female. In *Bombus terrestris*, the male, which is small, buzzes in *la*, whilst the female, which is larger, buzzes an octave higher.[1]

[1] Lubbock, *Of the Senses, Instincts, and Intelligence of Animals*, I.S.S.

The note of the fly is *fa*, or 335 vibrations per second. Of these facts Marey has obtained graphic demonstration in the following manner. We know that a fly held by the legs moves its wings regularly. Marey made the wings of a fly held in this way touch a smoked cylinder, which was revolving with great rapidity. On this, of course, every stroke of the wing left a mark. The velocity of the cylinder being indicated by means of a recording tuning fork, he found that the fly moves its wings 330 times per second.

Bees, which have been more minutely studied, furnish us with a very conclusive demonstration that emotion affects their flight, just as it does the gait of man. When startled or excited they emit a shriller sound. When in tranquil flight they seek honey from the flowers, they emit a *la*, and when in the evening they arrive wearied at their hive, the hum is on a lower note, namely, *sol*, just as we ourselves slacken our pace after a long walk.

IV

> As doves, by strong affection urged, repair,
> With firm expanded wings to their sweet nest,
> Borne by the impulse of their will through air.[1]

Thus Dante describes the flight of doves, and I have often thought of these lines during the long hours which I have spent in my laboratory awaiting the return of my pigeons from their journeys. My laboratory, like the majority of those in Italian Universities, is situated in an old convent. Whenever

[1] *Inferno*, v. 82. Wright's Translation.

pigeons are set free in Bologna or Ancona, the station-master sends me a telegram. At the time the birds may be expected, I go up alone or with my assistants to the neighbouring church tower, and there we wait, telescope in hand. The pigeons arrive very quickly; one has scarcely time to perceive them before they are on the roof. And yet, having traversed the 300 miles between Bologna and Turin, they are bound to be tired. I recollect once taking a newly arrived pigeon in my hand to measure its rectal temperature. Afterwards, when I threw it from the balcony, it turned back and flew by me, alighting on the cage where its companions were. I opened the door, and it popped in. When placed along with the others, the fatigued pigeons can easily be distinguished, for they sit crouched down and motionless, nor do they fly about and play for several hours.

I shall record one of my experiments on the pigeons, copying it from the journal I kept at the time.

June 23, 1890.

Journey from Bologna to Turin.

Distance in a straight line, 184 miles.

In the evening Caselgrandi went by train to Bologna taking with him thirty pigeons. At 8.30 next morning I received a despatch informing me that the pigeons had been liberated at 7 o'clock. At five minutes past 11, when Dr. Aducco and I were on the church tower, there suddenly appeared five pigeons which alighted on the roof of the laboratory. They did not appear at all tired; they perched on the window of a high tower which stands in front of the pigeon house, and sported and cooed as if they wished to make love ; a few minutes afterwards they decided to enter their house.

We lifted them out at once, and having taken their rectal temperature, found that it was on an average 43° C. ; that is, slightly above normal, which is about 42° C., as was shown by taking the temperature of six normal pigeons of the same age. The atmospheric temperature was 24°. But pigeons which have made a journey cool down very quickly, and after an hour or two have a temperature lower than that of pigeons which have remained in the cot.

In order to find out the physical changes which had taken place in these pigeons after their journey of 200 miles, I killed two which had just returned from Bologna, and also two normal birds of the same age.

By blowing gently I raised the breast feathers, in order to compare the pectoral muscles as they appear below the skin. I found the muscles of the pigeons which had performed the journey were darker in colour than those of the birds which had remained at home.

The phenomena of most interest to me at that time were the occurrence of rigidity and the changes in the blood. Having laid the pigeons on the table, I found that after eight minutes the fatigued birds were rigid, and after twenty had their wings raised, whereas the normal birds showed no trace of rigidity. Having assured myself of this fact, I took two other birds which had just arrived, and repeated the experiment with the same result.

On detaching the pectoral muscles in order to study their chemical composition, I saw that the small one looked paler than the large one. The reason of this difference is probably that the small muscle does less work, its function being limited to raising the wing. The greater part of the fatigue certainly falls to the large muscle, which lies above and gives the ponderous stroke of the wing.

A final observation made on that day should be recorded, as it is of importance in connexion with the phenomena of fatigue which have been observed in the nervous system. I exposed the brains of the four dead pigeons which had made the journey from Bologna to Turin, and compared them with those of the normal birds. The difference in colour was so apparent that every one in the laboratory observed it. In the fatigued birds the brain was pale, almost bloodless. This fact probably explains why the quails on their arrival from Africa do not see so well as usual, and why we ourselves are incapable of doing brain work after great fatigue.

When evening fell, twenty pigeons had arrived, so that only one-third were lost. On the following day, two others returned.

V

In spring, flocks of birds are sometimes seen flying in two lines which meet at an acute angle ; these are wild ducks migrating from Africa to northern climes. A few days later some of these flocks may be seen passing over the Baltic Sea ; they then cross Finland nor stop till they reach Lapland or Siberia. The family *charadriidae* includes about a hundred species which migrate every year from the equator to Iceland, Spitzbergen, or Siberia.

I will mention two examples of this large family: the Turnstone, which nests on the shores of the Arctic Ocean, and winters in Central Africa, Polynesia, or Australia; and the Plover, which spends the winter in South Africa, and on the coming of spring goes to the Arctic circle to make its nest.

Seebohm has written a very important work on the migrations of the *charadriidae*; his observations being made both in Natal and in the Polar regions. He spent a winter in Siberia, near the banks of the Yenissei (lat. 66°), in order that there he might await the arrival of the *charadriidae*, which takes place whenever the long night of winter has passed away. I quote the following words from his book—

"The rapidity with which the transformation of nature is completed under the warm breath of the south wind is incredible. Twelve hours after the disappearance of the snow, anemones and rhododendrons appear, and the country is gay with a hundred other kinds of flowers. Gentian and saxifrage cover the meadows with their azure and yellow blossoms.

"On May 22 the migration was complete, and the number of birds which had arrived was prodigious."

Seebohm calls these polar regions the paradise of the *charadriidae*; and according to his description, they must for two or three months be in truth a paradise, so great is the abundance of birds, fish, and flowers. But the summer of the Arctic regions is so short that the birds begin their work of reproduction immediately on arrival, and, in their haste, make no nest; they simply make a little hole in the earth or the sand, and therein lay their eggs. Towards the end of July the young begin to use their wings, and towards the end of August, when the sun dips for a few minutes below the horizon, they make ready to depart. In October life ceases altogether in these latitudes, and for two months total darkness reigns.

Having studied very carefully all the places where certain species of birds have been seen and those where they are unknown, Palmén formulates a law which he regards as the fundamental statement of his book.

The migratory routes of birds towards their nesting places and towards their winter quarters follow a definite course, but not a uniform direction. On the contrary, the routes by which they pass from the northern countries where they nest to Africa or Southern Asia, where they spend the winter, are fixed highways, well marked geographically, and forming diverse curves. In countries which border these tracks, or which lie between them, the birds are not found as a rule, unless they have been carried thither by a hurricane or have lost their way.

An examination of the map of these migratory routes in Europe and Asia shows that the birds follow by preference the great river valleys and the shores of sea and ocean. One of the most frequented routes in Europe is the valley of the Rhine as far as Switzerland. It is round the Swiss lakes, indeed, that the greatest number of northern birds are found. To go to Africa, they pass the Lake of Geneva and reach the Mediterranean by the valley of the Rhone. Here the route divides, and the birds reach their destination by either the Italian or the Spanish coast line.

Migratory birds, in passing from their winter quarters to their northern nesting places, cross the Alps where the altitude is least. Carrier pigeons appear to have a certain aversion for the Alps. In some of the journeys from Belgium to Turin the loss of pigeons was so remarkable that they were believed to have lost their way in the defiles of the Alps and to have fallen victims to birds of prey, or to have circled the Alps by the sea coast, and thus returned to Belgium by the valley of the Rhone. I have said *appear* to have an aversion to the Alps, because in reality, according to the information published by Captain Malagoli, the loss of carrier pigeons from our military stations on Mont Cenis and at Fenestrelle is no greater than that of stations on the plain.

VI

Among the flocks of birds which frequent these highways of migration are some which make slight variations upon them ; they leave the main route for a little, and subsequently return to it. Sometimes, again, they are caught in storms, or join flocks of another species and let themselves be carried into countries whither they did not intend to go, until at last, tired out and with all sense of direction lost, they stop upon the way. By the ancients, the appearance of a foreign and unknown bird was regarded as a favourable omen; but nowadays a certain stigma attaches to these poor creatures which, if they are sea birds or birds of the marshes, must frequently die of hunger on arriving in a very dry region.

Often, however, they succeed in acclimatizing themselves; and to these vagrant guests naturalists attach a great importance in connexion with the modification of species.

From the frequency with which migratory birds lose their way and find themselves unable to continue their journey, one must conclude that their wonderful instinct may sometimes lead them to inevitable destruction. According to Palmén, the birds which go to Siberia from Egypt follow the coast to Asia Minor, and, going by the Sea of Marmora, skirt the shores of the Black Sea; they then follow the valley of the Don, pass from it to that of the Volga, thence cross to the river Obi, and by descending its course reach the Polar regions.

It sometimes happens that after issuing from the valley of the Nile, instead of wheeling round by the coast of Asia Minor, they attempt to cross it; and then they meet their death in the defiles of the Caucasus.

Vittorio Sella, in an account of his recent journey to the Central Caucasus, says, with reference to the migratory birds—

"Sometimes hurricanes of wind, accompanied by snow and fog, surprise them in the higher altitudes and prove fatal to them. Previously on the Alps I had observed similar facts ; but nowhere will such a quantity of dead birds be found as on the glacier of Bezinghi. The high wall which surrounds this spacious amphitheatre is perhaps an insurmountable barrier to the birds ; moreover, the frequent hurricanes which blow in the deep valleys of the Shkara and Zanner detain them in this vast circle as in a trap.

"In July, ducks, skylarks, quails, many unrecognisable skeletons and scattered bones had been washed by the water into crevices or left on the rocks of the glacier. In September my brother Erminio found many quails still alive, but quite lost, and so fatigued that they could not rise high enough to clear the surrounding heights.

"In the end of September, on a mountain to the west of Lars in the Dariel Pass, at an altitude of 12,000 feet, a cry from above made me look up, and I saw at a great height a flock of aquatic birds, probably geese, which were migrating from north to south." [1]

From the facts he has observed, Sella is led to believe that not only the crane and the duck, but also other birds, cross the Caucasus range by the lower passes.

I have what appears to be a splendid photograph of the glacier of Bezinghi, taken by Vittorio Sella.

[1] V. Sella, *Nel Caucaso centrale.* Note di escursioni colla camera oscura. *Bollettino del Club alpino italiano,* 1889, p. 265.

The outline of the mountain reminds me of our Alps and of other and sadder migrations, other and sadder cemeteries. Every year thousands of Piedmontese workmen go to France or Switzerland, returning at the beginning of winter by the valley of the Rhone. Every year many die of fatigue and cold on the Pass of the Great St. Bernard. The corpses are carried to a room about a hundred yards from the Monastery, and there they are left just as they were found, in order that other travellers or relatives going to look for them may recognise them.

No one who has once looked through the window of this mortuary chamber will ever forget what he has seen. Here and there upon the flagstones are gathered together single bones, skulls, shreds of clothing, half-buried in the dust of ages—the remains of hapless travellers piously collected and entombed under this spacious vault.

Against the walls lean skeletons which still stand upright on their rigid joints, and remain untouched until decay causes them to fall to the ground. Some have been there for fifty years. With arms raised, lips drawn back and whitened teeth, stick still in hand, they maintain the strange attitudes in which they were found beneath the snow. There are, perhaps, thirty corpses thus supported, and the ghastly spectacle is rendered yet more sad by the misery of their tattered clothing, which exposes to view the darkened colour of the mummified skin.

Among these skeletons is to be seen a woman holding her child in her arms in such a way that she seems still to be offering him the breast. Fascinated, one's eye rests on the form of this mother who, at the very moment of death, hopes still to save her little one. Like a ray of heavenly light her mother love illumines the darkness and relieves the horror of this charnel house. The sublime self-sacrifice betokened by the mother's attitude ennobles the death of those unknown victims, whom no one has sought, whom no one, perchance, has wept.

He who has not been in the Alps cannot picture to himself the sufferings of these unfortunate beings before the coming of death. They are Piedmontese peasants and workmen returning to their home at the approach of winter, with bag or valise on shoulder, bringing to their families their little savings. Sometimes they set forth too late, or the season becomes bad quickly, and snow overtakes them in the roads and passes of the Alps. Badly clothed and exhausted by fatigue as they are, when the north wind blows they are forced to stop; their hands and ears become frostbitten, and they are quickly benumbed.

Sometimes a fog renders further progress impossible. A veritable night comes on: the darkness is such that one can see neither the road nor the abysses which it skirts. In the Alps snow does not fall in large flakes as it does in the lowlands, but in a fine powder. Those are grains of ice which the wind dashes in your face; they bound and rebound, penetrate everywhere, glide along your skin, no garment, however close, sufficing to shut them out. The wind whirls the snow furiously round, sweeps it from the slopes and gathers it in the hollows. Such are the circumstances in which one watches the whirlwind crossing the dizzy route, breaking the fir trees, and rolling them down to the valleys. The whistling of the tempest, the crash and the roar of the avalanche must produce a terrible impression on the unfortunate travellers. And woe to them if despair arrests them, if hopeless or benumbed they seek some shelter. He who rests is lost for sleep overcomes him. This last supreme solace of his misery gently shuts his eyes and he feels nothing more ; no longer he sees the sad end which awaits him : from sleep he passes into death.

In August, 1875, I crossed the Great St. Bernard for the second time, and in the mortuary chamber I saw several corpses which, for the most part, appeared to have been placed there but a few days before. The monk who accompanied me said that these unfortunates had perished at the end of the preceding November ; and he gave me the particulars of their story.

The Aosta paper of November 25, 1874, gave the following account of the accident—

"On Thursday morning, a few steps from the Monastery, two bodies were found which were believed to be those of two sawyers. An expedition was organised to see if there were any other hapless travellers in danger. Two monks set forth, along with a servant, and upon Mount Pera found thirty people who for twenty-four hours had lived upon a little flour moistened with water, and some salt. On Friday they decided to leave Mount Pera, and, with great exertion, proceeded towards the Monastery.

A drift of snow barred their way, and buried the whole party.

"The catastrophe was made known at the Monastery by the arrival of a St. Bernard dog in a pitiable condition; and all the remaining monks immediately went to the rescue. Close at hand they met one of the brothers and a Piedmontese workman who had succeeded in extricating themselves from the snow. Everything possible was done for them, but they died shortly afterwards.

"Six corpses were taken from the snow, and two workmen who were still alive, but who died soon after. The two monks and the servant, who formed the first rescue party, also died. Alone of the whole party two Piedmontese workmen were rescued alive after a sojourn of two-and-twenty hours under the snow."

CHAPTER II

UPON THE HISTORY OF THE STUDY OF THE MOVEMENTS OF ANIMALS

THE physiological study of animal movement begins with Alfonso Borelli, a Neapolitan physician, who died in 1680. In studying the functions of muscles and nerves, no one nowadays reads the works of Galen or of Oribasius, who were the classical medical authors at the time of the Roman Empire. But the work entitled *De Motu Animalium*, written by Borelli more than two centuries ago, is a treatise which modern physiologists should still consult and study.

By the middle of the seventeenth century, experimental philosophy had made such progress, thanks to the achievements of Galileo, that his disciples conceived the hope of applying the principles of the new sciences to the study of all nature. This was the most glorious epoch of the scientific renaissance, and with the work of Harvey on the circulation of the blood, published in 1628, the history of modern medicine begins.

Recognising that the entire edifice of physiology had to be rebuilt, and that the older medicine had no scientific basis, Borelli sought to give it the same firm foundation as mathematics, chemistry, and experimental physics, because, said he, "the basis of the operations of Nature is anatomy, physics, and mathematics."

The Grand Duke Ferdinand appointed Borelli Professor of Mathematics in the University of Pisa, and charged him to verify Pascal's experiment of measuring the height of mountains with the barometer. Borelli, whilst he was editing Euclid, discovered the law of action and reaction, and the very important theory of the attraction and repulsion of floating bodies; he studied the digestion of animals, constructed the first heliostat, and commenced the investigation of capillarity. In 1661 he described a malignant fever, which broke out in the city of Pisa. Applying himself to astronomy, he wrote an account of Saturn's ring for Leopold de' Medici; and shortly afterwards turned his attention to Etna, and wrote a description of the eruption of 1669. Alfonso Borelli was one of those large minded men who characterise the renaissance. Like Redi, he was a poet, and his verse, according to Marchetti, is marked by both sweetness and beauty. Malpighi, who was already celebrated at this time, desired to be a pupil of Borelli, in company with Lorenzo Bellini. He narrates how he went for the first time to Borelli's house in Pisa to be present at the anatomical dissections and how, during one of these lessons, whilst he was examining a heart, he discovered for the first time that there are some muscular fibres in this organ which have a spiral direction. Malpighi records with gratitude the instruction and advice which Borelli gave him upon his work, and having gone three years later to Bologna he confesses that it was in that school "that he escaped from the darkness in which he had hitherto been plunged, from the balderdash of popular medicine."

I do not believe I exaggerate in affirming that the mechanical views which constitute the basis of modern physiology find their first expression in Borelli's work, *De Motu Animalium.* To prove this it is only necessary to cite this phrase which is found in the introduction to that work—

"The performances of animals are due to mechanical causes, instruments, and reasons."

Even in a modern book, the conception of mechanism could not be expressed better.

II

The reader who desires to understand whence come the fundamental conceptions which, to this day, guide us in the study of fatigue will, I hope, consent to my taking a rapid glance at the physiology of the ancients. I confess I do this willingly, because in this way we may see the birth of several of the elementary conceptions which are essential for the study of fatigue.

It was already known in the time of Galen that the nerves come from the brain and spinal cord; that they are like white cords, and form communications between the brain and the muscles. The greatest difficulty in the study of movement was to understand exactly how the nerves act upon the muscular fibres and make them contract. The first physiologist who expressed clearly the mechanism of muscular contraction was Alfonso Borelli. In his book upon the movement of animals, in proposition xxii, he writes : " In the production of muscular contraction two causes concur, of which one resides in the muscles themselves, and the other comes from without. The excitation of movement can be transmitted from the brain by no other route than by the nerves. All experiments agree in proclaiming this fact in a very evident manner. One rejects, however, the hypothesis that there is any question here of the action of any immaterial power or spirit ; one must admit that some material substance is transmitted from the nerves to the muscles, or that a shock is communicated which is able, in the twinkling of an eye, to produce the swelling of the muscles."

All this is accurate, and even to-day we dare add nothing more. Borelli supposes that the motor excitation is given by a "strong acid, which is diffused to the end of the nerve so as to irritate the muscle."

" The swelling, the hardening, and the contraction," says Borelli, " are not produced in the nerves, that is to say in the tracks by which the motor property is transmitted or in which it resides, but outside of them, in the muscles. The substance or property which is transmitted by the nerves is incapable of producing a contraction by itself ; it is necessary for it to unite with something else which is found in the muscles and is there distributed abundantly, and from these substances there results something which may be compared to fermentation or ebullition, and which produces the sudden swelling of the muscles."

Our conception of nerve fatigue must depend chiefly upon the nature of the processes which take place in the nerves themselves. This is therefore one of the crucial points. Borelli has put forward, at the end of his introduction, two hypotheses, and physiologists still have the alternative of choosing one or the other without being able to determine with certainty which is correct. The transmission of the nervous impulse to the muscles, the order which goes, for example, from the brain to the muscles of the hand, may be a chemical change which each molecule transmits to the next in the substance of the nerve. To use a rough simile, one might compare the nerves to tinder, or to a train of grains of powder placed one against another from the brain to the muscle. The action of the will would consist in kindling the first grain within the nervous centres, and the combustion of the last grain would start a change in the state of the muscle, and thus produce the contraction. In the present state of science this conception is the one which has the greater degree of probability. But unfortunately, we do not yet know what the chemical changes are which occur in the nerves when functioning, and some physiologists having observed that nerves do not fatigue, or at least fatigue much less than the brain or the muscles, hold that the transmission of the nervous impulse along the nerves is not due to a chemical transformation comparable to that which occurs in the train of powder. According to these physiologists the agent would be of a mechanical nature, a kind of vibration of the molecules transmitted along the nerve without altering its chemical composition. This mechanical stimulus, which we might compare to the transmission of sound through the molecules of a solid body, reaching the muscle from the nerve centres, produces an explosive decomposition, namely, the chemical change of the contraction. The earliest conception of this mechanism is also due to Borelli, and I will quote his own words: "It still remains to discover what this force is which passes along the nerves, in what manner it is distributed in them, and by what channels. It is clear that the nerve, although as small as a very fine hair, is composed of numerous fibres united by a membranous sheath. Each fibre is hollow like a reed, although to our too feeble vision it appears completely solid. It is not impossible that the nerve fibres may be little hollow tubes full of some substance like the pith of elder."

It is remarkable that Borelli, in affirming what he had never seen because he lacked the microscopes which we possess to-day, approached so near the truth. Ranvier demonstrated some years ago that the sheath which protects each fibre has nodes and condensations which limit the segments as in the reed or the elder, and that these segments are full of a fatty, almost liquid substance named myelin. The myelin forms an envelope which serves to protect and isolate the central filament known as the axis cylinder. Moreover these nodes, which Ranvier discovered in the nerves, serve to prevent the liquid substances which enter into the composition of the nerve from inducing by their displacement any change in the nerve itself.[1] We see therefore that, in comparing the nerve to a twig of elder, Borelli had divined the truth.

Borelli added further : " We must suppose that the spongy cavities of the nerve fibres are always filled to turgescence by a juice or humour which comes from the brain. And just as we see that, if a piece of intestine is filled with water and closed at the two ends, and is then compressed or lightly tapped at one end, the movement or vibration is immediately manifested at the other end, because the fluid particles which are displaced against one another, each giving an impulse to the next, propagate the movement to the end; just so any slight compression or irritation in the brain at the beginning of the canaliculi produces a disturbance which is propagated as far as the muscles."

In order to show that, in the action of nerve upon muscle, there is no great expenditure of energy, and that a slight cause suffices to produce contraction, we need only recollect (he says) that the slightest touch of a feather in the nostrils, in the ear, or in the throat is able to produce contraction or even intense convulsive movements in the muscles of the organism.

What Borelli was forced to conjecture, or what perhaps he had vaguely seen, we are now able to observe easily in the muscles of insects which we place under the microscope alive. On bringing about

[1] Ranvier, *Leçons sur l'histologie du système nerveux.* Paris, 1878, p. 131. t. i.

a contraction, we see, starting at the point where the nerve reaches the muscle, a swelling which runs along the muscular fibre like a wave spreading to the parts of the muscle which are most distant from the nerve.

Two centuries have passed away, and we must confess that in this department of physiology but little progress has been made, since we are unable even yet to describe with certainty the intimate nature of the nervous process.

Speaking of the mechanism by which we execute voluntary movements, Borelli says: "When the animal spirits are at rest or asleep it is inconceivable that a voluntary act should take place, or the faculty of sensation be aroused. For this it is necessary that the animal spirits in the brain be awakened by some local disturbance such as is demanded by the nature of their property of movement. We can understand how thereafter the humours of the brain, affected by these animal spirits, whether by means of a transmission of movement or by a pungent acidity, appeal to and stimulate the sources of the nerves."

If Borelli's mode of expressing himself, in explaining voluntary movement, may appear obscure, no physiologist would dare to reproach him for it, because even to-day we are unable to say anything more intelligible. The origin of voluntary movement has always been the great stumbling block of physiology, and unfortunately it is a problem so important that all should occupy themselves with it, and especially philosophers.

Speaking of involuntary movements, Darwin says: "It seems probable that some actions, which were at first performed consciously, have become through habit and association converted into reflex actions, and are now so firmly fixed and inherited, that they are performed, even when not of the least use, as often as the same causes arise which originally excited them in us through the volition."[1]

Such is the opinion which Spencer also supports in his *Principles of Psychology*. But Borelli had already formulated this difficult problem in nearly the same terms as modern philosophers have adopted.

"It is not impossible," says Borelli, "that actions which are now accomplished by habit have once been voluntary, and we who are no longer aware of having willed them, believe them to be involuntary. It is thus that the movements of the heart are accomplished without the consent of the will, and although we do not pay attention to them. We see besides that many other movements, which without doubt began by being executed under the control of the will, are eventually carried out without our being aware of it, and sometimes also without our desiring it."

Such propositions of Borelli should occupy the spiritualistic philosophers and be combated by them, because Borelli has challenged the orthodox conception of the will. He attributed to it a share even in the movements of the heart when he said: "The movement of the heart, then, is due to a conscious and seeking faculty and not to a hidden organic necessity." Obviously we here touch one

[1] Ch. Darwin, *The Expression of the Emotions*, p. 39.

of the gravest problems of philosophy. The Abbé Antonio Rosmini, reproaching Borelli with confusing the sensitive principle with the reasonable soul, says that in this doctrine of his "one may see the origin of modern materialism."[1]

III

In the Church of Saint Pantaleo near the piazza Agonale in Rome may be seen the tomb of Alfonso Borelli. To the left of the principal door, above the font of holy water, there is a white marble stone with a border of *giallo antico*, over which hangs an oil painting of the great physiologist. The inscription sets forth the eventful life of Borelli, and ends with the words—

HEIC ADMIRANDUM DE MOTU ANIMALIUM
OPUS ABSOLVIT SIMUL CUM VITA.

The romantic figure of Borelli deserves to be described in detail, so singular were the vicissitudes of his life from his birth in barracks to his death in the monastery of the *Padri Scolopi*.

Borelli was the son of a Spanish soldier, and was born in the *Castel Nuovo* at Naples. He passed his childhood in poverty among the troops raised by Philip III. His father was a man of such depravity that the son, in order to escape from infamy, abandoned the name Alonso, and took that of Borelli from his mother, who was a Neapolitan. While still young he was appointed a teacher of mathematics in the University of Messina. In one of Targioni-Tozzetti's manuscripts in the National Library at Florence,

[1] A. Rosmini, *Psicologia*, Libri dieci, p. 192.

entitled "Notes of some additions to Physical Science made in Tuscany," Borelli is spoken of at length. In vol. xi, p. 140, we find the following passage : "Borelli was of a hasty temperament, punctilious and very jealous regarding his discoveries ; hence through mere jealousy he was the enemy of Vincenzo Viviani, and of Niccolo Steno ; and inasmuch as he desired to be chief in the Academy of Cimento he did not agree with the other Academicians, nor were they well pleased with him, as I learn from the records of Cimento. Finally in 1668, through mere caprice he gave up his chair at Pisa, to the great displeasure of the Grand Duke."

Returning to Sicily he took part in a conspiracy to free the country from Spanish rule. The plot being discovered he fled into exile. A servant robbed him of all his possessions, and the poor old man, having sought refuge in Rome, received an appointment as lecturer on mathematics in the *Scuole Pie.* Queen Christina of Sweden, a great patron of letters and science, offered him a large pension in order that he might finish and publish his studies on the motion of animals. Borelli was correcting the proofs of the first volume, when he died suddenly of inflammation of the lungs.

The *Padri Scolopi* at Rome undertook to issue the second volume, the manuscript of which had been left unfinished by Borelli.

It is a strange thing that so materialistic a book should have been written in a monastery. And when one reads the second volume, in which all the vital functions are explained on the mechanical theory, one could never imagine it to have been brought out by monks.

Father Carlo, S.J., who was Borelli's companion in his studies, as if foreseeing that some day the immortal pages of Borelli might lead far from the faith to the mechanical philosophy which is incompatible with the vitalistic doctrine and belief in the soul, tells in the life which he wrote of the great physiologist, of having seen him on his knees in his cell absorbed for a long time in meditation and in prayer.

But few decades had passed since Galileo Galilei summoned before the Inquisition in the neighbouring church of Santa Maria sopra Minerva, had been obliged to yield and write with his own trembling hand that he "abjured the opinion that the earth moves and that the sun is the centre of its motion, promising, binding himself and swearing to regard it as false." The breach between science and faith appeared healed by the sacrifice of Galileo, and Borelli, like his master, might declare: *Ita sancta docet Ecclesia, ita credendum.*

IV

Alfonso Borelli died in a humble convent cell. His rival, Nicolaus Steno, a great anatomist and physiologist of this period, was a bishop, an apostolic vicar, and died in the odour of sanctity.

The finest physiological experiment of the seventeenth century bears Steno's name to this day. Upon tying the great artery which carries the blood to the legs, he observed that the power of movement disappeared from the hind limbs of the dogs operated upon after a few minutes and that the limbs became rigid. Upon removing the ligature which obstructed the passage of the blood, the mobility returned in the paws almost immediately.

Steno demonstrated that the tendons are inert cords and that the muscles contract only in their red and fleshy part. He was the first to prove that there is no difference between the muscles of man and those of animals, and he settled a great controversy which arose fifteen centuries before upon the substance of the heart. Hippocrates held that the heart was made of flesh like the muscles. Galen denied it. Steno demonstrated that the heart is a muscle like the rest.

Studying the movements of the heart when separated from the body, he concluded, contrary to Borelli's opinion, that this organ does not receive its impulse to movement from the brain.

Other ideas which we hold to-day upon the structure of muscle we owe to Steno.[1] He indeed showed that each muscle has its own arteries, veins and nerves, and it was he who was the first to describe the lymphatics of the muscles.

In order to study the changes which occur in a muscle when it contracts, Steno recommended that the fingers should be placed upon the masseter muscle, against the angle of the jaw, and the teeth clenched. The muscle thickens and one feels it become harder and more wrinkled. Even after the arteries and veins of a muscle had been divided it continued to contract. He thus proved that the

[1] *Myologiæ specimen*, Florence, 1667.

contraction does not depend upon an injection of blood among the muscular fibres in the act of contraction as was then believed by many physiologists. He showed that in freshly-killed animals there are muscles which still contract, although the head has been detached and the heart plucked out. This new experiment he repeated upon divers animals. In the dog, for example, he saw fragments of the thoracic wall detached from the body still continuing the movements of respiration. From this he concluded, contrary to Borelli's observations, that muscular movement does not depend upon the blood, nor upon the nerves, nor upon the nervous centres. Further, he showed that even after section of the nerves, the muscles could still contract if they were stimulated directly. By this experiment, Steno forestalled Haller by more than a century in the doctrine of muscular irritability.

Steno's works are distinguished from those of his predecessors by the severe and merciless criticism which he passes upon doctrines which are not based upon accurately observed facts. The famous anatomist, Winslow, speaking of Steno's dissertation on the anatomy of the brain, says: "Steno's discourse alone was the first inspiration and the general model of all my anatomical investigations."

V

I have before me the works of Steno, Redi, Malpighi, Borelli, Bellini, and other famous physicians of this period. Some of the volumes are printed in Elzevir type, in pocket editions, with splendid engravings in the frontispiece. And I muse within myself upon the greatness of the change betwixt then and now. The Princes of Tuscany corresponded with the most celebrated philosophers and men of letters in Europe, and communicated to them their doubts, and the observations and experiments which they either made themselves or caused others to make. And if so many contemporary writers had not accepted it as truth, this enthusiasm of the princes of the time for letters, art, and science might perhaps appear exaggerated.

I will quote a passage which I have copied from the manuscript of Targioni-Tozzetti in the National Library at Florence :—

" The Grand Duke, enamoured of worthy studies chiefly through the influence of Galileo, would often lay aside the grave affairs of the government and seek recreation in the pleasant paths of philosophical speculation, not indeed for the sake of vain and profitless diversion, but to find out truth, bare, pure and unmixed ; therefore with royal and unwearied liberality he constantly supplied many skilful men with all that was necessary to reach such a praiseworthy end. A memorable sight it was in truth to see the chosen band of learned men who frequently formed a brilliant circle round his table ; but still more remarkable was it to look upon himself in his private apartments, with the burden of regal dignity laid aside, distinguished from his celebrated companions in nothing except the excellence of his memory, the clearness of his intellect and the quickness of his understanding, devoting himself to the most sublime speculations, and intent by means of the clear light of experiment to make truth plain amid so many false and obscure opinions."

To understand what a glorious epoch this was for the University of Pisa, it is sufficient to remember that there at the same time were to be found Borelli, Redi, Bellini, Malpighi, and Steno. And many documents give evidence of the easy life then led by scientists, in illustration of which I will quote a few lines of a letter written by Redi from Pisa to Steno—

"I have lately made a beautiful discovery, and I will in the meantime describe it to you shortly, waiting to speak of it at length until you shall have returned to the court at Pisa, when, having dined and supped, we shall stand together by the fire with nothing else to do."

From Malpighi's letters we learn that the Grand Duke went to the University to be present at the lectures on experimental physics and at the vivisections which were performed in the class of physiology.

"On Steno's arrival at Pisa about the year 1666, the Grand Duke Ferdinand II heard how much this ultramontane youth had surpassed many others who had devoted themselves to the study of science, and especially to the more recondite knowledge of the innumerable products of nature. Ferdinand detained him at his court, made him his physician, providing for him like an equal, and giving him an honourable position as lecturer." [1]

[1] Domenico Maria Manni, *Vita di Niccolo Stenone*. Florence, 1775, p. 34.

The celebrated men of this time differ from modern scientists especially in the universality of their knowledge and in their habit of cultivating the most disparate branches of science. Steno, who wrote an immortal work upon the glands and was both a physiologist and a zoologist, was moreover a distinguished geologist. He first demonstrated that the crystal is the typical form of inorganic matter, and he gave the first laws to crystallography. In 1881 the geologists assembled at the International Congress at Bologna had a stone with a representation of Steno on it placed under the portico of the church of San Lorenzo in Florence.

VI

Steno was born at Copenhagen and was called Stensen, whence the name Steno, Stenonis. At the court of Tuscany, together with Redi, he made various important zootomical observations and experiments on the effects of certain poisonous substances on animals. Redi writes in a letter to Steno—"You will remember how many and many a time we have shown His Serene Highness the Grand Duke Ferdinand, our master, the experiment of causing an animal to die almost immediately by opening one of its veins, and how afterwards we have introduced the point of a syringe through the aperture, and made the air contained in it penetrate with force into the veins of the animal."

Steno published his celebrated book on myology in the same year as he abjured the Protestant faith, namely in 1667. Five years later we find him

Professor of Anatomy at Copenhagen. The King of Denmark had invited him to return to his native country, giving him the chair and granting him permission to remain a Catholic. After a few months Steno left Denmark to return once more to Tuscany, but we do not know the reason for this. Redi, writing in December, 1674, says that Steno "should be in Florence in a few weeks' time and would perhaps have brought with him Schwammerdam, who is a very promising youth."

This Schwammerdam is the great Dutch naturalist, one of the most powerful minds of his age, whose life presents a curious point of resemblance with that of Steno. Schwammerdam came under the influence of a certain Antonietta Bourignon de la Porte, and her religious exaltation had a fatal effect upon his life. He became melancholy, full of mysticism, and absorbed exclusively in questions of theology. Steno's life took a similar turn, and the woman who influenced him was a certain Florentine nun, Sister Maria Flavia del Nero. I have found certain manuscripts in Florence relating to this incident, but this is not the place to institute an historical inquiry into Steno's private life. I myself have certainly found it very interesting to search out the story of this Sister Maria Flavia del Nero, and the influence she exerted on Steno's conversion and his return to Florence. Several of his letters to her still exist; and in her old age Sister Maria Flavia del Nero wrote in the Convent Chronicles that Steno's conversion and his saintly life had been her work.

From a contemporary biography of Steno we learn "how great were the penances, how great the acts of piety he performed when he was appointed by the Elector of Hanover to the office of bishop. Having made a vow to go from Florence to Loreto, from Loreto to Rome, and from Rome to the place appointed, on foot, and living upon alms; having given all his goods to the poor, he set forth with bare feet, and so arrived at Loreto; but his health had suffered, and he had to remain to be cured."

How changed are the times! There is no one nowadays in whom these sublime sufferings do not awaken a bitter feeling of commiseration. Yet in Manni's biography[1] it is regarded as a merit in Steno to have endured all these things which led him prematurely to his grave. While he was in Northern Germany seeking to bring back to the Church the provinces she had lost, we know from documentary evidence that he led a life of the utmost poverty.[2] His last years, before penances and vigils brought him to the grave, were those of a martyr. He died in the full fervour of his mission in the year 1684, in Schwerin in Mecklenburg. I know not whether his love for Italy had remained with him so strongly that he desired that his bones should rest here, or whether religious intolerance denied him the repose which every one hopes to find in the land of his birth. Cosimo dei Medici had his body brought with great pomp to Florence, and the remains of the great

[1] Manni, *Vita di Stenone*, p. 268.

[2] Anon. *Notizie, della vita e della morte di Monsignor Niccolo Stenone*. This manuscript is in the National Library at Florence, where certain letters written by Steno to Magliabecchi are also preserved.

physiologist rest under the spacious cupola of the Medicean Chapel, near that monument by which Michelangelo has immortalized those princes who deserved so well of Science and of Art.

I went one day to visit Steno's tomb in the crypts of San Lorenzo; to reach it I had to pass over the stones covering the bones of Donatello, the great master of verisimilitude in art. In front is the resting-place of Cosimo, the Father of his Country, and to the right on a stone near a pillar are these words—

NICOLAI STENONIS,
EPISCOPI TITOPOLITANI
VIRI DEO PLENI
QUIDQUID MORTALE FUIT HIC SITUM EST.

The inscription goes on to recount the pious deeds of the bishop. The stone was placed there some years after the death of Steno, at a time when many were desirous that he should be canonized, and there is on it not one single word regarding Steno's immortal services in the investigation of nature. Religion and faith have entirely eclipsed the glories of physiology and science.

CHAPTER III

THE ORIGIN OF THE ENERGY OF THE MUSCLES AND OF THE BRAIN

I

THE cause of movement in a machine is readily intelligible. The wheel of a mill is moved by water falling down a slope, and the ultimate cause of this movement is the heat of the sun. The latter raises the water from the sea, and collects it in clouds which eventually come to rest upon the tops of mountains, and thence the water flows back in streams and rivers. The clock on the steeple is moved by a weight, the watch which we carry in our pocket by a spring. The energy which is employed in turning the wheel to mark the time is equal to that which has been expended in winding up the timepiece. In a gun, the sudden chemical combination of carbon with saltpetre and sulphur, at the moment the powder is ignited, produces the detonation and gives the impulse to the bullet. In the telegraph, zinc and sulphuric acid are used up in producing the electric current.

What is it which takes place in our arm when it has to overcome resistance and perform work?

What is consumed in the brain when it thinks? In order to give a more or less satisfactory reply to these questions, we must in the first place understand the law of the conservation of energy.

It was two German physicians, Robert Mayer and Hermann von Helmholtz, who discovered this law, which is admitted to be the greatest discovery of last century.

The most complete and evident display of the law of the conservation of energy is found in the field of mechanics, but I must limit myself to some examples drawn from elementary physics.[1]

We all know that sometimes the axles of the wheels of railway carriages take fire if the friction in the nave is not diminished by means of grease. Heat is not a new substance which is added to a body, but is derived from the movement which is imparted to the molecules of the body in question. At any time we may see that a match is kindled by friction, our hands are warmed when we rub them quickly together, and, when they are emaciated, the skin may be heated to a point at which the epidermis gives off an odour like burnt bone, an odour which the Tuscans call the odour of death.

According to Reuleaux, the first machine invented by man would be a piece of wood sharpened at one end and fitted into a hollow in another piece placed

[1] Whoever wishes a better understanding of this new philosophy of nature should read the popular lecture given by Helmholtz in 1862, *Ueber die Erhaltung der Kraft*, and the writings of Robert Mayer, *Bemerkungen über die Kräfte der unbelebten Natur*, 1842. *Die organische Bewegung in ihrem Zusammenhang mit dem Stoffwechsel*, 1845. *Die Mechanik der Wärme*, 1867.

on the ground ; it would be held in a vertical position and made to whizz round between the two hands until the fire was kindled.

Physicists have demonstrated that a definite quantity of heat can be transformed into a definite quantity of work ; and this quantity of work may be changed back into exactly the same amount of heat. From the mechanical point of view these two quantities are equivalent. The steam engine, which has conferred so many benefits on mankind, has conferred a very important one upon science, inasmuch as by transforming heat into motion it has demonstrated that in generating movement heat is destroyed ; and that the energy of movement is a new form in which a determined quantity of heat may be manifested.

When we compress and fix a spiral spring, as is done in many toys, the work which appears to be used up in this act is transformed into work which is called potential. Directly the spring escapes, it stretches, and the energy which we expended in compressing it is restored under the form of motion. The same thing happens in the case of a stone raised by a crane to be a copestone of a house ; as the stone ascends it might seem that all the work of the masons' arms is used up ; but this work is not lost : it is found in the stone which is now at a distance from the earth in a potential state. If the stone falls to the ground from that height, we shall see it acquire a kinetic energy equivalent to that which we have expended in raising it.

Like heat, light depends upon molecular movement.

Physicists suppose that there exists an imponderable substance which they call ether, a substance which fills space and to whose waves our eyes are sensitive. And of these luminous waves—that is to say, of their length and of the velocity with which they are propagated in space—they speak by this time with the same confidence as we all talk of the waves we have seen passing over the surface of a tranquil lake into which a stone has been thrown.

To understand the nature of heat and of light we need only recall what we have seen in a blacksmith's forge. A piece of iron when heated becomes first brown and then red, and on being heated still further assumes a brilliant white colour. When the vibrations of the molecules have attained their maximum rapidity, the iron when placed on the anvil will light up the forge. As it gradually grows cold it will become dark and brown, and the vibrations which were capable of acting as light upon our eyes will cease. If we place our hand near it, we shall feel that it is still scorching; it is now diffusing slower undulations, which are invisible to the eye but which the hand feels in the form of heat. At the Congress of Scientists at Heidelberg, in 1890, Professor Hertz of Bonn showed that electricity also is an undulatory movement which follows the laws of light, and he thus opened a new horizon in the domain of physics.

To demonstrate the transformation of energy, the most convincing illustration is again given by the smith who makes his nails red hot by hammering them with swift and weighty blows upon the anvil.

Some forms of energy may be measured by the work which the unit of mass would produce in falling from a certain height, or again by the amount of heat necessary to raise one kilogramme of water from 0° to 1° C. The work necessary to raise one kilogramme a height of one metre is called a kilogram-metre. The mechanical equivalent of heat is 425 kilogrammetres; that is, the heat sufficient to raise the temperature of one kilogramme of water 1° C. corresponds to the work necessary to raise 425 kilogrammes 1 metre in height, and *vice versa*.

After physicists had learned to measure energy, under whatever form it appeared, they proved that, through all its transformations, none of it is lost.

The examples which I have given and all the phenomena of nature are united by an inflexible law which admits of no exceptions. The spring which by compression we put in a state of tension can afterwards perform a certain amount of work, but it becomes relaxed and inert when it has completed the work of which it was capable. The stone raised to be the coping stone of a house can by falling thence perform work, but when it has reached the ground its power to do work is exhausted.

When oxygen combines with carbon, it gives rise to heat and light; but once these two bodies have combined and the heat has been dissipated the resulting carbonic acid no longer produces either work or heat. In order to produce an electric current we must employ chemical or mechanical forces, or again, as is done in electric lighting, we may make use of heat which we first transform into motor energy and then into electricity and light. In all these examples we see that when the potentiality of a natural force is destroyed in order to produce work, a new equivalent activity always appears.

I cannot refrain from quoting some lines from the celebrated lecture on the conservation of energy which Helmholtz gave at Carlsruhe in the winter of 1862. In thinking of the works of this great genius, who will leave an indelible impress on the history of human thought, one is filled with admiration at the facility and the clearness with which he rendered the most difficult problems of natural philosophy comprehensible.

"If, now, a certain quantity of mechanical work is lost, there is obtained, as experiments made with the object of determining this point show, an equivalent quantity of heat, or, instead of this, of chemical force; and, conversely, when heat is lost, we gain an equivalent quantity of chemical or mechanical force; and again, when chemical force disappears, an equivalent of heat or work; so that in all these interchanges between various inorganic natural forces working force may indeed disappear in one form, but then it reappears in exactly equivalent quantity in some other form; it is thus neither increased nor diminished, but always remains in exactly the same quantity. We shall subsequently see that the same law holds good also for processes in organic nature, so far as the facts have been tested.

"It follows thence that the total quantity of all the forces capable of work in the whole universe remains eternal and unchanged throughout all their changes. All change in nature amounts to this, that force can change its form and locality without its quantity being changed." [1]

II

When clouds are formed above the sea by evaporation we know that a certain quantity of heat becomes latent. The wind which causes the clouds to course through the sky, also owes its movement to the sun's heat, since it is the inequalities of temperature in the various regions of the earth's surface which engender the atmospheric currents. The water which falls upon the Alps, the glacier which melts away, the wind which swells the sail, are able to reproduce in various ways the heat which was the first cause of their movement.

But what is it which warms our bodies and makes them move ? Towards the end of last (the eighteenth) century it was believed to be vital force. But a century before, the mechanical school, founded by Borelli, attributed the heat of the body to the friction of the blood against the walls of the arteries and veins, or to a fermentation, and this opinion was not far from the truth. Let us hear how Robert Mayer expresses himself in his famous memoir, *Organic Movement in its relations to the Mutations of Matter*—

"The sun is, so far as human knowledge goes, an inexhaustible source of physical energy. The stream of this energy which pours forth upon our

[1] Helmholtz' Popular Scientific Lectures. First Series. Translated by E. Atkinson, Ph.D., F.C.S.

earth is the everlasting spring which maintains the activity of everything which moves upon the globe. The surface of the earth would in a short time be covered by the ice of death if the great quantity of energy which is continually dissipated into space, in the form of undulatory movement, were not continually restored to it by the sun.

"Nature has set herself the problem of clipping the wings of the light which arrives upon the earth, and of storing in a fixed form the most mobile of all the forces. To attain this end, she has clothed the earth's surface with organisms which, in living, collect the light of the sun. These organisms are the *plants*. The vegetable kingdom is a reservoir in which the rays emanating from the sun are fixed and accumulated in order that they may be utilised again; a providential arrangement, upon which depends the existence of the human species, and which excites in us an instinctive feeling of pleasure every time our eyes fall upon rich vegetation.

"Plants receive a force, *light*, and from it produce another, *chemical change*.

"The physical force accumulated by the activity of the plants comes to the service of another class of creatures who make it their prey, and use it for their own benefit. These creatures are the *animals*.

"The living animal constantly takes from the vegetable kingdom oxidisable foods to combine them afresh with oxygen from the atmosphere. Parallel with this result is manifested the characteristic feature of animal life, the production of mechanical work, the production of movement, the raising of weights.

"The chemical force contained in the ingested foods and in the inspired oxygen is the source of two manifestations of energy, namely movement and heat, and the sum of the physical energy produced by an animal is equal to the corresponding and simultaneous chemical processes."

When we put lighted coal into the forge, and blow a current of air upon it with the bellows, the atoms of oxygen dash upon the atoms of carbon, and the molecules which result from their combination are in a state of very rapid vibratory motion. The potential energy of the affinity between the carbon and the oxygen is transformed into thermic energy, the product of this combination becoming hot and luminous. The energy of the solar light appeared to be spent when in the leaves of plants new chemical combinations were formed by the splitting up of the carbonic acid of the atmosphere; the energy which then, as if exhausted, remained for years and centuries in the fibres of the wood, wakes up again to-day in the trembling motion of the molecules which are again formed and which generate heat and light.

The intimate nature of the processes of combustion once recognised, we see at once that respiration is also a combustion of the carbon of the tissues under the influence of the oxygen of the air, and that the temperature of our body and the functions of our tissues are due to a simple transformation of the energy which proceeds from the light. The evidence of this chain of events is such that it is accepted by every one. Father Secchi himself, at the conclusion of his work, *The Unity of the Physical Forces*, says—

"Thus everything depends upon *matter* and *movement* and we are brought back to the true philosophy of nature inaugurated by Galileo, namely that in nature all is movement and matter, or simple modifications of these by mere transposition of parts or variation in quality of movement."

And, speaking of animal life, he adds—

"If any one maintains that there exists in the living animal a vital force, a source of energy independent of the ordinary molecular forces, and that there exists among them a chemistry different from that of inorganic bodies, he is wrong."

III

Physiology, like chemistry, physics, and all the sciences, is founded upon two principles.

The first, established by Lavoisier, is the principle of the conservation of matter, which asserts that in chemical transformation there is neither loss nor creation of matter.

Bodies may be submitted to slow boiling, incineration, evaporation; but however complicated the manipulations, however marvellous and powerful the chemical operations of nature, nothing in the world is destroyed or created. The sum of matter remains for ever the same. The molecules may be combined in new associations, may assume new aspects, and become invisible in vapour or in gas, but the balance pursues them and overtakes them. The number of the atoms has remained and will remain immutable throughout the immeasurable procession of the ages.

The second principle is that of the conservation of energy. These laws are the thread of Ariadne which guides us in our search of the unknown; by their means the most secret region of science becomes illuminated by a ray of light, which shows the path which we ought to follow in the study of molecular mechanics.

Psychic functions are so intimately united with the phenomena of nutrition and reproduction that we necessarily have to consider them as vital functions. Certain prejudices which we have inherited from the schools are disappearing little by little. Such is the opinion that between the intelligence of man and that of animals there is an impassable abyss; that animal instinct is blind; that this instinct can never, by gradually and insensibly increasing and becoming more perfect, be transformed into reason.

Romanes has collected in his works observations enough to convince every one that mental phenomena form a continuous chain which branches, but is never interrupted, between the most simple animal forms and man himself; that the elementary faculties of our intelligence have their origin in the phenomena which the nervous system of the lower animals produces. Romanes, who was a disciple and friend of Darwin, displayed in his works a marvellous wealth of proofs in his study of the mental evolution of living beings, and has succeeded in taking several definite steps towards the origin of thought.

In the Psychology of Antonio Rosmini there is a complete historical exposition of the opinions of philosophers regarding the nature of the soul. It is a learned work, and one which is gladly read even by those who do not agree with the ideas of the author. The Abbé Rosmini concludes with these words: "How many vigils, how many sweats, how many meditations have these opinions cost the noblest and most lofty minds! And yet, although all searching through many ages for the self same thing, they have not succeeded in arriving at one accord, as if whilst truth unites men, science divides them."

I do not think it just to cast upon science the reproach of this division; the real cause of it is the haste with which man wishes to solve all the problems and all the enigmas of nature, the want of criticism, and the full and blind faith in hypotheses which have no basis in experiment.

The existing doctrines as to the nature of the soul may be reduced to two, of which one is the orthodox and is outside science; the other is the physiological. Spiritualistic philosophers hold that the soul is a substance which possesses none of the properties of the body or of matter, which has neither extent nor form, which is born with man's body, and is so intimately united with his material organization that its every modification produces a change in the body; and which is able, independently of any exterior cause, by itself and apart from anything which gives an impulse to it, to modify the movements and material functions of the organism. Physiologists on the other hand hold that mental phenomena are a function of the brain. They do not assert that they understand the nature of thought, but they do not renounce the hope of being able to do so; and placed in the dilemma of choosing between the spiritualist doctrine and the law of the conservation of energy, they accept the latter.

Indeed it is not possible to do otherwise, if we are convinced that the universe is governed by fixed and immutable laws; if we wish to follow the light of reason; if we are persuaded that mental phenomena lie within the scope of science; if we are certain that they are a fact of nature; if finally we feel ourselves obliged to consider them as the expression of the activity and of the changes which take place in the brain. We cannot select as our guide a doctrine which our mind is incapable of understanding, which forces us to postulate a miracle with every sensation, with every thought, in order to explain the action of the immaterial upon the material and vice versa. In studying psychology we cannot accept a hypothesis which would place us from the first in contradiction with all the known facts of science and which would lead to absurdity.

All the phenomena which take place in nature must have a cause, and the cause must be equal to the effect. If a physiologist is asked for an incontrovertible proof of the non-existence in the brain of an immaterial force, he cannot give it; but, judging by analogy, comparing the phenomena of the brain with all the other phenomena of nature, he finds himself constrained to suppose that the brain also is subject to the law of the conservation of energy. The probability is at least so great that it wants but little of certainty.

In his Essay on the Human Understanding, written more than two centuries ago, Locke said: "Where we have the clear and evident sentence of reason, we cannot be obliged to quit it for the contrary opinion, under a pretence that it is matter of faith; which can have no authority against the plain and clear dictates of reason."[1]

There is, however, one point where science and faith are in agreement, namely in the recognition that first causes are unsearchable, and that the mind of man has not been constructed so as to understand the origin of matter and of energy. Upon yet another point we may walk in agreement, whatever be the creed or the philosophy of each, namely upon the scientific method of studying the laws to which a phenomenon is subject. Physiology does not recognise the artificial divisions of creeds and schools; unmoved she proceeds in her search for the truth, and her objective is the determination of how a phenomenon takes place in a constant manner, given the same conditions, no matter whether it takes place in the brain or in any other organ of the body.

IV

Life, one might say, is the daughter of the sun. The rays whose waves fall upon the chlorophyll

[1] Locke, *Essay concerning Human Understanding*, Book iv. chap. xviii.

in the leaves of plants, produce a chemical action which man has been unable to obtain by the synthetic methods which are now at the service of science. The living energy of the sun is absorbed and transformed: his potential energy goes to sleep, if it is permissible so to express it, in the leaves, in the seeds of the plants, in the albuminoid substances which are produced in vegetable cells.

The green leaves of plants decompose the carbonic acid of the air and of water, setting free the oxygen and storing the carbon in their substance. The growing plant adds to its substance little by little the carbon which it combines with hydrogen, and accumulates thus the energy of the sun's rays, which are absorbed in this synthesis.

Animals are machines capable of transforming the substances which the vegetable kingdom assiduously prepares. The starch and albuminous substances which the plants have accumulated in their seeds, fruits, or root tubers, will serve to nourish the succeeding generations; the work which the plants have done to provide for the conservation of the species will not be employed entirely in the service of their offspring; a part will be plundered by the animals which draw their life and energy from the destruction of the plants. The elements of the vegetable foods introduced into their system will recover the oxygen from which they were forcibly separated, and, thanks to the vital processes, the oxygen in combining anew with the carbon, will set free the energy which appeared to have fallen asleep, and will produce heat and mechanical work.

The mountain rock, the barren shore of the sea, the sand-covered plains, are warmed by the sun, and then cool down and restore all the heat received: but the verdant field of corn, the flower-spangled meadow, the vines whose branches prepare the starch which is converted into sugar in the grapes, the trees of the forest, do not restore the whole of the heat nor send back the whole of the light of the sun. When we are crowded together in a room and the temperature gradually rises, let us call to mind that it is a part of the heat absorbed by the forests and the fields that we are restoring to the atmosphere.

Herbivorous animals are warmed by the heat which the plants have absorbed. Substances which they have accumulated in their muscles, in their brain, or in their viscera, to transform into the energy of movement or of heat, other stronger animals seize for their own use.

It is only since the discoveries of R. Mayer and von Helmholtz that we have known exactly how all forms of mechanical movement are a transformation of the heat of the sun, and that the will can awaken and call into action the chemical energy asleep in the muscles, but has no creative power. Animals and man can transform the matter which they are constantly introducing into their organism, can transform the forces which already exist in nature, but cannot create any of them.

"The world appears like a great reservoir of energy, which cannot be increased, but likewise cannot be diminished by the complex changes brought about by the processes of nature; inasmuch as it persists unaltered in phenomena which are changing continually, it remains like matter immutable in quantity from eternity to eternity." [1]

Every time we contemplate a natural phenomenon, no matter what it is, we are certain that a corresponding amount of energy is consumed, that force is transformed, that there is a cause which produces an equivalent effect.

V

It was Lavoisier who first affirmed that life is a chemical function, and all the progress of physiology for a century past has gone to confirm his opinion.

The muscles are formed of very fine fibres like little tubes which contain an albuminoid substance capable of contraction. At the maximum of its contraction, the muscle is able to shorten its length by one-third. A very slight stimulation of the nerve, by an electric current so feeble that no galvanometer is able to measure it, can determine a chemical change in the muscle and produce a contraction. The intensity of the chemical processes in the brain may be conjectured by reflecting upon the persistency of the trace which some phenomena leave upon it. The impression of a thing seen may remain unaltered throughout life, or grow faint extremely slowly. In the one case, the electric stimulus has transformed the albuminous substances which are found in the muscular fibres, in the other the stimulus, instead of producing a mechanical effect, has produced a mental phenome-

[1] Von Helmholtz, *Vorträge und Reden*, Leipzig, 1884, 349.

non which is revealed by a modification in the state of consciousness.

That the activity of the chemical processes is much more intense in the brain than in the muscles, we are able to demonstrate by various experiments. As a simple example I shall cite what happens in anaemia of the muscles and of the brain.

It is possible for us to drive the blood out of the forearm to such an extent that the hand becomes pale like that of a corpse and cools three or four degrees in a quarter of an hour. The hand does not lose its power completely, for half an hour after the interruption of the circulation we can still move the fingers and clench the fist. But after fifteen or thirty minutes a tingling and pain are produced which necessitate the re-establishment of the circulation in the arm.

In my book on *Fear*[1] I have written a chapter upon the circulation of the blood in the brain during emotion. I now return to this subject to call attention to the changes which the functions of the brain undergo when the afflux of blood to it is diminished. It is one of the most convincing experiments for showing the indissoluble bond between the mental phenomena and the material functions of the organism. The cerebral hemispheres are so sensitive to every cause which diminishes their nutrition, that when even for a few seconds the quantity of blood which flows to the brain is lessened, consciousness disappears immediately.

[1] Mosso, A. *Fear*. English Translation by E. Lough and A. Kiesow. London, 1896.

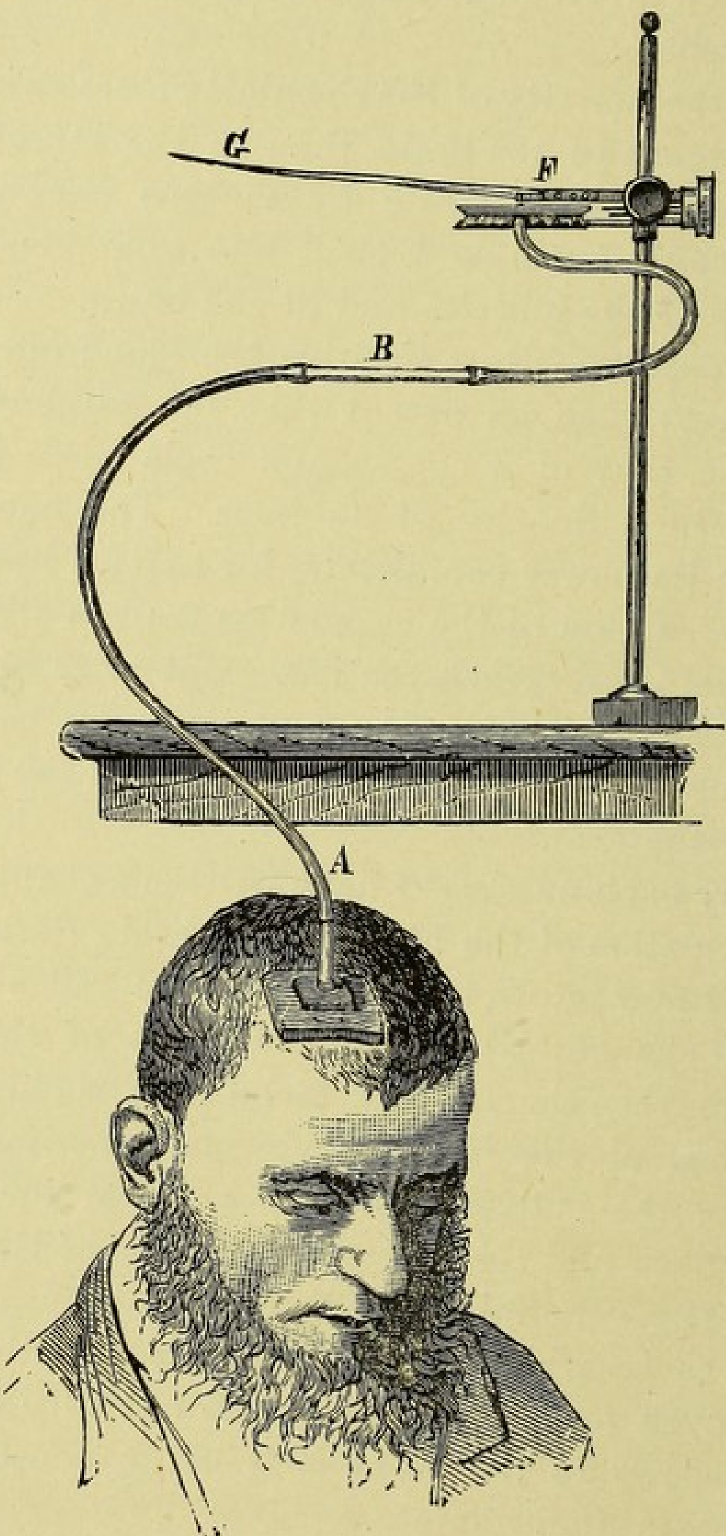

FIG. 1.—Arrangement of the apparatus used to write the pulse of Bertino's brain.

This is an experiment which I made upon that same Bertino whose history I have published in my work on *Fear*. To avoid repetition in detail of the description of the apparatus which I constructed in order to study the movement of the blood in the brain, I give the figure in which one can see how the experiment which I shall now describe was arranged.

Bertino had an opening two centimetres in size in the frontal region of the skull. This I covered with a sheet of guttapercha which bore a glass tube in its centre. This tube was continued by another tube of indiarubber, A B, which was connected with a lever-tambour, F. The tambour, by means of the pen, G, inscribed the movements which were transmitted by the brain to the air contained in the registering apparatus.

VI

I quote an extract from a paper of mine on the circulation of blood in the human brain in which I have studied anaemia and hyperaemia of the brain.

At 1 p.m. on September 29, 1877, I arrange with Doctor De Paoli to make some observations on cerebral anaemia. The sheet of guttapercha is firmly fixed on Bertino's head so that the movements of the brain may be recorded. This record is shown in line C of Figure 2. By the application of my hydrosphygmograph to his right arm the pulse of this part of his body is contemporaneously registered. Thus in line A we see the swelling which takes place in the forearm at every systole of the

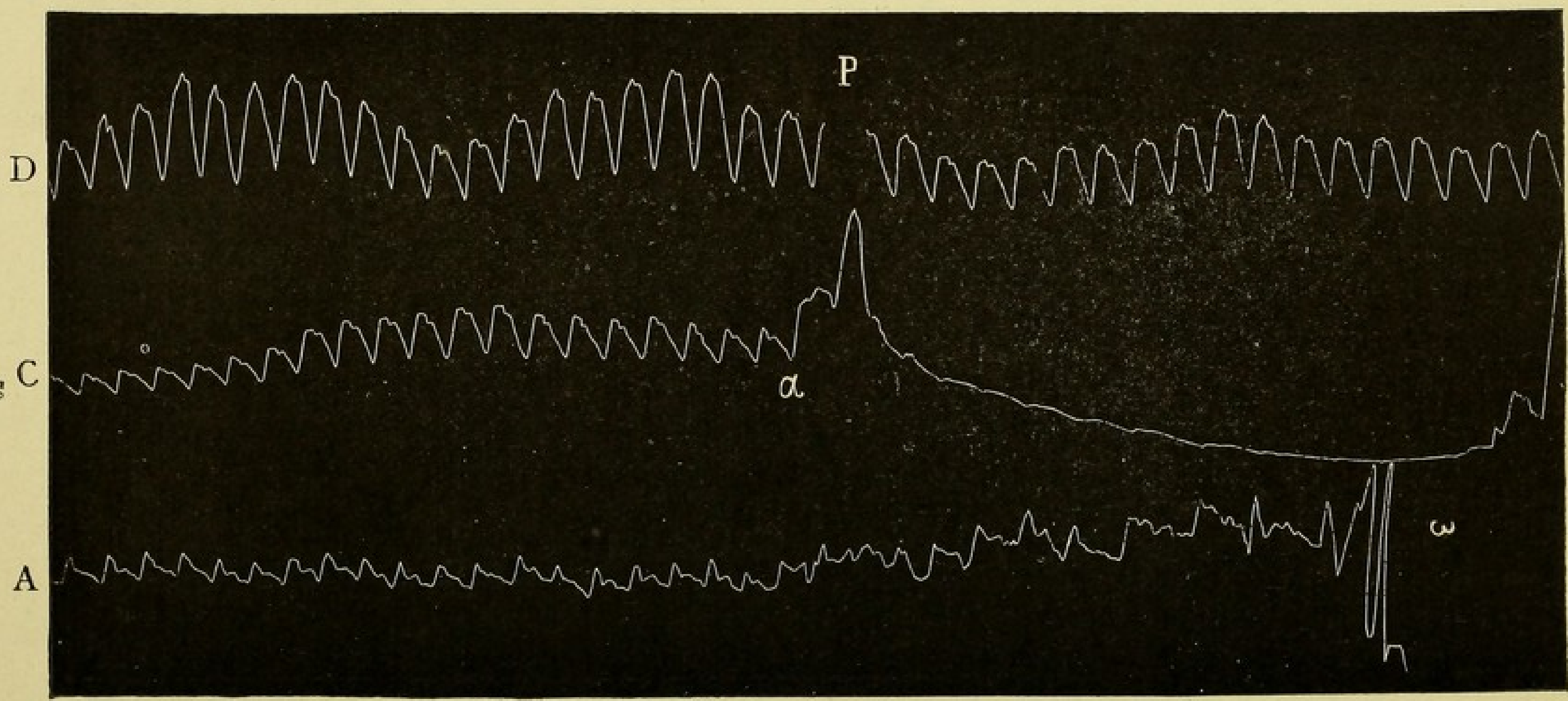

FIG. 2.—Rapid anaemia of the brain from α to ω observed in Bertino, in consequence of the compression of the carotid arteries. Line C is the brain pulse, Line A the pulse of the fore-arm written synchronously, line D above is the tracing of the cerebral pulse written twenty seconds after the anaemia.

heart, and in line C the corresponding phenomenon in the brain.

I had explained my object to Bertino beforehand, and begged him to pay great attention to what he should feel during the experiment, that he might describe it afterwards. Doctor De Paoli sat down in front of him and applied his two thumbs to the two great arteries which we feel pulsing in the neck and which are termed the carotids. For my part, I watched the pen of the instrument which was registering upon a smoked cylinder the pulsations of the brain. Doctor De Paoli began by pressing lightly upon the arteries—to close them. When I noticed the pulsation disappear, I made him cease the compression. Everything was now ready for the experiment. Bertino said nothing. The apparatus which makes the cylinder turn is set in motion, and lines C and A begin to be written. At the point marked α, the carotids are compressed. The two first pulsations are greater than normal; but the third is less, and the brain diminishes rapidly in volume. After the eighth systole the pulse becomes slower and the pulsations are scarcely visible. At the twelfth pulsation, that is after about eight seconds of cerebral anaemia, Bertino fell back in a fit of convulsions. On looking at him, I saw that his face was pale and his eyes turned upward, and I at once caused the compression of the carotids to cease. Bertino opened his eyes like one stunned. The registration of the cerebral pulsations continued without interruption. The point at which the anaemia ceased is marked ω in the figure. Bertino said that everything had become dark, but that he had experienced nothing disagreeable. Undoubtedly he had lost consciousness, for in the first moment he was much astonished to find himself there in that position. He expectorated, and suffered a slight degree of nausea. In a little he asked us to begin again. We were astonished at such sang-froid, but as we had observed, while he was unconscious, the convulsive movements of his hands, his pallor, and the rolling of his eyes, we had not the courage to repeat on that day or afterwards any experiment in cerebral anaemia.

Line D (Fig. 2) was written twenty seconds after the end of the convulsions. I was unable to register the pulse of the arm, because the apparatus had been disarranged. The most striking point in tracing D is the increase in the height of the pulsations. This increase does not depend upon increased action of the heart. It is quite a local phenomenon, being due to a relaxation of the walls of the blood vessels caused by the diminished circulation of the blood. This paralysis of the blood vessels is a phenomenon which can be demonstrated very readily in the arm, by compressing the brachial artery with the finger for a time, and then letting free again the circulation of the blood. Identical disturbances must be produced in the brain, and the paralysis must be much more prompt, because in less than six or seven seconds consciousness is lost.

The great impressionability of the blood vessels of the brain, and their dilatation in every disturbance of nutrition which diminishes in the least the flow of blood, constitute one of the mechanisms by which nature ensures the functions which are most important to life. In fact the most efficacious means of immediately making good impairment in the nutrition, and therefore in the functions, of the brain, and of every other part of the body in consequence of a diminution or an arrest of circulation, consists precisely in providing a more copious flow of blood by an automatic dilatation of the blood vessels.

If anyone would like to test, by an experiment upon his own person, the importance of the circulation of the blood upon the functions of nervous tissue, let him close one eye with his hand, and while he is looking at something with the other let him compress it gently with the tip of the index finger at the outer angles of the eyelids. At the end of from eight to ten seconds vision is obscured and objects become confused. The anaemia produced by the compression is already sufficient to impair the functions of the retina. When one recollects that muscles are still able to contract twenty minutes after interruption of the circulation, one sees that the brain must be regarded as the organ which has the greatest need of active renewal of the material necessary for its functions. But this comparison is not complete. For the brain receives the blood of four great arteries, two of which, the vertebral arteries, are deeply situated against the cervical vertebrae. In the experiment upon Bertino, we compressed only two arteries, the carotids. Consequently we had interrupted only half the blood current which goes to the brain, yet that was sufficient to banish consciousness.

CHAPTER IV

UPON THE GENERAL AND SPECIAL CHARACTERISTICS OF FATIGUE

If an example is necessary to show sceptics that in natural science nothing should be considered impossible, it should suffice to recall the manner in which man has succeeded in discovering and measuring the speed of the propagation of nervous stimuli. Johann Müller was one of the greatest physiologists of our century, one of those who have made the most careful study of the functions of the nerves. In his celebrated work on Physiology, speaking of the way in which the nervous current is propagated, he says that "the stimuli act instantaneously all along the nerves, and in all the fibres, at whatsoever point they are excited." [1]

Six years later, in 1850, a disciple of this very Müller, Hermann v. Helmholtz, made out exactly the rapidity with which the mandates of the brain are sent along the nerves to the muscles, and measured the velocity with which impressions made on the

[1] J. Müller, *Handbuch der Physiologie des Menschen*, 1844. vol. ii, p. 551.

surface of the body reach the brain.[1] Everyone has noticed that scarcely do we feel ourselves pricked before we instinctively withdraw our hand. Helmholtz measured the time which elapses (1) between a prick and the perception of the pain, (2) between the perception of the pain and the muscular contraction in response. He found that in man the nerve current passes along the motor nerves with a velocity of 30 metres per second. The rapidity with which stimuli are propagated along the sensory nerves, which conduct impressions from the periphery of the body to the nervous centres, is very similar. Some writers have found that the rate of propagation along the nerves may be as slow as 20 metres per second.

The studies of Helmholtz were the first ray of light which penetrated the darkness in which is still wrapped up the nature of the nervous processes ; and everyone was astonished to find that our voluntary movements, our sense perceptions, and our mental processes are propagated so slowly along the nerves.

By way of illustration, let us suppose that Bartholdi's Statue of Liberty, which has been erected in New York Harbour, were miraculously brought to life. The lively and practical Americans would send their gift back to the French, because they could make no use of her, not even as guardian of the port, so slow would she be both to feel and to move. As she is 138 feet in height, if she had nerves and a spinal cord like ours, one would have to

[1] H. v. Helmholtz. *Messungen über den zeitlichen Verlauf der Zuckung animalischer Muskeln und die Fortpflanzungsgeschwindigkeit der Reizung in den Nerven*, 1850. Wissenschaftliche Abhandlungen, 2 Bd. p. 764.

wait about four seconds after touching her foot before she would give any sign of sensation and begin to move.

The great discovery of Helmholtz regarding the nature of the nervous current was the beginning of a new scientific epoch in the study of muscular contraction also. In order to make his investigations Helmholtz constructed an instrument which recorded the contractions of the muscles, and to which he therefore gave the name *myograph.* He separated from the leg of a frog the muscles which correspond to the calf, and holding the thigh bone firm with a pair of pincers, he fastened the tendo Achillis to a lever in such a way as to record the contractions of the muscles. The point of this lever traced a horizontal line on a smoked cylinder, and the lever was raised in a vertical direction whenever the muscle contracted. It was in this way that the graphic method was employed for the first time to measure the length of time taken by the nervous current in passing along the nerves.

In the movement of the muscles we must distinguish muscular shock from muscular contraction. The muscular shock is a very rapid movement of the muscle produced subsequent to a single stimulus. I do not know any true example of this among the natural movements of the muscles. The winking of the eyelids, the contraction of the heart, hiccough, all the movements which appear instantaneous, are certainly caused by more than one single stimulus coming from the nervous centres to the muscles. To form some idea of a shock one must make use of the instantaneous stimulus of an electric discharge applied to the nerve or the muscle. In the frog the movement which follows lasts barely three or four hundredths of a second. In other animals it lasts longer, sometimes even a whole second. The contraction has always a longer period than the muscular shock, because it is produced by a series of stimuli.

Our senses and the eye itself are too slow in comprehension and would be of no use in the study of phenomena which, like muscular shock, take place in minute fractions of a second. The graphic method supplies us with a record which reproduces exactly the minutest particulars of the movement, and reveals to us a whole world of phenomena which would otherwise have remained unknown or obscure.

We shall shortly see the modifications which fatigue produces in the contraction of muscles. Wundt, the great philosopher of Leipzig, in about 1858, thought of making use of the myograph to study the modifications which are produced in the muscle as the effect of fatigue.

II

Charles Ludwig introduced the use of registering apparatus in physiological research; and after him, Marey, with his mechanical ingenuity, the interesting nature of his discoveries, and his indefatigable perseverance, popularized the graphic method in medicine.

Scarcely had Helmholtz published his works, when a series of distinguished physiologists brought about an important advance in the physiology of muscles and nerves. Among them I may mention the names of Fick, Heidenhain, and Pflüger. Marey perfected the myograph, and eliminated the distortion which too heavy instruments produced in the contraction curve. Some physiologists confined themselves to registering the height of the contraction only. This method had the advantage of permitting a comparison of the intensity of contraction in a series of stimulations, but it did not show the modifications taking place in the details of each contraction. Marey suggested tracing one above the other the contractions given by a muscle until it was exhausted, and he obtained a tracing similar to that in Figure 3.

Figure 3 represents the tracing of ninety muscular shocks inscribed one above the other, beginning at the bottom. I will not linger to describe the arrangement of the apparatus, which indeed the reader will understand if the tracing is explained to him. Let us suppose that the leg of a frog severed from the body has a bristle tied to the end of one of its fingers; and that this bristle inscribes a white line on the smoked paper covering the surface of a rapidly revolving cylinder. The first time the electric current stimulates the nerve, the muscle contracts, and by thus shortening itself inscribes the first elevation which is seen at the bottom of the figure. Let us pause a moment to examine this first shock.

The wavy line which is seen below records the vibrations of a tuning fork, the rate being 100 per second. This serves to measure the duration of the phenomena of shock in the frog; and under analogous conditions the tracing would be little different in the case of man. The duration of the electric stimulation was so short that it could not be measured; therefore the muscle does not contract immediately,

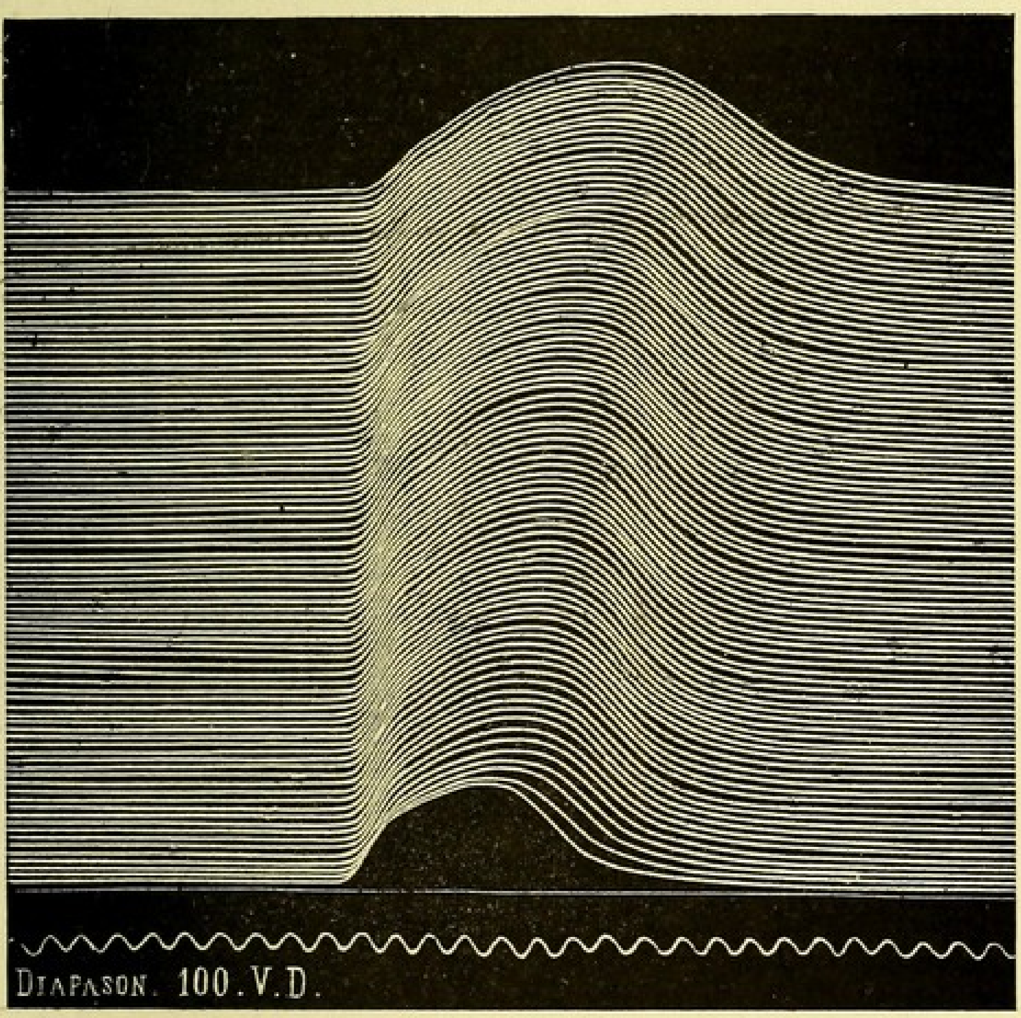

FIG. 3.—Tracing of muscular shocks written by the leg of a frog. The first contractions are in the lower, the last in the upper part of the figure; and in the latter is seen the effect of fatigue. A chronograph which makes 100 vibrations per second writes the undulating line at the foot of the tracing. Each undulation corresponds to $\frac{1}{100}$ of a second, and thus the absolute duration of the various phases of a shock can be measured. (Marey.)

about a hundredth of a second elapses before it begins to move. This retardation is called *time lost by the muscle*, or *period of latent excitation*. Directly the muscle contracts, the line ascends. The time during which the muscle gradually attains its maximum contraction lasts from three to four hundredths of a second, and is called the period of *increasing energy*. Afterwards comes the period of *decreasing energy*, namely that in which the line descends owing to the muscle's returning to its original length.

The apparatus is so arranged that when the cylinder has completed one revolution, the leg of the frog with its supports is raised one millimetre higher. A metal tooth in the cylinder opens the electric current which excites the nerve at the same point as in the preceding revolution. The muscle in contracting makes another record slightly different from the first. Looking attentively at the figure, we see that after a few turns the curves are very gradually modified as the muscle becomes fatigued. Thus the last line at the top is very different from the first at the bottom. And although the stimulus is the same in every case, we find that the muscle when fatigued remains in contraction longer than when it was fresh, and this increase of duration takes place as much in the ascent as in the descent. This last record therefore makes the effect most evident, namely that the distinction between a fatigued and a normal muscle is that the former attains its maximum contraction more slowly and more slowly returns to its original state.

III

The name of Hugo Kronecker is indissolubly connected with the study of fatigue. When I arrived at the Leipzig laboratory in 1873, I was in time to be present at the latest experiments made by Professor Kronecker[1] in completing his researches upon the fatigue and the restoration of the striped muscles of the frog. It is a duty—and more than a duty, a pleasure—for me to avow that it was these experiments which first fired me with the desire of applying myself to the study of fatigue. The exactitude of the method, the elegance of the apparatus, the precision of the results, could not but charm a novice; and the first experiments which I saw made by Professor Kronecker at Leipzig remained so imprinted on my memory that they have been the model which I have constantly followed in my investigation of fatigue.

The researches previously made by Ludwig and Alex. Schmidt had shown that the muscles of a dog live for a considerable time after being removed from the body if defibrinated blood is artificially made to circulate through their arteries.

Kronecker, by eliminating certain causes of error and by experimenting upon frogs, has given to the law of fatigue its most simple formula. With muscles separated from the body, he succeeded in obtaining 1,000 and even 1,500 contractions, one after the other, with the greatest regularity. As the contractions follow one another, their height diminishes in proportion as the fatigue increases, and goes on diminishing with regularity until it disappears

[1] H. Kronecker, *Ueber die Ermüdung und Erholung der quergestreiften Muskeln.—Berichte der Verhandlungen d. k. Sächsischen Gesell. der Wiss. zu Leipzig*, 1871, p. 718.

altogether. Upon this, Kronecker has based the following law: "The curve of fatigue of a muscle which contracts at regular intervals, and with equally strong induction shocks, is represented by a straight line."

Another law which he formulated is as follows: "The difference in the height of the contractions is less when the intervals of time are greater. In other words, the height of the contractions diminishes the more rapidly, the more rapid is the rhythm in which they are produced, and *vice versa*."

Kronecker studied the changes which occur in the substance of fatigued muscles, and demonstrated the marked individual differences which warm blooded animals as well as frogs present in their resistance to fatigue. There are dogs which, after having given 150 contractions, respond no more; their muscles when stimulated exhibit a very minute and scarcely visible shortening; whilst others, under identical experimental conditions, give 350 to 500 and even 1,500 contractions, raising 40 and 50 grammes before completely exhausting their energy.

Upon other parts of Kronecker's fundamental work I shall have occasion to speak later.

IV

The instruments for measuring muscular force are called *dynamometers*. It was Buffon who asked Régnier to construct for him an instrument to indicate exactly the strength of man at the various ages among different races and conditions. The old dynamometer of Régnier is that which every one still uses in medicine and anthropology. It consists of a steel spring in the form of an ellipse. It is taken in the hand and compressed in such a way that the pressure approximates its two curves in the line of the minor axis. The amount of approximation, or, otherwise, the distortion given to the spring by the force of the hand, is indicated by the deviation of a little pointer upon a graduated scale.

Some of these instruments can also record the strength of the contractions and are called registering dynamometers, or dynamographs. They all, however, have the serious defect of not furnishing constant indications. This is readily understood when we think of the considerable number of muscles which act when we close the fist. The cause of error is greater still if we wish to repeat a long series of contractions ; in this case the muscles come into play alternatively, and when one is fatigued, it is replaced by another which has not yet spent its energy.

Heretofore, almost all experiments have been made upon the muscles of frogs removed from the body. But with frogs it is impossible to reproduce the normal function of muscles and to imitate the action of a man who is doing mechanical work. Having dedicated myself to this study, I have first of all sought to construct an instrument which would measure exactly the mechanical work of the muscles of man and the changes which, as the effect of fatigue, may be produced during the work of the muscles themselves.

The difficulties I had to overcome were essentially two. The first consisted in satisfactorily isolating the work of one muscle so that no other muscle would be able to aid it in its work, especially when it was getting tired. The second difficulty was to maintain one end of this muscle fixed while the other, left free, was inscribing its contractions. To the instrument which I constructed I gave the name of *ergograph*, that is to say, register of work. It is composed of two parts, one of which keeps the hand fixed, while the other registers the contractions.

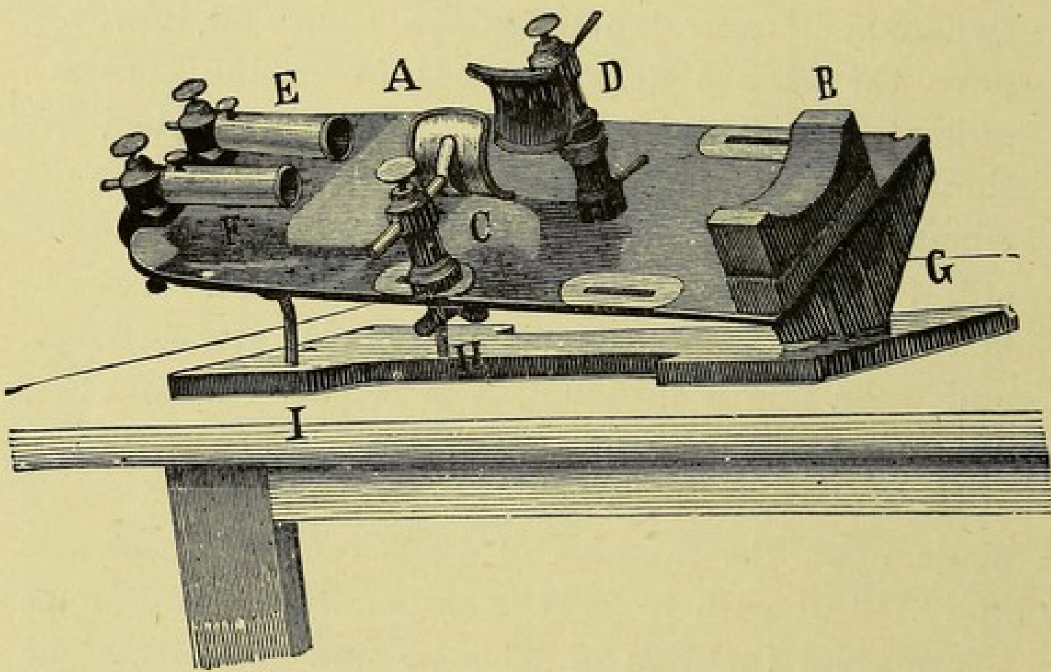

FIG. 4.—The supporting platform of the ergograph.

The fixing support consists of a plate of iron 50 centimetres long, 17 broad, and 0·7 thick, as is shown in Figure 4. To understand how the hand is fixed it is only necessary to look at Figure 6. There are two cushions (A, B, Figure 4). On the first, A, is laid the dorsal aspect of the hand, and upon the second, B, which is slightly curved in the form of a half-circle, is laid the forearm. In order to fix it firmly I use two other cushions, C, D, made in such a way as to grasp lightly the anterior aspect of the lower end of the forearm. Each cushion is formed of a half-circle hollowed out of brass and padded on its inner aspect. Upon the outer aspect is soldered a cylindrical metal bar which is introduced into the opening of a small bit, where it is fixed by a screw.

In Fig. 4 may be seen two bits C, D; at the base of each is a slot 2 centimetres deep and 8 broad which enables them to be fixed on the edge of the platform by means of a screw which is underneath. At first, when the hand is about to be fixed, all these bits are free. The hand is then placed with its dorsal aspect on cushion A and the forearm on cushion B; the two cushions C, D are approximated so as to encircle the wrist, then the four screws are tightened. The hand is fixed in front by two brass tubes, F, E, which have an internal diameter of from 18 to 22 millimetres, according to the thickness of the fingers of the subject experimented upon. Into tube E is introduced the index and into tube F the ring finger of the right hand. In the space left free between the tubes moves the middle finger, to which is attached a string which sets in motion the registering apparatus.

To give a comfortable position to the arm which is working, I advise that it should not be kept in full supination, but in slight pronation. For this purpose the platform is inclined about 30° towards the inner side, and slopes slightly so as to be two or three centimetres higher at the hand than at the elbow. These two inclinations necessitate a change in the position of the support according as one is working with the right arm or the left; this change is effected by means of the triangular support G at the back of the platform. In front there are two feet, I and H, five and twelve centimetres long respectively. These two feet are joined by a transversal piece of iron, which is not seen in the figure, because it is

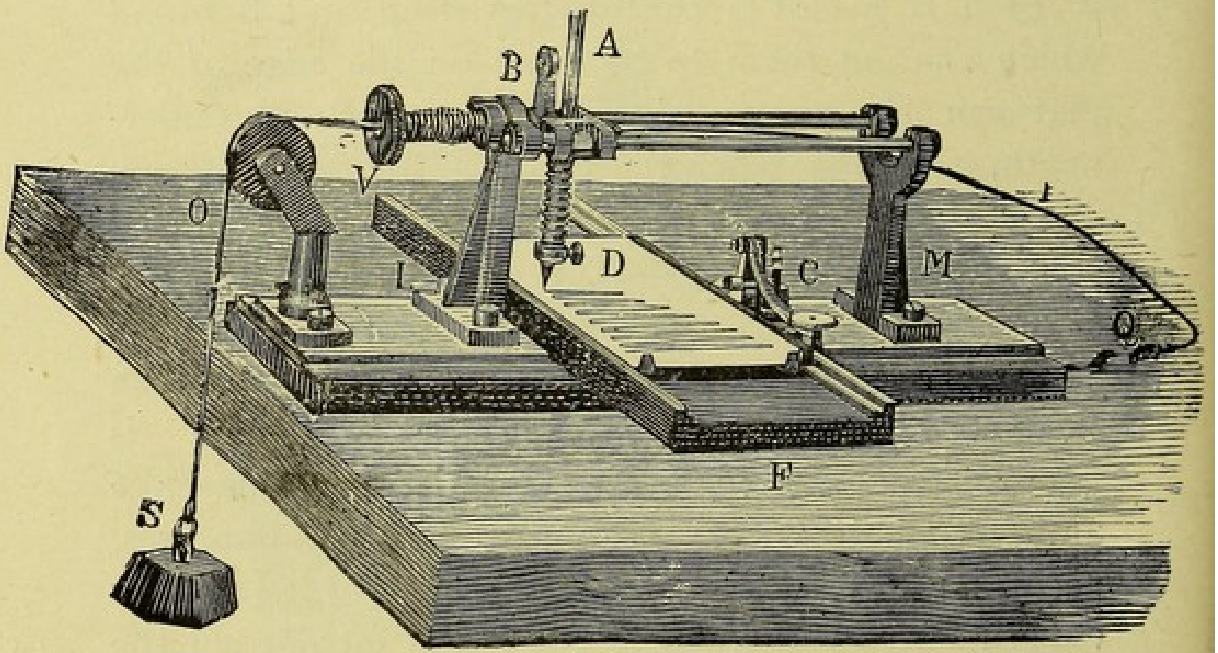

FIG. 5.—The registering runner of the ergograph.

on the lower surface of the platform. In the middle there is a set-screw, which permits of the piece of iron being turned so as to interchange the positions of the feet and incline the platform now to the right and now to the left, according to the hand upon which one desires to study the curve of fatigue.

The second part of the apparatus is the moving register (Fig. 5). It consists of an iron platform seven centimetres in breadth and 32 in length, upon which stand two little brass columns ; these are forked so as to support two cylindrical steel rods four centimetres distant from each other, which serve to guide the metal runner, A, B. The latter by means of two cylindrical holes glides upon the above mentioned steel rods and bears a pencil which marks the amount of the contraction upon the paper D. After this line has been traced, during the interval between two contractions the button C is pressed ; it acts upon a lever and makes the metal frame upon which the paper is stretched advance one millimetre to the right. The frame moves with slight friction in the hollow of the transversal platform F. In this way are recorded one after the other all the successive heights to which the weight is raised.

In experiments made in the laboratory we prefer to make use of a smoked sheet on a cylinder which turns slowly by means of clockwork. The moving register in this case bears a pen at the side, as shown in Fig. 6. The apparatus is somewhat more costly, but has the advantage of not compelling us to move the paper for ourselves after every contraction. The runner A, B is provided with two hooks : to one is fastened the cord P, which draws the runner on flexion of the finger. At the end of this cord is a strong loop of leather, Q, into which is introduced the first phalanx of the middle finger. To the second hook of the runner, which is found at its other end, is attached by means of another cord O, a weight of three or four or more kilogrammes, as is indicated in the figure. This cord passes over a metal pulley;

As these little cords wear out easily, when one is working continually with heavy weights it is better to make use of catgut, such as is employed for violoncellos.

Figure 6 shows the apparatus arranged for perform-

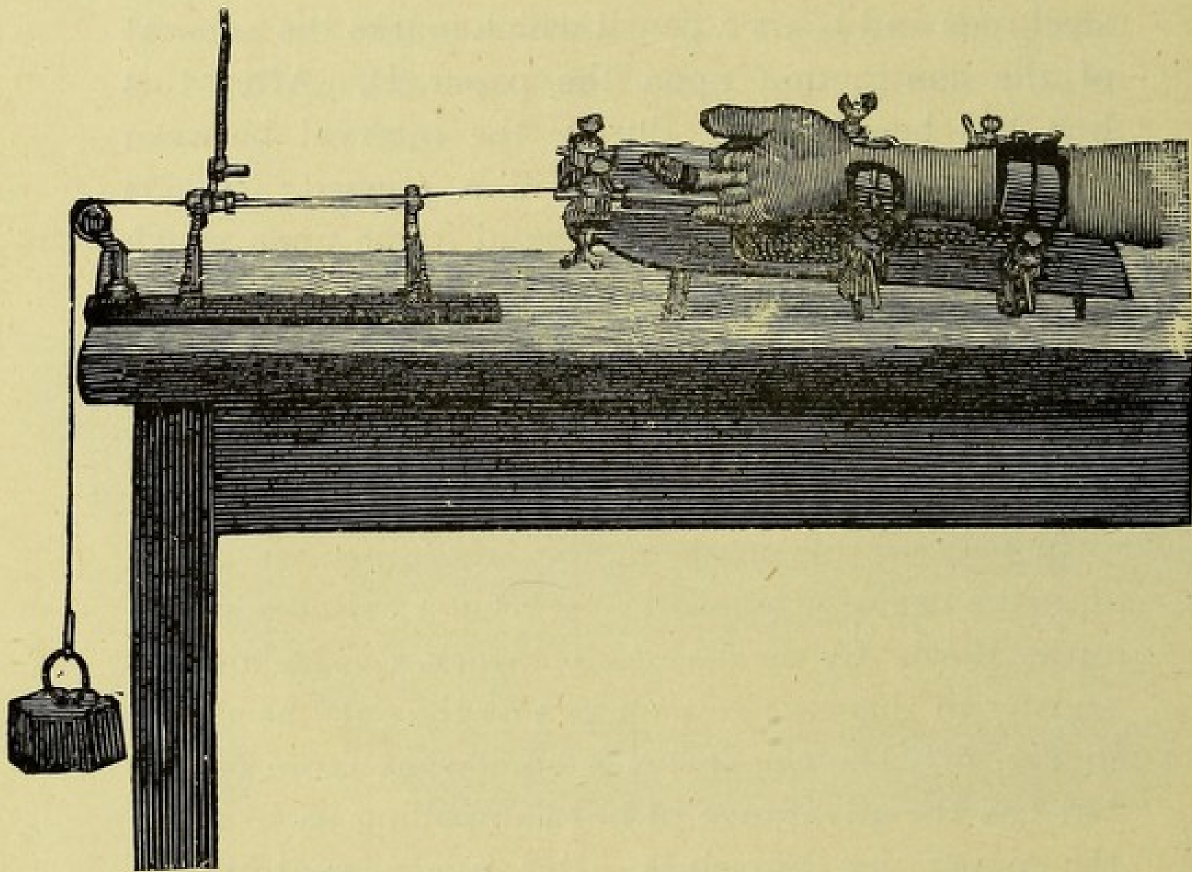

FIG. 6.—Arrangement of the ergograph to take a fatigue tracing.

ing an experiment. The only thing lacking is the smoked cylinder, which it was not worth while to represent. The contractions of the middle finger follow the rhythm of a simple pendulum marking seconds, or of a metronome.

V

Let us examine Fig. 7, which represents the curve of fatigue of Professor Vittorio Aducco, taken in 1884. The right hand was fixed in the ergograph in the manner represented in Fig. 6. The cord connected with the weight was fastened to the second phalanx of the middle finger, the flexion of which raised a weight of three kilogrammes. The registering

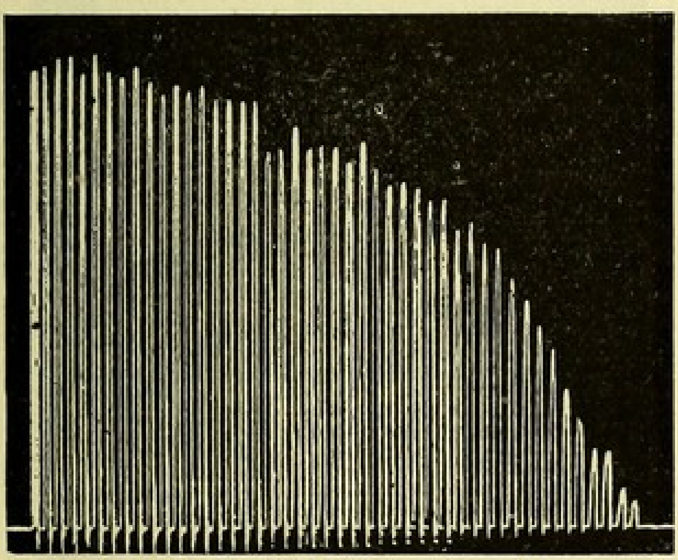

FIG. 7.—Fatigue tracing written by Professor Aducco in 1884.

apparatus marked the height of every contraction, as is shown in the longer lines on the left and the sudden fall thereafter to the position of repose. A metronome beat one stroke every two seconds. Following this rhythm, Professor Aducco continued to contract the flexors of the middle finger. We see that the length of the contractions gradually diminishes, until the muscles through fatigue are no longer able to raise the weight, and the tracing ceases.

The profile of the curve, that is the line which is obtained by uniting the summits of the contractions, forms a curve which varies in different people. I have been unable to find a reason for this fact, and have ended by convincing myself that it is in truth a constant feature which indicates the diversity which every one presents in his way of becoming fatigued.

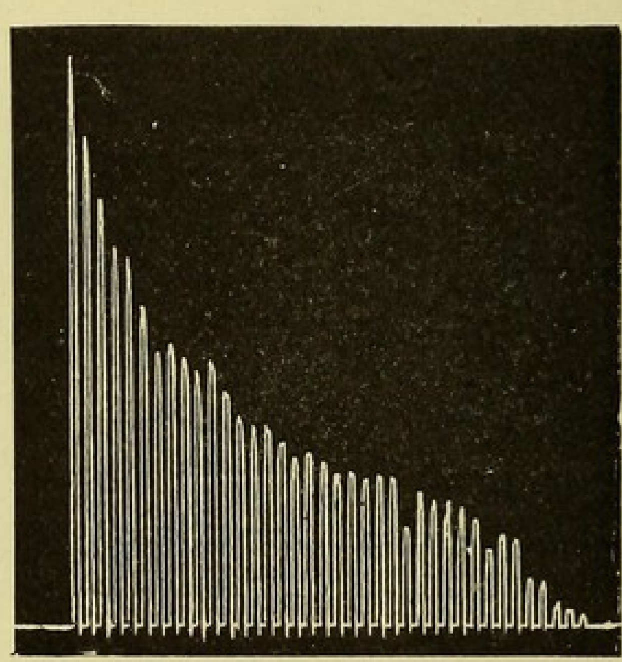

FIG. 8.—Fatigue tracing written by Doctor Maggiora in 1884.

Fig. 8 represents the fatigue curve of Doctor Maggiora in 1884. Comparing it with the tracing of Professor Aducco, we see how great may be the difference in the fatigue curve of two people in identical experimental conditions, that is, raising the same weight of three kilogrammes and following the same rhythm of two seconds.

Professor Aducco and Doctor Maggiora were both about twenty-eight years of age; they lived in the same surroundings, had the same occupations, and the same mode of life. Comparing the two tracings, we see that in the case of Professor Aducco the contractions at first maintained nearly the same height, to fall very suddenly when exhaustion of energy began. In other persons this sudden diminution of energy was still more apparent, even to the almost abrupt cessation of the contractions, which fell from several centimetres in height to a few millimetres.

Doctor Patrizi executed about forty-five contractions, which diminished slowly, and then suddenly and against his will the energy of the muscles disappeared all at once.[1] They executed a few more feeble contractions and then stopped. In Dr. Maggiora fatigue follows an inverse course, that is, the force diminishes rapidly at the outset, and then the contractions become gradually more feeble until exhaustion is reached. We have here a great change from the straight line found by Kronecker as the expression of fatigue in frogs' and dogs' muscles after separation from the body. This shows that in man the phenomenon is considerably more complex. We may say that in the muscular curve registered by the ergograph we read the characteristic difference shown by different

[1] Figures 7 and 8, and the others following, are a little smaller than the real tracings. On measuring upon the original tracing the height of the forty-six contractions made by Professor Aducco, and on adding them together, we found that he had raised a weight of three kilogrammes to a height of 1.177 m.; so that the work in kilogrammetres was 3·531. Dr. Maggiora in thirty-eight contractions raised the weight a height of 0·596 m. which is 1·788 kilogrammetres of work.

subjects in their resistance to work. Some suddenly feel tired and give up work, while others, more persevering, gradually expend their energy until by degrees complete exhaustion supervenes. The ergograph thus gives us a record of one of the most intimate and most characteristic features of our individuality—the manner in which we fatigue, and this feature remains constant. If every day at the same hour we were to make a series of contractions with the same weight and in the same rhythm, we should obtain tracings which all had the same outline, and thus we should convince ourselves of the constancy of the individual type of fatigue. For seven years I have been making experiments with my apparatus, and the curves of the different subjects have varied little.

In the memoir which I have published upon the laws of fatigue,[1] tracings are reproduced which demonstrate this constancy in the personal character of the curve inscribed by the ergograph. Here, for the sake of brevity, I confine myself to saying that these curves are similar, and that the tracings taken in 1888 cannot be distinguished from those taken in 1884.

Nevertheless, it would not be quite correct to say that the fatigue curve remains absolutely constant. Its type does vary when the conditions of the organism are modified. In the case of Dr. Maggiora there is a perceptible difference between the fourth and the sixth year, but he has become

[1] A. Mosso, *Le leggi della fatica studiate nei muscoli dell'uomo. Mémorie della R. Accademia dei Lincei,* 1888.

stronger, and his health is better. He is more resistant to fatigue, and while his curve to-day in its first part decreases rapidly, which is his personal characteristic, it presents in its second part a considerable resistance to fatigue before his energy has been totally exhausted.

As Dr. Maggiora and Professor Aducco have worked with me for about seven years, I have kept a whole series of their curves during that time. A month has never passed without our making observations with the ergograph, for some reason or other. I have therefore all the transformations, the augmentations and diminutions, which for various reasons their energy has shown.

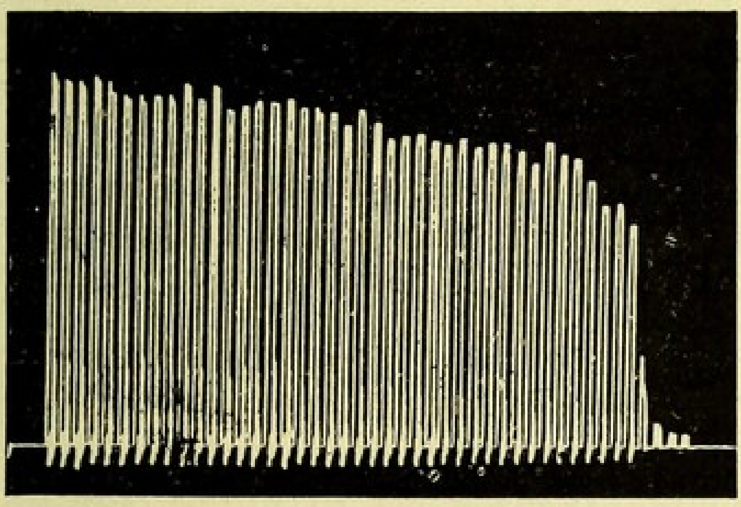

Fig. 9.—Fatigue tracing written by Doctor Patrizi in 1890.

I have observed that the variations are more marked in my colleagues who are young men than in myself, in whom the type has remained invariable.

To obtain the same curve every day, it is necessary to maintain our body under identical conditions.

The way of living, the night's rest, the emotions, mental fatigue, exert an obvious influence upon the curve of fatigue. Let one digest or sleep badly or indulge in any excess whatever, and immediately the curve changes, not only with respect to the duration of work, that is to say, the number of contractions, but even as to the type of the curve itself, so that any one whose curve was like that of Professor Aducco might, through the influence of debilitating causes, furnish one resembling that of Dr. Maggiora.

Such an alteration would affect not only the amount of work and the form of the curve, but also the time necessary for recuperation of the muscles, so that one would have to wait longer than in normal circumstances for the muscles to regain their energy. That is, we should find that after exhaustion of energy more than the usual two hours' rest would be required before the muscles could give again a normal curve.

A remarkable difference in the amount of energy occurs with change of season. I have convinced myself of the fact by numerous observations made upon Professor Aducco, whose nutrition is distinctly modified by the heat of summer.

Of all the causes which modify the physical condition, exercise is that which most increases the strength of the muscles. We see this in Fig. 10, a tracing by Professor Aducco, which is about double the length of the preceding one, the contractions being eighty in number, and the sum of their heights approximately 2·959m.

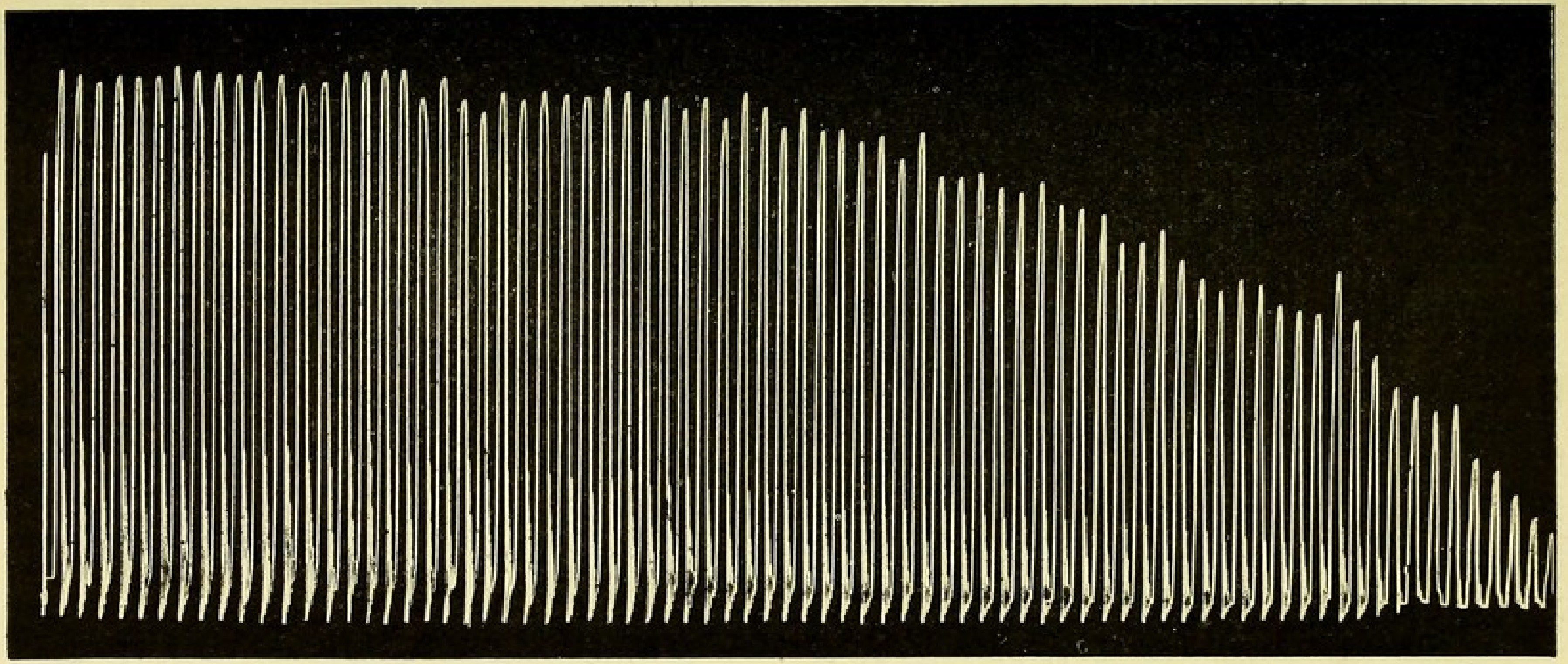

Fig. 10.—Tracing written by Professor Aducco, showing the effect of exercise in increasing the force of the muscles.

This tracing was inscribed whilst the cylinder was moving more rapidly than was the case for Fig. 7; hence in the former the lines are somewhat further apart; but the rhythm of the contractions was still every two seconds. The work performed during this tracing to exhaust the energy of the flexor muscles of the middle finger was 8·877 kilogrammetres. We see, therefore, that a month's exercise has doubled the amount of work.

When I deal with muscular fatigue, I shall have to devote a chapter to training, upon which I have made many experiments. I have thought it well to make mention of the influence of exercise, because my whole present exposition of the physiology of the muscles will serve as an introduction to render nervous fatigue better understood. Every one knows that we have a training for the brain also, and exercise has a great influence in rendering mental work easier. To give a single proof of this, let me quote what Victor Alfieri has written in his autobiography: "These were to me most delightful and most useful moments when I fell back upon myself and strove effectually to brighten up my poor intelligence and to revive in my memory the faculties of learning, which during those ten years of disuse had been obstructed beyond all belief."[1]

VI

Look now at Fig. 11, showing how the hand functions in the ergograph; note how the middle

[1] *Vita di Vittorio Alfieri*, p. 190.

finger, as it bends, occupies successively the positions M M′ M″, which represent the curve which must

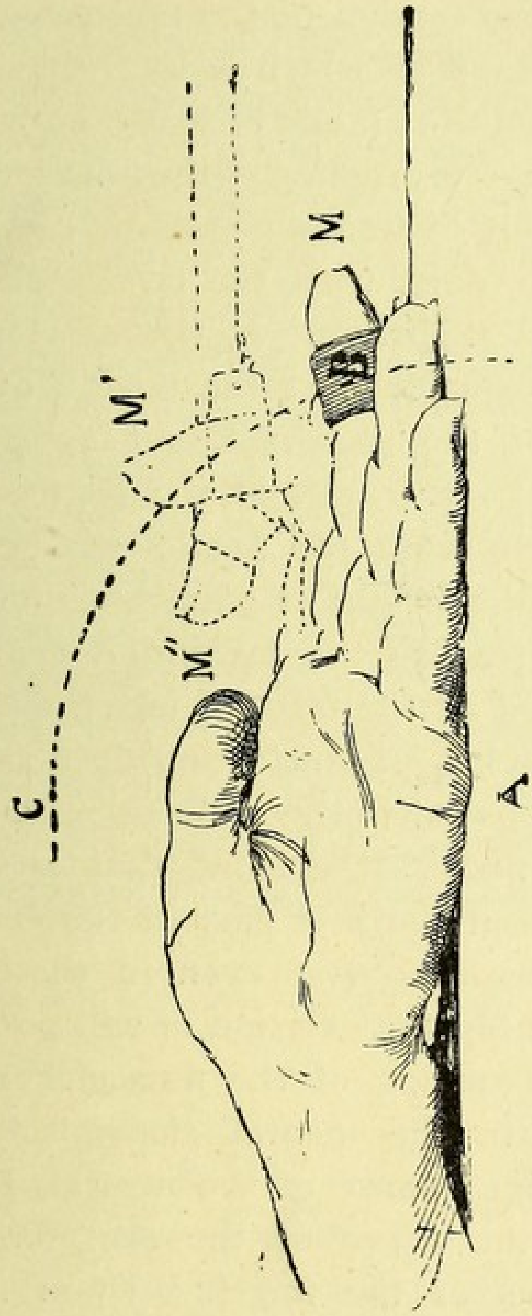

FIG. 11.—Successive positions assumed by the middle finger in raising the weight of the ergograph.

be described by the second phalanx, round which is passed the leather loop B, to which is fastened the cord which raises the weight. In order to eliminate the doubt that the movement of the phalanges might not correspond to shortening of the flexor muscles, I took the hand of a corpse, and attached to the tendon of the muscles a continuous screw, by means of which I was able to pull the tendon a definite (and measureable) amount, in imitation of the contraction of the muscle.[1]

As the result of this experiment, I may say that when work is done with the ergograph, the finger at rest being slightly bent, the shortening of the muscle is proportional to the flexion of the finger. The bones of the phalanges act as levers, which nearly double the length of the contraction of the muscles which cause the flexion of the fingers.

When a light weight is employed, one feels that at first one reaches the maximum flexion without having exerted all the force of which one is capable. But when one has become fatigued, in spite of every exertion, one is no longer able to raise the weight.

This fact makes it evident that an exact comparison between the first part of the curve and the last is impossible. But even in these conditions it is easy to keep the exertion of will power constant until the exhaustion of the muscular force.

To eliminate the mental element which might alter the fatigue curve of the muscle, I thought of stimulating the nerve of the arm, or rather the flexor muscles of the fingers. Upon applying an electric current to the skin, the electricity passes through it and diffuses to the muscles or the nerve found underneath.

1 For fuller details see Mosso, *Arch. ital. de Biol.* t. xiii, p. 135.

In this way one can make the muscles perform work without the aid of the will. Tracing 12

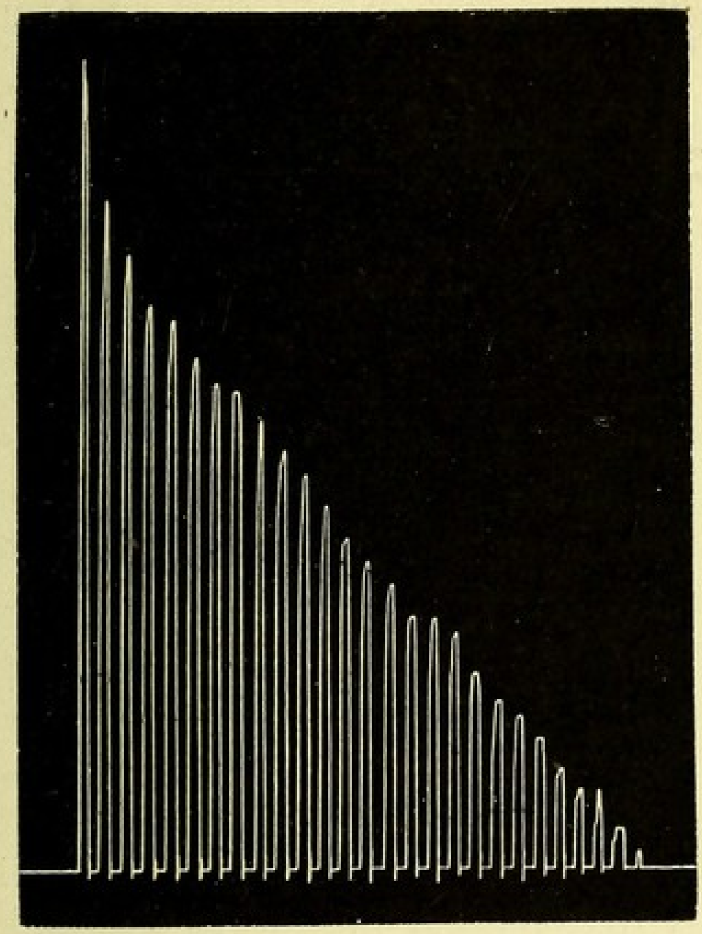

FIG. 12.—Fatigue tracing in a series of non-voluntary contractions. The flexor muscles of Dr. Maggiora's fingers were stimulated directly by an electric current, and raised a weight of one kilogramme.

represents one of these curves of artificial fatigue, if I may so express myself in order to indicate that in this case fatigue of both brain and nerves was excluded, the muscles having been stimulated directly by the electric current.

I shall not here delay to explain how the current was applied, because I should have to enter into too many particulars, which I have already given in the original works; I shall only state that the duration of the stimulus and the number and frequency of the electric shocks imitated as nearly as possible the instigation of the will. The flexion of the middle finger raised a weight of one kilogramme. The surprising feature is the regularity of this curve, which demonstrates that the energy of the muscle is exhausted by definite degrees when it does work without the participation of the will.[1]

Instead of stimulating the muscle directly we may excite the nerve. In this case, we apply the electrodes a little below the arm-pit, at the inner border of the biceps muscle, where in some people the nerve can be felt through the skin near the brachial artery. Such experiments are very important to us physiologists, because they allow us to see what takes place in the muscles when they work under the influence of a stimulus applied to the nerve, and become fatigued without participation of the brain in the work, as was the case in Fig. 13. We thus exclude the mental factor, and yet the curve maintains a certain resemblance to the voluntary curve. The correspondence cannot be complete, because the weights which the muscle lifted in these experiments were smaller. I have already said that, in Tracing 12, the muscle raised a

[1] [Speaking of involuntary fatigue in *Arch. ital. de Biol.*, vol. xiii, 1890, p. 139, Professor Mosso states that in some cases he found the summits of the contractions to form a straight line (as Kronecker did in the case of frogs), but that in most cases they formed either a convex or a concave curve. The curve, in short, varied with the person experimented upon.—*Tr.*]

weight of only one kilogramme. To make it raise three kilogrammes, so strong and so painful a current was required that I had not the heart to use it, in spite of the devotion of Dr. Maggiora.

In this tracing (Fig. 13) the middle finger of the right hand in its contractions raised a weight of three kilogrammes. Fatigue was produced with

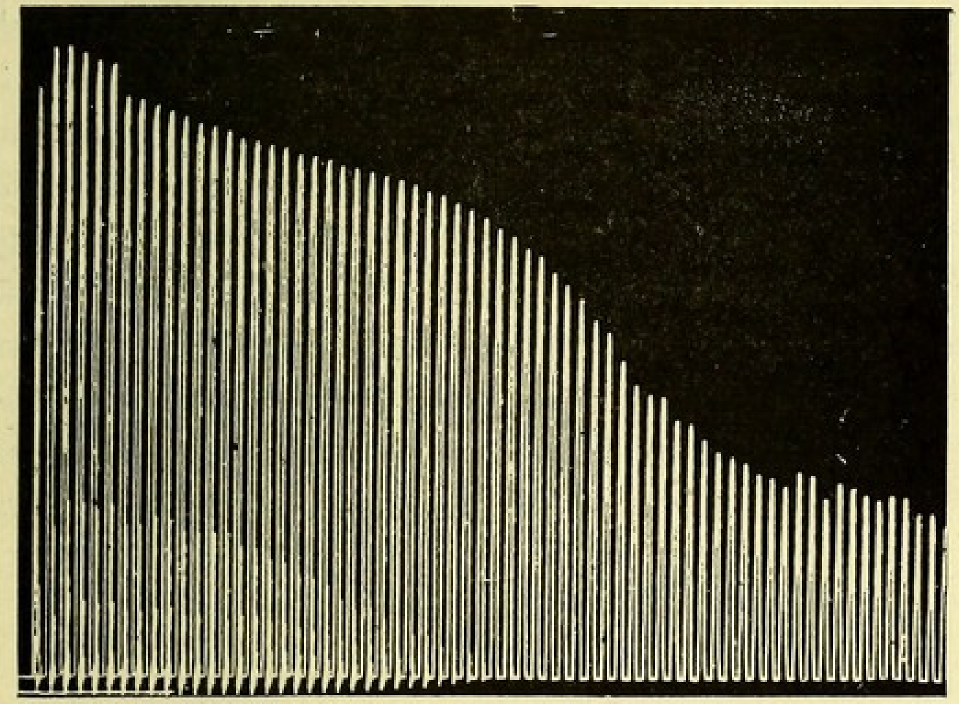

FIG. 13.—Fatigue tracing in a series of non-voluntary contractions, obtained by stimulating the median nerve in Dr. Maggiora's arm. The flexor muscles of the middle finger raised a weight of three kilogrammes.

the same curve as when the muscles contracted voluntarily. If the personal type of fatigue remains the same when there is no participation of the will, one must conclude that the mental factor does not exercise a preponderating influence, and that fatigue may even be a peripheral phenomenon.

We must admit that the muscles have an energy and an excitability of their own, which they exert independently of the energy and excitability of the nervous centres. The muscle is not an organ which obeys like a slave the commands transmitted by the nerves, because these cannot exhaust its energy in a different way from that in which it does itself when it does work without being incited by the will.

However complex may be the mental act which gives rise to a voluntary contraction, we must, after these experiments, recognise that the function of the muscle is itself not less complicated, and that the changes which are produced in the state of the muscles are equally characteristic. The most novel and interesting result of these researches with the ergograph is that we must attribute to the periphery and to the muscles certain phenomena of fatigue which were believed to be of central origin.

CHAPTER V

THE SUBSTANCES WHICH ARE PRODUCED IN FATIGUE

I

"WHEN we read the works of the celebrated physiologists Spallanzani and Fontana, who in the latter half of last (eighteenth) century shone in Italy like twin stars, we must confess that those men had the same end and sought to reach it in the same way as the latest generation of investigators, so magnificent were their methods and their achievements. Although not quite free from the error of vitalism, in their investigations they followed the rules of a sound induction, and were simply physicists and chemists who laboured in the field of physiology, and all the vast resources of chemistry and physics, with their united powers, they applied to the study of life." These are the words of Du Bois-Reymond,[1] the celebrated physiologist of Berlin, whose knowledge of history and of science was as profound as his genius was prolific of new methods of research.

Lavoisier discovered the composition of air in 1777, and was the first to understand the true sig-

[1] *Reden von* E. Du Bois-Reymond, *Zweite Folge*. Leipzig, 1887, p. 212.

nificance of respiration, which had been explained by the ancients either not at all or erroneously. Spallanzani confirmed the theory of the great French chemist, amplified and corrected it, and by his researches on the respiration of the tissues, opened a new horizon for science. The memoirs of Spallanzani on respiration[1] will serve as a model to all physiologists who after him analyse the gaseous products of respiration. Of the greatest importance is the idea expressed for the first time by Spallanzani that death from asphyxia is due to two causes: first, the want of oxygen, and second, the accumulation of carbonic acid within the tissues.

But the carbonic acid which is produced by the body is not derived immediately from the respired oxygen which is combined with the carbon of the tissues. Spallanzani demonstrated that animals give off carbonic acid even when they are immersed in hydrogen or carbonic acid gas. Unfortunately he died while he was engaged in writing his memoirs on respiration. Many years afterwards P. Bert took up the studies of the great Italian physiologist, and in a chapter on respiration in confined air he arrived at similar results.

Fatigue is a chemical process. At the end of the eighteenth century, Lavoisier, in a memorable series of chemical analyses made jointly with Séguin, succeeded in demonstrating a fact of fundamental importance, namely, that muscular exertion increases the quantity of oxygen absorbed and of carbonic acid eliminated by man.

[1] Spallanzani, *Memorie sulla respirazione*, vol. v.

The most demonstrative experiments in the analysis of fatigue are usually made upon cold-blooded animals, commonly on frogs. When the sciatic nerve is stimulated, we notice a contraction of the leg. The contraction, upon being repeated a great number of times, becomes more and more feeble. This diminution of energy is not to be attributed to the dissipation of some explosive substance, so to speak, in the muscle, that is to say of the substance capable of giving rise to contraction. In fact, the muscle will still continue to contract for a long time, but no stimulus will produce a contraction so strong as the first ones. The lack of energy in the movements of a weary man depends, as in the case of the frog, upon the fact that the muscles, during work, produce noxious substances which little by little interfere with contraction.

The proof that we are not here dealing with a phenomenon of deficit is found in the fact that after the frog's leg has been fatigued by prolonged exertion, we can restore its contractility and render it capable of a new series of contractions, simply by washing it. Of course we do not wash the outer surface, but having found the artery which carries blood to the muscle, we pass through it water in place of blood. But not pure water, which is a poison to all the cells of our organism — a fact which it is well to remember when one has to wash deep wounds. The muscles would swell up and die if pure water were introduced into the circulation instead of blood. Hence a little kitchen salt is added to the water (seven grammes to a litre), and this solution very closely resembles blood serum. Upon the passage of a current of this liquid through the muscle, the fatigue disappears, and the contractions return as vigorously as at the beginning.

We shall see in the sequel, in speaking of massage, that it is only necessary to knead a fatigued muscle well in order immediately to restore the energy which it had before it became fatigued.

II

Of all the functions of the body, respiration is that which is most visibly modified in the course of fatigue. Dante has expressed this physiological observation in some of his lines—

> And as a man by running sore opprest
> Suffers his comrades to pursue their flight,
> Until he hath relieved his panting chest.[1]

When old people are going upstairs they are obliged to stop every now and then for want of breath, nor does any amount of will power avail to drag them forward. And we all know the profound alteration which the respiration of a dog undergoes when we throw something to a distance and make him run in search of it.

I have made use of the regattas on Lakes Como and Maggiore to study the maximum frequency attained by the respiratory movements in intense muscular effort. After the exertion of rowing, the rate rose from fourteen per minute to the enor-

[1] *Purgatorio*, xxiv. 70. Wright's Translation.

mous figure of 120. These oarsmen, who are reckoned among the most vigorous men of Italy, respired with a frequency ten times as great as in repose. In some boat races I have seen the breathlessness become so great as to suppress respiration; the rowers, about the middle of the course, fell back as if breath failed them and they felt suffocated.

The breathlessness which seizes us when we run upstairs quickly may be explained in two ways. Recognising that in going upstairs there is a great expenditure of energy, because the weight of the body has to be raised a certain height, some say that the shortness of breath is due to the fact that we have to inspire a greater volume of air in order to furnish a greater quantity of oxygen to the organism which is undergoing more rapid combustion. Others, on the contrary, assert that, when fatigued, we take more frequent and deeper breaths in order to expel from the body the waste products of the muscles, that is to say, carbonic acid.

Let us examine these two theories. In the winter time, a frog whose heart has been removed and whose circulation is arrested, does not die at once. If the temperature is a few degrees above zero, the muscles continue excitable and contract readily even at the end of a week. In summer, the legs separated from the body can give contractions for a day at most.

As long ago as 1846 Matteucci demonstrated that the muscles of frogs separated from the body produce carbonic acid when they contract. And Professor Hermann of Königsberg demonstrated that oxygen is not indispensable for muscular contraction, seeing that one can produce it even in a vacuum.

Among the substances which are produced by fatigue in the muscles or in the brain, one of the most important is lactic acid—the same substance which is found in sour milk. Now carbonic and lactic acids are not produced by direct combination of the air we breathe with the muscle substance. It is, on the contrary, much more probable that the oxygen is already in weak combination with albuminoid substances which form the muscle fibre. During exertion these albuminoid bodies are decomposed, and, in producing mechanical energy, give birth to other chemical compounds such as carbonic and lactic acids.

An interesting experiment is that of Pflüger and Oertmann, who found that after removing the blood from a frog and replacing it by saline solution, the animal continued to move and to produce carbonic acid.

This experiment, with all its oddness, is highly significant. The blood, that mysterious liquid which Moses believed to be the seat of life and which Pythagoras called the nutriment of the soul, is not absolutely necessary to the functions of life, since we can remove it entirely and put saline solution in its place. The experiment is performed by cutting the abdominal vein and fastening therein a fine reed. Saline solution (0·75 per cent.) is then injected by means of a syringe until nothing but this clear liquid is circulating, and we obtain a frog which contains no blood. Frogs in this condition can live for a day or two, and during the first ten or twelve hours they are difficult to distinguish from normal frogs. It is not possible to perform such an experiment upon a warm-blooded animal, because the nervous system cannot stand so great a disturbance of its environment.

Shortness of breath as the result of movement may be seen in all animals, even in fish, which, as we know, need very little air, and breathe only the small amount which is found in the water. I have myself experimented upon eels. In my laboratory I have large aquaria with glass sides more than six feet in length, where I keep some very big eels, which live for several years. In order to breathe, an eel, like all fish, fills its mouth with water, which it then passes out through the gills. As the best means of discovering the alterations which take place in fish in the rhythm of respiration, I adopted the graphic method in preference to standing watch in hand and counting how many times they took breath per minute. I constructed a kind of telegraph to the air, by means of which the respiratory movements of an eel can be recorded on the smoked sheet of a revolving cylinder. In Fig. 14 every line represents a minute's time, and every notch corresponds to a respiratory movement of the eel. I must inform the reader that in winter an eel's respiration ceases to be continuous, and becomes periodic. The first four lines in Fig. 14 were inscribed during a period of repose in which the eel did not respire.

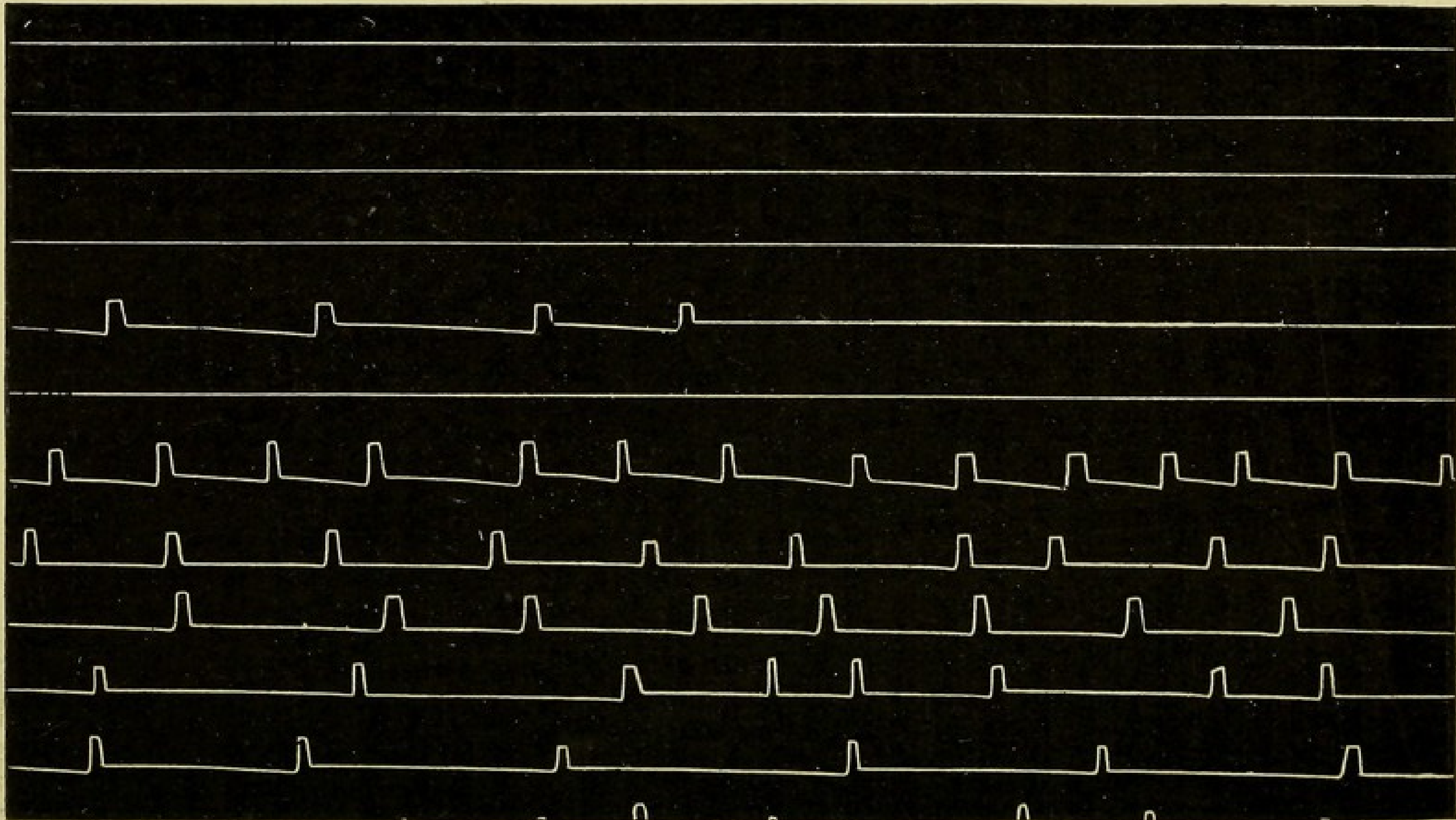

FIG. 14.—Augmentation in the frequency of an eel's respiration in consequence of vigorous movements which the animal was made to perform after the sixth line.

It is not that the eel falls asleep during this time, for it moves its eyes and fins, but it does not feel the need of taking breath. In consequence of the low temperature of the water the chemical activity of the tissues is diminished and the vital processes become slower, so that the animal requires less oxygen.

In the eel as well as in man, when the necessity for air diminishes, the centres of respiration, instead of causing very slow but regular breathing, begin to observe periods of activity and of repose. Eels breathe four or five times, as is shown in the fifth line of Fig. 14, and then remain for perhaps a quarter of an hour without taking breath. There are many maladies in which man exhibits similar periods in his respiration, the intervals of rest, however, being much shorter. Many hypotheses have been suggested by pathologists to explain this strange mode of respiration; but I have demonstrated that a normal man in a deep sleep presents periods which are quite as well marked, and that hibernating animals breathe only in this way. It seems then that pathologists may agree in recognising the physiological basis of periodic respiration.

In the eel observed each period of repose was very prolonged, lasting from ten to fifteen minutes, after which the animal made four or five respiratory movements. This extreme slowness of respiration made it necessary to cut off part of the tracing, there being no respiratory movement apparent in the upper lines.

The temperature of the water was about 6° C.

After the first six lines were inscribed, I suspended the observation and began to poke the eel with a stick in such a way as to force it to move, making it go up and down the aquarium for a couple of minutes. After it was allowed to lie quiet the respiratory movements were at once seen to be much more frequent. They are also much stronger, but of this increase it is impossible to give any measurement.

There is here another fact of which we ought to take account. Respiration depends not only on the chemical needs of the organism, but also on the physiological state of the nervous centres. When one is excited one breathes more frequently. In the sequel we shall fully discuss this fact, which I have called *nervous respiration* or *respiration de luxe*. In the meantime let us remember only that we have observed that even in fish the excitement of movement increases the frequency of respiration.

III

The experiment upon frogs' muscles washed in saline solution shows that, in order to maintain muscular contractility, there is no need of continual contact between the muscular fibre and the oxygen of the air through the medium of the blood; it is only necessary to eliminate the carbonic acid. The respiratory augmentation may be considered as necessary to remove this noxious substance from the blood, by means of more active respiratory movements. The augmentation would not, therefore, be comparable to the more rapid movements of the bellows of a forge by which a stronger current of oxygen is produced in order to make the carbon burn better, but rather to the ventilation of a theatre in order to remove the vitiated air, and expel the carbonic acid, which should not be allowed to accumulate beyond a certain limit.

But this second theory is still insufficient. While recognising that it is indispensable to free the tissues and the blood from the carbonic acid produced by muscular contraction, Geppert and Zuntz made known the existence of other causes which accelerate the respiration when the muscles are fatigued.

To render less incomplete this exposition of the most important opinions which physiologists have maintained to explain the dyspnoea resulting from muscular exertion, I will mention the experiments of Charles Richet.[1] When we breathe more rapidly the temperature of the body falls, for two reasons: in the first place, more rapid evaporation of water in the lungs takes place; and, in the second place, the air generally enters the body at a lower temperature than that of the blood, and is heated by it. If a dog is placed in the sun, its respiration is sometimes accelerated beyond what is necessary for the regulation of the temperature, and it may happen that the internal temperature of the animal, instead of rising, falls, although it has been lying exposed for several hours to the July sun.

Charles Richet has shown that we have two nervous mechanisms, which, independently of our will,

[1] Ch. Richet, *La Chaleur Animale*, Bibliothèque scientifique internationale. Alcan, 1889.

regulate the respiratory movements so as to cool the blood by aeration. The first is composed of the sensory nerves which are found in the skin; but, "if, for any reason whatever," says Richet, "this peripheral apparatus is thrown out of gear, the foresight of nature has prepared another and more central cooling mechanism, which takes its place when the stimulus of the peripheral nerves is at fault. This apparatus, which is found in the central nervous system, is a supplementary one, which does not normally function, but which is able to replace the reflexes produced by the cutaneous nerves when these are insufficient or when their functioning is interfered with."

If a dog make, say, sixteen respiratory movements per minute, and if one causes its temperature to rise by electric stimulation of its nervous centres, it will make 340 respiratory movements per minute when its temperature reaches 42·8°. This is an enormous increase, since the dog breathes nearly twenty-two times more rapidly than in the normal condition. But if the animal is cooled down to 39·7°, it will still take 240 respirations, that is to say, fifteen times as many as at first. There is therefore a degree of inertia in this apparatus for reducing the temperature by means of the respiration, for an animal placed in a much hotter atmosphere does not all at once respire with greater frequency, nor after return to the normal temperature does the dyspnoea cease immediately.

IV

The causes of the breathlessness which supervenes when one goes upstairs are therefore multiple, and from the rapid sketch I have given of the more important, we see how complex is the problem of fatigue.

The first idea was that the muscles when doing more work would require more oxygen. But it was shown that, even in the absence of oxygen, the contraction of the muscles gives rise to carbonic acid. Hence it was said that we breathe more quickly when we are fatigued in order to eliminate the carbonic acid. But by an indirect proof this hypothesis also was shown to be insufficient. Then came the theory of lowering the temperature; and again some physiologists would explain the augmentation in respiration as depending upon the disturbances which are produced in the movement of the blood during exertion; but even this opinion, which, for the sake of giving it a name, we may call the hydraulic theory, is not sufficient.

There is then nothing for it but to examine anew the muscles and the nervous centres, and to ask whether, in our organs, any substances other than carbonic acid are produced, which are capable of modifying the respiratory function. This is not the time to set forth or even to indicate the very complex investigations which have been made regarding the modifications which a muscle undergoes during exercise. I intend to take these up later; but in the meantime I cannot pass over in silence two important facts, because they mark the beginning of our knowledge of the chemistry of muscle.

In 1845 Helmholtz discovered that a muscle in repose contains only a small quantity of matter soluble in alcohol. Let 1 represent the quantity found. Upon taking an equal weight of muscle from a fatigued animal, he found that there was a greater quantity of such matter, the amount being 1·3. This is an experiment made, as the saying is, *en bloc*, by which one gets a glimpse of the changes which are produced in the muscles as the result of exercise.

Another discovery of no less importance is that of Du Bois-Reymond, who found that the fatigued muscle is acid, while the muscle in repose is alkaline. Physiologists are not yet agreed as to the significance and value of these two observations. Whatever be the outcome of the controversies to which they have given rise, it is certain that during work the muscle substance engenders waste products, dross, so to say, which is toxic.

To demonstrate that muscles accumulate products which interfere with contraction, Ranke made an aqueous extract of muscles which had been exercised, and having injected this into a fresh muscle, found that its power of exertion was diminished. After it had been washed, however, its energy returned.

A convincing proof that toxic substances are produced in the body is found in the infection emanating from corpses. Animals and man at the point of death undergo a modification which causes the liquids in their flesh and viscera to become poisonous. Every year in the great medical schools some professors or students are poisoned by the subjects, since a scratch or abrasion of the skin is sufficient to admit the virus ; and occasionally death results. Somewhat better known is the nature of other poisons arising from corpses, discovered by Professor Selmi, of Bologna, and named by him *ptomaines*.

In our organism toxic substances are produced continually during life.

It was a French chemist, Gautier, who isolated some of these substances which are derived from the albuminoids of living cells. He gave them the name of *leucomaines*, to indicate that they are chemical compounds arising from the decomposition of albumen. Here we have some very recent observations which open a new horizon in the study of the causes which produce disease. Brieger, of Berlin, who has distinguished himself greatly in this new line of investigation, has succeeded in isolating poisons produced by the bacilli of typhoid fever, of tetanus, of diphtheria, etc.

To convince ourselves that certain products of life are poisonous, it is sufficient to call to mind Koch's recent discovery.[1] The poisonous substance which he employed to inject into consumptives was obtained by the artificial culture of the tubercle bacillus. These minute organisms, which settle in the lungs, in living and multiplying produce a toxic substance. The better to explain Koch's idea, I

[1] *Deutsche med. Wochenschrift.* 1891, U. .

will quote a few of the words in which the celebrated bacteriologist announced his discovery: "Without positively affirming it, I imagine that when tubercle bacilli multiply in living tissues as in artificial cultures, they produce certain substances which have a toxic influence on the cells and the organic matter around them. Among these substances is found one which, when it reaches a certain concentration, kills living protoplasm."

In the same manner as the bacteria, the cells of our body—those of the brain, for instance—give off noxious substances, and the more intense are the vital processes of the brain the more abundant are the waste products of the cells which contaminate the surroundings amidst which they live, and, if one may so express it, soil the blood which, after having laved the brain, is to irrigate the nerves and cells of other parts of the body.

V

I have now given a rapid glance at the toxic substances which are produced in the organism. They are not so much poisons as dross and impurities arising from the chemical processes of cellular life, and are normally burned up by the oxygen of the blood, destroyed in the liver, or excreted by the kidneys. If these waste products accumulate in the blood, we feel fatigued; when their amount passes the physiological limit, we become ill.

Thus is our conception of fatigue widened. It is a process which, as we examine it, seems ever to become more complicated. Meantime, we know that fatigue is not produced merely by the lack of certain substances which are consumed during exertion, but that it depends also in fact upon the presence of new substances due to decomposition within the organism.

Observing that, after a whole day's walk, even the muscles of the arms are tired, I was struck by the thought that fatigue might alter the composition of the blood ; and so long ago as 1887 I found that the blood of a fatigued animal is toxic, for if injected into another animal, it produces the phenomena characteristic of fatigue.

An experiment which I communicated to the International Medical Congress at Berlin in 1890 is also very conclusive. Having rendered a dog unconscious with morphia, we can then inject into his veins the blood of some other dog without producing any modification either of respiration or of the beating of the heart. In a word, nothing happens which is worth mentioning. But if we strongly stimulate the nervous system of another dog by an electric current, and if we produce tetanus even for only a couple of minutes, the blood of this animal will no longer be normal. Injected into the veins of an unconscious dog, it produces difficulty of breathing and rapid beating of the heart. This does not depend upon carbonic acid, but rather upon the substances which have modified the composition of the blood, for if the blood is beaten up with air so as to arterialise it, it still remains capable of accelerating the respiration and the contractions of the heart.

The idea that fatigue is a kind of poisoning resulting from products derived from chemical changes in the cells is not new. The physiologists Pflüger, Preyer, and Zuntz especially did much to establish the basis for this opinion. But we are still at the beginning of our researches, and can say nothing precise as to the nature of these substances, and the question is so complex and so controversial that I shall certainly not attempt to indicate our present position with regard to it. I shall content myself with mentioning some of the more simple observations.

When any one who is not accustomed to the use of alcohol drinks a glass of wine or beer in the evening, it often happens that he suffers from a little headache in the morning. This is probably due to poisoning by leucomaines and other noxious substances which are produced in the stomach and digestive apparatus.

Headache is a common symptom in exhaustion of the brain. In most cases it is simply *a heaviness of the head* which is complained of. The cause of this sign of fatigue is to be sought for in the decomposition products of the nerve cells, which soil, with the waste products of work, the environment in which they live. Probably fatigue is localized in particular parts of the brain, for we often notice that people who have become incapable of thinking about a given question find relief in thinking about something else, or even get rid of the feeling of dullness by directing their attention to some subject of quite a different kind, such, for instance, as a game of chess.

However, even in these cases of intellectual fatigue confined to certain regions of the brain, it is recognised that the poisoning is general, for when the slight headache appears, it is accompanied by muscular fatigue, by exaggerated nervous excitability, by lack of energy, and changes of temper so that one becomes less cheerful.

Enormous individual differences of course exist, as every one constantly notices. Some people are tired after a short walk, others can do sixty miles without a rest. Some are intoxicated by one glass of wine, and a cup of tea or coffee keeps them from sleeping the whole night. The same differences exist with respect to the products of fatigue. More than anything else, exercise and habit enable men to resist fatigue both of brain and of muscle.

I applied to some of my military friends for information regarding the phenomena of fatigue observed among soldiers when they are learning to read and write. Colonel Airaghi replied as follows: "At the class examinations at which soldiers have to give proof that they are not illiterate in order to obtain their discharge, I have often seen great strong men perspire until drops of sweat fell upon the paper. At Lecco I saw one faint during the examination, then, feeling better, demand another trial; but on the threshold, at sight of the paper and book, he turned pale and fell into a fresh faint."

Undoubtedly brain work, to those unaccustomed to it, must cause more fatigue than exercise of the muscles.

MacCauley relates the story of some Indians in Florida whom he interrogated with persistence, with the result that they very quickly became quite paralysed, so rapidly did the strain of attention exhaust the energy of their brains. One of them asked him not to ask any more questions without giving him time to rest, so that he might be able to understand; and afterwards begged that he would return next year to interrogate him, saying that he would go to school in the meantime, and that he would undoubtedly answer better afterwards and without so much fatigue.[1]

There are some people, robust so far as the development and energy of their muscles are concerned, who are incapable of any intellectual work. Even the reading of newspapers and stories fatigues them. They write no letters, nor occupy themselves with business, nor engage in conversation, because whenever they have to speak at any length they feel great discomfort, palpitation, headache, and great prostration following any brain work whatever which has been continued for a short time. I have known young people who succeeded in passing the matriculation examination and then had no energy to continue their studies at the University. Others at a later period became incapable of giving themselves up to their work.

One of my pupils, a young man of very lively intelligence, had passed all the medical examinations with honours, and had taken his diploma. He was ambitious of following a university career. His first published works made an excellent impression. Then,

[1] *Seminole Indians of Florida,* by Clay MacCauley. *Fifth Annual Report of the Bureau of Ethnology,* 1883–4, p. 493.

all at once, he stopped work, brought out no other publication, and allowed his name to be forgotten. I learned that he was suffering greatly from headache, that he had become slightly melancholic, but that, nevertheless, he continued to attend assiduously at the hospital. One day I met him, and he told me in despair of the profound alteration which had taken place in his power of intellectual work, which was diminishing continuously, until the reading of even a few pages fatigued him. This resulted from no defect of his eyes, which were very good, but from enfeeblement of brain power. Apart from this he was feeling well, and was taking long walks, so that if it had not been for this progressive inability to work, and the chagrin of seeing his hopes rudely shattered, he would have had no reason for uneasiness. I comforted him by telling him of other cases where this condition had been transient.

Sometimes incapacity for mental work shows itself at an advanced age. I asked one of my teachers, when he was old, whether intellectual effort cost him greater fatigue than when he was in his prime. He told me that little by little he had had to lay aside scientific books. No one would have thought much of this, on account of his age, but the reason which he gave me certainly showed that scientific thought was becoming more fatiguing to his mind, and that his mental energy was no longer capable of tackling works of that kind. He said to me, "I am an assiduous reader of novels, even during the night; but if I take up any scientific treatise or paper, my eyes become red and give me pain."

VI

When we speak of " excess in eating or drinking," we give no measure of what constitutes excess, because this is relative to the person of whom we speak. It is with fatigue as it is with love. What would constitute excess for some, for others is merely an agreeable stimulus, for which they feel the better.

Medical men call those people *neurasthenics* who quickly exhaust the energy of their nervous centres, and who are slow in repairing the loss of that energy. We shall see in the sequel that there have been neurasthenics who, in spite of the frailty of their nervous system, have produced immortal works in science and art. For example, I cite the name of Charles Darwin. In robust people fatigue produces merely a local disturbance of the organs which were taxed, such as the brain, the eyes, the muscles, etc. In neurasthenics fatigue very readily induces general disorders.

We perceive, therefore, that there are other considerations which must be added to the preceding, and which increase the complexity of the question which we are studying at present. Different persons vary in their power of resistance to the toxic action of the products of fatigue, or, at least, have different supplies of energy in the nerve cells, and vary in the rapidity with which their organism repairs its losses.

But I have not concluded my enumeration of the causes which produce the phenomena of fatigue. We have all noticed how the feet become swollen after a long walk. The work of any organ is always followed by a change in the circulation of the blood and lymph. If the activity of the organ passes a proper amount, this is made known by oedema and great redness in the neighbourhood. A very slight disturbance of the lymphatic circulation of the brain is sufficient to make itself manifest by a modification in function.

Professor Guye recently described a disease following upon a nasal disorder, to which he gave the name of Aprosexia, that is, the incapacity of fixing the attention on any subject whatever. I give here one of the clinical reports published by Professor Guye.[1]

"S——, medical student, twenty-three years of age. When he was a boy, suffered from chronic catarrh of the nose. Three years ago he found himself unable to think on the day following a bad night's sleep. After a few days this sensation disappeared of itself. A year ago the phenomenon recurred, after a slight excess in drinking. The patient remained in bed for a day, and the inability to think disappeared. Three weeks ago, after having worked longer than usual in the evening and passed a sleepless night, he found it absolutely impossible not only to work, but even to read; and when he attempted to force himself to do so, he felt a slight vertigo. This condition continued for three weeks. The least intellectual exertion produced headache and dizziness. He has not courage to take up even a newspaper. Sometimes he determines to attend a lecture, but has to constrain himself not to listen

[1] Guye, *Deutsche Med. Wochenschrift*, 1887, U. 34.

carefully, and not to think of what he hears, because attention causes him great discomfort. In this state he had decided to give up his studies and devote himself to a country life, because he thought the disease was incurable. On examining his nostril, Professor Guye found a large adenoid tumour. He extirpated it, and after two months, the deep cavity in the nose being quite healed, the student was able to return to his work."

Professor Guye reports several similar cases showing that a disease of the nasal mucous membrane may bring about a grave disorder in cerebral activity, characterised by inability to fix the attention upon anything or to constrain the brain to any occupation. We cannot regard this inability to think as a phenomenon of fatigue, because it appears without the commission of any previous excess.

Of course, in everyone there is an aprosexia caused by fatigue, since exhaustion of the brain renders us incapable of thought, but although the result is the same, the mechanism and the origin may be different.

Professor Guye explains this phenomenon by the supposition that the swelling of the nasal mucous membrane produces an interference with the circulation of lymph in the brain, and that this is the cause of a disturbance in cerebral nutrition, which brings about the incapacity for thought. In schools he has often observed aprosexia arising from diseases of the nose, and in the case of children whose work was deteriorating, he has sometimes been able to assure himself that they slept with their mouths open, and that the cause of this was the state of their nose.

A very little thing suffices to interrupt the work of thought, and to disturb the reason. Proofs of this abound, but here is one, little known to the lay public, namely, the disease called *folie circulaire.* This occurs in lunatics who have lucid intervals with complete clearness of intelligence, and who after a short time relapse into furious delirium. The accessions of mania may last more than one day, even for weeks or months, but the extraordinary thing, which astonishes any one who has witnessed it, is the sudden cessation of the attack, which disappears as if by magic. The patient desists from his cries and excitement, his eye becomes tranquil, he understands what is going on, and addresses himself to the attendant, begging him to unloose him. The lucid interval may last only a single day, and there are some lunatics who are of sound mind every other day. Some people become mad regularly once a year, and others have even longer lucid intervals.

The famous philologist Gherardini, after a terrible domestic tragedy, had his nervous system so shaken that he became seriously ill. Professor A. Verga[1], who published the history of this illness, writes—

" Sensation, internal and external, was abolished. Doctor Gherardini perceived neither hunger nor thirst, neither heat nor cold, neither taste nor smell. Stuporose, sleepless, without energy, he seemed likely to die of inanition. But one morning, after having slept at last, he felt the desire for a pinch of snuff. He roused himself, seated himself at the table, seized

[1] A Verga. *Della malattia che trasse a morte il dottor Giovanni Gherardini*, Milan, 1861.

a pen, and wrote his work, *Voci e maniere di dire additate ai futuri vocabolaristi*. But if the intelligence appeared to emerge from that illness strengthened, the physical powers retained a bitter souvenir."

After seven years he had a relapse, with the same profound stupor. Artificial nourishment was necessary. He no longer swallowed, and the saliva flowed from his mouth. After presenting this melancholy spectacle for a year and a half, he recovered his intelligence all at once, and began to write another treatise, the *Lessigrafia e il Supplemento ai Vocabolari*. After other seven years he had a third attack, but Dr. Gherardini was now seventy-seven years of age, and strength was wanting for a third resurrection.

CHAPTER VI

UPON MUSCULAR CONTRACTURE AND RIGIDITY

BEING unable to separate the study of the muscles from that of the nervous system, I have thought well to restrict myself in this book to the study of brain fatigue. This choice does not arise from my having more knowledge of this subject than of muscular fatigue, the contrary is indeed rather the case ; but since up to the present, so far as I am aware, no one has written a book upon cerebral fatigue, it has occurred to me that it may be useful to collect and arrange the observations made by others on this subject and join them with my own.

I shall speak of muscular fatigue and of the changes which take place in the muscles only so far as may be necessary for a better understanding of fatigue of the brain. The problem of the soul is so great, so sublime, that the desire to attempt, apart from any hope of solving it, is of itself an end to inspire the mind.

Let us now try to understand some of the more important changes which take place in the muscles, and subsequently we shall consider whether there are any changes in the nervous centres which resemble those which occur in the muscles as the result of use.

At rest the flexor muscles of the fingers are at an advantage. It requires an effort on the part of the extensor muscles to overcome the natural flexion of the fingers in repose. Too strong a contraction or excessive work will keep the muscle from relaxing completely, and to this condition of abnormal muscular tension the name *contracture* has been given.

Suppose we seize hold of the bar of a trapeze and raise the weight of the body several times by our arms; or again, suppose we row for a considerable time; we shall find that, if our arms are afterwards allowed to fall by our sides, our hands will remain closed.

One of the most common examples of contracture is furnished by *rheumatic torticollis.* When, from any cause whatever, the sterno-cleido-mastoid muscle becomes permanently contracted, we are no longer able to hold the neck straight. The chin deviates to the opposite side and is slightly raised, so that the head is inclined towards the shoulder. By touch we feel that there is upon this side of the neck a tense muscle which we are unable to relax voluntarily.

There are some people of an excitable disposition who experience, when weary of writing, extreme fatigue in the hand. The movements of the fingers become painful and uncertain. The difficulty is increased when they feel themselves watched, and pay greater attention to what they are doing. Their writing is much affected, and in some cases becomes almost undecipherable. In the case of clerks who have much writing to do, the trouble makes very rapid progress. After an hour or two of work they are obliged to stop, because their hand shakes and their fingers become almost rigid. Scarcely have they ceased writing when the hand and arm no longer present any irregularity in their movements, although the pain persists. This trouble, which is known as writer's cramp, is very common. The most characteristic symptoms are great fatigue in the hand and a difficulty in the movements of the thumb, the index and the middle finger.

Some people find the writing of a few lines sufficient to exhaust their hand ; they are forced to desist not only because the writing becomes illegible, but also on account of the pain, the tingling, and the sensation of tension which they experience in the muscles of the hand. When muscular cramp occurs in pianists and violinists, it forces them also to rest. Usually such persons are hypochondriacal, nervous, and slightly hysterical ; they misuse their muscles, and are so excitable that a few minutes' work is sufficient to bring on the contracture.

There are very good swimmers who dare not go far from the shore, because they are afraid of cramp in their calves. We have all experienced the pain caused by cramp when it occurs unexpectedly at night during sleep. Usually it occurs after muscular contraction, but in very nervous people it may happen when the legs are immobile. Upon feeling the leg, we may discover which muscle is contracted. In spite of all efforts of the will, we are unable to relax it, and the pain may continue for some time.

Among hysterical women contracture is common, and doctors observe it also in some diseases of the spinal cord. Contracture is therefore a phenomenon depending upon the nervous system, but it may also be of local origin. There are some hysterical people in whom it is sufficient to compress a muscle slightly for it to enter the state of contracture and be unable to relax, so that one may produce an artificial torticollis by gently squeezing or even by merely touching the sterno-cleido-mastoid muscle.

In hypnotised subjects, sometimes the fingers, the arms, the legs, the muscles of the trunk and of the neck retain without resistance the position in which they are placed, as if the subject were made of wax. This particular state of the muscles is also known under the name of *catalepsy*, and is seen more especially in the hypnotic state, so that some authors would call it *experimental catalepsy*. By touching the muscles of the face or of the eyes, contractures and grimaces which may last for several hours are produced.

Sometimes contracture becomes a grave disorder, and there are hysterical subjects whose extremities remain fixed in certain positions, without their being able to move them. Only under chloroform do the muscles relax, but no sooner does the action of the anaesthetic cease than the contracture is reproduced. Some women who had their arm flexed, and who in spite of every effort of their will were unable to extend it, found it in another position when they awoke, but still contracted and rigid, the position having been changed when they were under the influence of chloroform. This is *spastic* contracture, and may be seen occasionally in somnambulists; it may last for some minutes, for hours, or even for whole days.

The pathology of contracture has been studied especially by Charcot, whose masterly pages upon this subject are to be found in his works upon nervous diseases, in which are photographic reproductions of the strange attitudes of these patients.

II

The diseases of muscles may all be classified as involving either an exaggeration or a diminution of function. Let us look at the physiological conditions which underlie these pathological facts.

Professor Kronecker in 1870 gave the first exact description of the phenomenon of contracture. With him were associated several physiologists—among others, Rossbach, Ch. Richet, v. Frey, and v. Kries. But none of these experimented upon man. Now, by means of the ergograph, we can easily study in ourselves the phenomena which have been observed in frogs.

I shall begin by giving a tracing of contracture (Fig. 15), in order to show how this phenomenon presents itself in the train of electric stimulation of muscles.

Doctor Colla with his hand fixed upon the ergograph supported a weight of 500 grammes attached to his middle finger. To the flexor muscles we applied an induced current. Every two seconds the stimulus made them contract independently of his will.

We see in the tracing that the second contraction is higher than the first, and so successively with those which follow, so that a sort of ladder is formed by the first five contractions. As the result of contracture, the muscle once contracted does not completely relax. At the summit of the ladder is a

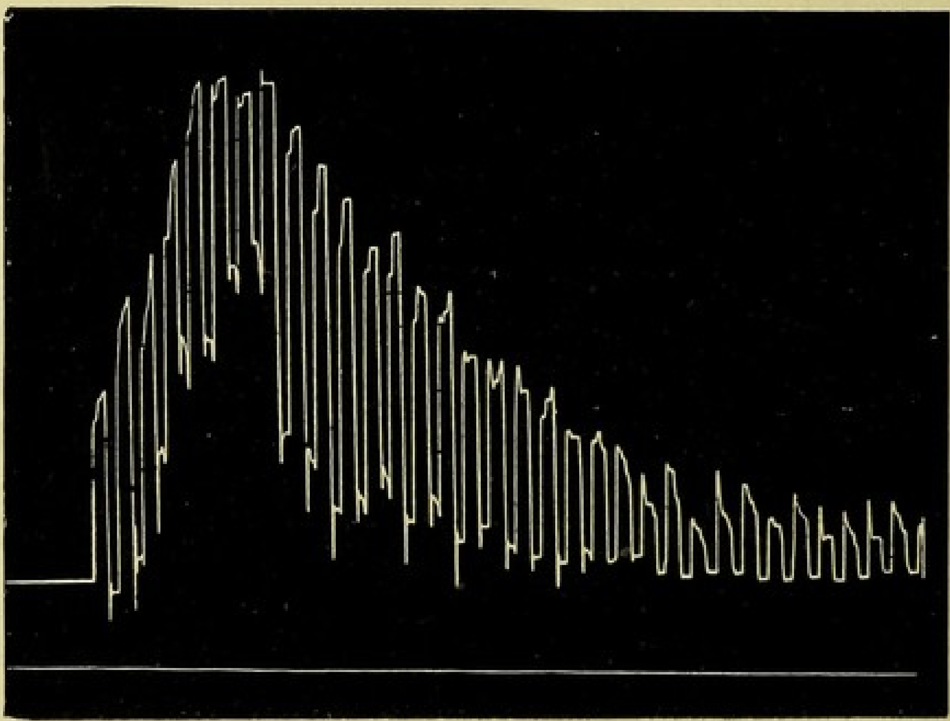

FIG. 15.—(Dr. Colla) Contracture of the flexor muscles by direct electrical stimulation.

more feeble contraction, then all at once the phenomenon of contracture ceases, and the descending portion of the curve (otherwise called the relaxation of the muscle) tends to return to the normal state. It is important to observe that when the contracture diminishes fatigue begins to show itself, or, at least, the height of the contractions begins to diminish.

The phenomenon of contracture may also be observed in voluntary contractions, and in some people this state is so marked that the muscles are able to keep raised a weight of three kilogrammes.

Kronecker had already observed that in the frog contracture is always produced at the beginning of a series of contractions, that it quickly attains its maximum, as we have seen reproduced in man, and then disappears. A rest of even two minutes suffices for it to disappear.

By the employment of a stronger electric current the phenomenon of contracture becomes more marked, as is seen in the following experiment (Fig. 16)—

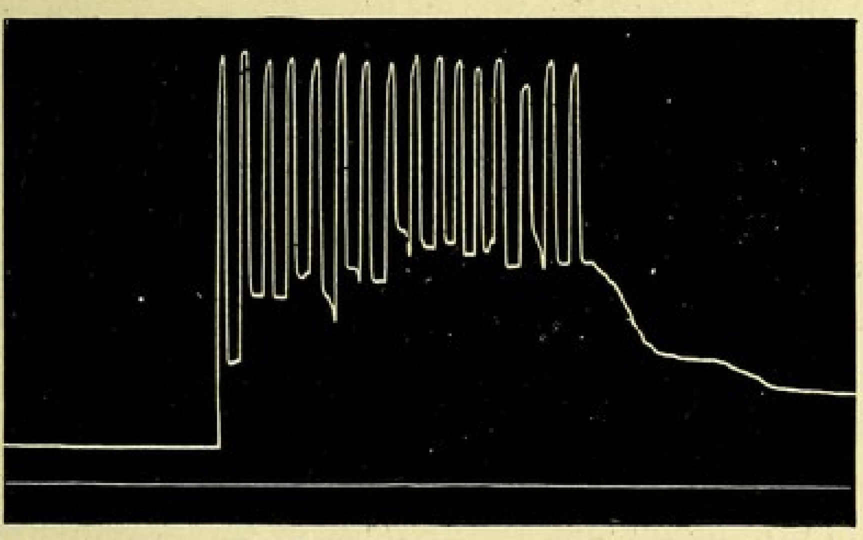

FIG. 16 (Dr. Colla) Contracture by a stronger electrical stimulation than in the preceding tracing.

The middle finger of the left hand supports a weight of 200 grammes. The muscle is directly stimulated by an induced current, and a first contraction takes place. When the stimulus ceases, the muscle does not relax completely. After two seconds the stimulus is repeated; the muscle contracts, but does not wholly relax, and thus the middle finger remains flexed, contracting at every stimulus. After sixteen contractions the current is withdrawn; and then the contracture ceases in the muscle, which slowly relaxes, as is shown in the tracing.

Ch. Richet had previously made some very important observations upon contracture in the muscles of the crayfish. He found that the muscles no longer exhibited the phenomenon when the crayfish had been kept for a long time in captivity away from their natural surroundings. Even by using a very strong current he could obtain no trace of contracture. This failure Richet attributed to diminution in the excitability of the muscles.

In man also very remarkable differences may be observed. I have found contracture more marked in very excitable persons. That contracture is a phenomenon which occurs independently of the action of the nervous system is shown by the fact that it was first observed and studied in muscles removed from the body. As I found it more marked in very nervous people, I concluded that in such persons all the phenomena of exaggerated excitability should not be laid at the door of the nervous system, but that in them even the muscles have a higher degree of excitability.

All the muscles are not equally excitable. For instance, the flexors of the foot of a frog contract more readily than the extensors, but the flexor muscles also fatigue more readily than the extensors.

If a muscle is fatigued and the circulation of the blood in it is then obstructed, contracture appears at once.

Contracture as it presents itself physiologically is therefore the beginning of a pathological phenomenon. Sometimes one may notice in patients suffering from paralysis of the facial nerve that, after the muscles of the face have been stimulated by too strong electric currents, they immediately pass into the opposite state of persistent contracture ; so that the half of the face which had been expressionless and death-like on account of the paralytic immobility becomes on the contrary contracted and distorted for a considerable time.

Even in healthy people we should consider contracture an abnormal and almost pathological phenomenon, a symptom characteristic of an alteration undergone by the muscle under the influence of a too strong stimulation, and therefore as a kind of fatigue which is manifested by the muscle at the beginning of its activity. I think it highly probable that the first contractions of a thoroughly rested muscle are of a different nature from those made by a fatigued muscle.

In short, I regard the physiology of a muscle in repose as different from that of a muscle in a state of fatigue. We observe that, when the phenomenon of contracture at the beginning of a series of contractions has passed off, those which follow, if fatigue does not supervene too quickly, are much more like one another than they are like the first contractions. Evidently the phenomena here are complex. A muscle undergoing exertion rapidly modifies its excitability. It seems strange to suppose a muscle beginning to work after a long rest produces at once a sign of fatigue under the influence of a too strong nervous stimulus, and that this fatigue persists although the contractions augment in amplitude, but I see no more logical interpretation of the facts.

III

We are all aware that our eyes become fatigued when we read or write. The explanation of this fatigue, which is easily produced, I must postpone to another section of this book. Meanwhile, I shall examine certain alterations in vision which appear to me to be connected with the phenomenon of contracture.

In order to see a near object, we have to modify the form of a lens made of living substance which is situated in our eye. A muscle is found at the periphery of this lens, and is inserted into it like a girdle. This muscle, which is called the ciliary muscle, modifies by its contraction the radius of curvature of the lens, and so enables us to see distinctly near or distant objects. When the object regarded is near, we must modify the eye, just as in the same circumstances we lengthen a telescope. The ciliary muscle has to contract every time we look at near objects, as in reading or writing, and it remains contracted so long as our attention is fixed.

There are some people, to all appearance quite strong, who cannot long bear the strain which is necessary for fixing their eyes upon a near object.

When they begin to read or to sew, they see clearly the objects which they focus, the words or the stitches, but after a certain time their vision becomes dim. At first they think that tears or mucus veil their eyes. They shut their eyelids and rub them. After resting a little, they again see things as distinctly as at first, but in a few minutes, if they still continue to work or to read, vision again becomes confused, and their eyes become red and painful if they persevere long. To this fatigue of the eyes the name *asthenopia* has been given (ἀσθενής, feeble). Rest has such an effect upon vision that some workmen, such as printers, tailors, and shoemakers, after their Sunday rest, see very well for several days ; but in the middle of the week the symptoms of asthenopia recommence ; and so troublesome are they that the sufferers have to cease work and go to the doctor, complaining not only of obscurity of vision, but of pain extending from their eyes to the frontal and occipital regions of the head.

Sometimes defect of vision is due to a state of excessive contraction of the ciliary muscle, and here the condition is the reverse of the preceding. There are some very impressionable people who, after emotion, become suddenly shortsighted.

A lawyer, whose case Schmidt Rimpler has published, used to carry about with him two pairs of spectacles. When his mind was calm, he used the weaker glasses, but he knew that in the excitement of a speech he would require the stronger ones, to enable him to read. Nearly every one experiences an analogous phenomenon, but to a slighter degree.

When we read for a long time, there results in the ciliary muscle a condition of persistent contraction similar to that which keeps the hand closed after a long and hard pull at the oars, or after a fatiguing exercise on the trapeze.

This is an extremely common phenomenon ; all who read much suffer from it more or less, and the pain which we feel in the eyes after having over-fatigued them depends on this *spasm of accommodation*, as this pathological state of the eye is called. I shall quote an observation made upon myself in order to show what are the conditions and what the symptoms of this fatigue of the eye.

My notes of the observation are as follows—"To-day I read for about five hours consecutively. I was looking for something which I thought should be in a book, and I read almost a whole volume, running through it attentively. When I had finished I found I was tired, and I went out on the Valentine Road. I felt a great desire to close my eyes, and the houses and trees on the hill of Turin appeared to me a little cloudy. I had a newspaper in my hand, and I found that I saw the words very clearly. I repeated my experiment several times, looking first at distant then at near objects, and convinced myself that I had a spasm of accommodation, and that the ciliary muscle, having been contracted too long during my reading, could not relax and let the eye return to the position of repose necessary for looking at distant objects. After about half an hour this affection of vision passed away."

School children often suffer from this spasm of accommodation. Reuss found it in twenty-five per cent. of the pupils in the Vienna gymnasia ; and this liability of the ciliary muscle to persistent contraction tends to modify the form of the eye and produce myopia. Doctors are now all agreed in recognising the strain of accommodation caused by looking at near objects as the most frequent cause of myopia in schools.

IV

There is a disease called Thomsen's disease (from the writer who first described it), in which the phenomenon of contracture is produced every time the patient wishes to perform a voluntary movement. The disease is hereditary : Thomsen was himself a sufferer, and for the four previous generations it had been in the family. If such a person has to go upstairs, the first step will cost him a great effort, and he will have to make use of his arms to aid his ascent ; but in a few seconds the rigidity diminishes so much that he will ascend the last steps as quickly as a normal person.

A conscript in the German army suffering from this affection greatly puzzled the doctors, who were not acquainted with the disease, and thought he was simulating a defect. The only symptom that he presented was that he could not take the first steps in line with the others when the command to march was given after a few minutes' rest ; thus he was always behind during the first movements of the drill, but after these were over all went well. One of Professor Eulenburg's patients told him that in dancing she had had great difficulty ever since she was a girl in taking the first steps, owing to a severe pain in the calves of her legs, but that she could do the final turns as well as any one.

The French proverb *ce n'est que le premier pas qui coûte* assumes visible shape in this disease. The rigidity which appears in the muscles every time the sufferers perform a voluntary movement does not show itself only in the legs, but in every part of the body. Even in the muscles of the eye and tongue the symptoms appear, but there they are less apparent. After a long silence the first words pronounced come out with difficulty, and sometimes in eating the mouth cannot be properly opened. One of my acquaintances here in Turin suffers slightly from Thomsen's disease. He is a strong man, but every morning just after rising he has for a few minutes great difficulty in walking. He told me that he suffers from this contracture more especially in winter. In summer he feels it only when he has had a long walk.

The muscles of such people are very excitable, and contracture can easily be produced in them by means of the electric current. The disease is therefore the exaggeration of a physiological state, and it is neuropathic individuals who are most subject to it. The malady is not dangerous, and in old age tends to disappear.

Although contracture may be regarded even in healthy persons as a pathological phenomenon, we must not suppose that the muscle is rendered by it less suited to its work. We have here an inconvenience which nature, if I may so express myself, has been unable to avoid. In order to obtain certain useful results she has been obliged to put up with certain inconveniences. There are moments in which contracture is even an advantage to the muscle. In exceptional circumstances when a very strong contraction may prove the safety of an individual, contracture becomes necessary, since when it is added to contraction the maximum shortening and maximum strength of the muscle are obtained.

V

That the albumen of an egg changes from liquid to solid under the action of heat is a well-known fact. In the blood we have a liquid albuminous body which coagulates without the aid of heat as soon as it issues from the blood vessels ; in the tissues of the organism there are other liquid albuminous bodies which solidify on the cessation of life. The rigidity of death is a phenomenon of coagulation.

Some animals—the sardine, for example—become rigid with great rapidity. I remember that when I was making a study of the blood of these creatures, it was almost impossible to procure any living specimens. In spite of all the pains taken by the fishermen attached to the Zoological Station of Naples, the mere lifting them from the nets to place them in a pail of water caused them to die immediately and become rigid. I went out myself in the boat, because I fancied the agitation of finding themselves prisoners and the violent efforts they made to escape might be the cause of death. I found that they did actually become rigid in two or three minutes. To this very rapid coagulation of the muscular tissue corresponds a very rapid alteration in the blood, so that there is no way of preserving the corpuscles without their losing their haemoglobin and becoming discoloured. I conclude that there are organisms possessing cells of extreme fragility. On the other hand there are fish which take a long time to become rigid, and it appeared to me that the more the blood resisted change the less rapid was the appearance of rigidity. Coagulation is therefore a phenomenon common to the cells of the organism, and is one of the characteristics of death.

It was Professor W. Kühne who first explained the actual mechanism of coagulation. He had observed that a frog's muscles become rigid very slowly if kept in a cold place, and that they can be frozen hard without losing their excitability when they are thawed. Kühne took a number of frogs' muscles in winter, and having thoroughly freed them from blood and every other albuminous liquid which they might contain, he pounded them in a mortar at a temperature of 7° C. He extracted and filtered them at a temperature of about zero ; and found that the liquid obtained was opalescent and of a yellowish colour. At the temperature of the room it coagulated like blood. To the coagulated substance Kühne gave the name of myosin ; the liquid which remains is the serum of the muscles. By the same method Halliburton extracted the myosin of the rabbit and other warm-blooded animals. We may now regard it as proved that the principal part of the albuminous bodies, and hence also of the contractile substance of our muscles, is made of myosin.

In a dead body the first sign of rigidity is to be observed in the jaws. The muscles which close the teeth are perhaps the most excitable. In shivering and in fever the teeth begin to chatter before any of the other muscles have been affected. The locking of the jaws in tetanus is only one of the symptoms marking the commencement of this terrible malady. The time elapsing before the appearance of the rigor of death varies from half or even a quarter of an hour to twenty-four hours. If the muscles of a rigid corpse are divided the joints are found perfectly mobile. This proves that the cause of the inflexibility is in the muscles themselves, and that no change in the articulation takes place as the effect of death.

I studied the death rigor in the heart of the dog along with Professor L. Pagliani,[1] and we found that it sometimes begins before the heart ceases to beat spontaneously. It is probable that the same thing happens in the case of the human heart, and that, when its beats become slower in the death agony, the process of alteration in the muscle which will bring about rigidity has already commenced. In order to gain some idea of this phenomenon we experimented upon a dog, and found that in the first four hours, with the exception of some movements of the fibres and some very small oscillations, the heart, when separated from the body, remains almost motionless. About the fourth hour the true contraction of the death rigor begins, and it attains its maximum in about two hours.

[1] A. Mosso and L. Pagliani, *Critica sperimentale della attivitá diastolica del cuore.* Turin, 1876.

VI

The essential point in muscular contraction consists in the fact that the muscle has the power of shortening itself at any moment, and that having done so it can return again to its original length. It is therefore worthy of remark that all causes of injury to the muscle tend to maintain it in a state of contraction. Too strong electric shocks, fatigue, some poisons, the arrest of the circulation of the blood, all produce contracture and rigidity. It must certainly appear strange that the function of an organ is exaggerated by causes which tend to result in death. This is the reason why the physiologist Hermann compared the contraction of the muscles to *rigor mortis*. The difference would consist in this that, in the case of muscular contraction, whenever the myosin in the muscle has coagulated, it would immediately thereafter have to become liquid again in order to allow the muscle to relax. Engelmann maintains that in muscular contraction a liquid substance within the elementary fibres is set in motion. The most serious difficulty is to explain how the coagulation of this substance produces the shortening, since we know that when the muscle contracts it changes in form but not in volume. Bierfreund would find a new resemblance between the rigor mortis and physiological contraction. It is known that the death rigor ceases when putrefaction begins. Bierfreund would seek to show that the rigidity disappears by a special process which does not resemble putrefaction, but is similar to what takes place in the living muscle when it relaxes spontaneously.[1] To this explanation given by Bierfreund, Bernstein replies with other experiments ; so that we cannot yet decide whether in reality, as Schiff maintains, the rigidity of a corpse is to be considered as the result of the last contraction made by the muscles : whether, that is to say, it is the last sign of life or the first sign of death. It is, however, certain that there is a profound resemblance between muscular contraction and the death rigor.

In the first chapter we have already seen with what great rapidity carrier pigeons become rigid when they are killed after a long journey. Charles Richet saw the death rigor appear in rabbits killed by strong electric currents one minute after death.[2]

Drowning men who have made great exertions before death in the hope of laying hold of something which would save them, are found clinging with rigid hands to the objects they have seized, death having failed to relax the muscles. In the last terrible shipwreck of Italian emigrants near Gibraltar (March 17, 1891), in which three hundred persons perished, amongst the corpses which were found on the beach the following morning was that of a woman with a dead infant clasped to her bosom. Neither the death agony nor the tempestuous waves which had dashed these corpses on the shore had sufficed to relax the last embrace, to separate the mother from her little one.

[1] Max Bierfreund, *Untersuchungen über die Todtenstarre. Pflüger's Archiv.* 1888, B. 43, p. 195.

[2] Ch. Richet, *Physiologie des muscles et des nerfs*, p. 365.

Most affecting instances of the death rigor were found by Professor Rossbach on the battle-fields of Beaumont and Sedan during the campaign of 1870.[1] On a hillock near Floins lay stretched on the ground a long row of French hussars. Several of their countenances still expressed the pain they had felt in the last moments of their life—their brows were knit, their lips compressed, and although the bodies were already cold, a convulsive contraction terribly disfigured the muscles of the face. Many of them still clasped their swords in their hands. One was in the act of loading his gun. Some of the dead had a smile on their lips caused perhaps by the last thought which they had called up in the moment of death. One soldier had fallen on his back, and was stretching his arms towards heaven : from a distance he appeared to be still alive and entreating help ; on hastening towards him one found that he had become rigid in this attitude.

The bursting of a shell killed a whole company of soldiers who had sought shelter in a trench in order to take breakfast in peace. Of one of these, says Rossbach, one might be certain that he was telling some merry tale, so lively was the expression of pleasure on his countenance, although he had been killed by a terrible wound in the head. Another held his cup to his mouth ; but his skull was wanting, and of his mutilated face there remained only the lower jaw. Owing to the depth of the trench in which they had sought shelter, none of them had

[1] Rossbach, *Ueber eine unmittelbar mit dem Lebensende beginnende Todtenstarre, Virchow's Archiv.*, B. li. p. 558.

fallen to the ground ; they had remained sitting or lying so that from above they would have seemed to be alive, had it not been for such figures as that of the man who sat cup in hand in the act of drinking, but whose head was gone. A touching case of rigor mortis described by Rossbach is that of a German soldier shot in the breast, who on feeling the approach of death wished once more to look on the portrait of his wife or sweetheart. He was lying on his side, supporting himself on one arm, whilst with hand raised and rigid he held before his eyes the picture which he appeared still to be contemplating in death.

CHAPTER VII

THE LAW OF EXHAUSTION

I

THE consumption of our body does not increase in proportion to the work done. If I do a unit of work, I cannot say that I shall have a unit of fatigue ; nor that if I do twice or thrice the amount of work, I shall have twice or thrice the amount of fatigue.

Dr. Maggiora,[1] in a series of researches carried on in my laboratory, has shown that *work done by a muscle already fatigued acts on that muscle in a more harmful manner than a heavier task performed under normal conditions.*

His method was as follows : By a preliminary series of experiments he proved that two hours' rest is required before every trace of fatigue disappears from the flexor muscles of the fingers after they have been exhausted by a series of contractions in the ergograph. This was the period of repose which Doctor Maggiora, for example, had to allow his muscles in order to annul entirely all the effects of the exhaustion. If he diminished this period, if, for example

[1] Arnaldo Maggiora, *Le leggi della fatica studiate nei mus coli dell' uomo*, R. Accademia dei Lincei, vol. v. 1888.

he allowed only one hour instead of two to elapse between one series of contractions and another, it was only natural that the muscle should do less work because it was insufficiently rested.

Now it might be thought that if the work were reduced by one-half, the period of repose might also be reduced in the same proportion. But by experiment it was found that the period of repose might actually be reduced not to a half, but to a quarter ; that is to say, if thirty contractions are required to exhaust a muscle completely the period of repose necessary after fifteen contractions is only half an hour. These observations show that the expenditure of energy in the first fifteen contractions is much less than in those following; and that the fatigue does not increase in proportion to the work done. If this work is calculated by adding together the successive heights through which the weight has been raised, we find that the work done during the first fifteen contractions is much greater than that done during the second.

Each of these experiments was begun in the morning and continued until evening, the tracing corresponding to fifteen elevations of the weight being repeated every half hour. And the fact that these tracings are every one equal in height shows that this period of repose was sufficient for the muscle. From this experiment, which I do not describe in detail, it appears that if the energy of the muscle is not completely exhausted, that is to say, if the final contractions are not made, the fatigue is much less, and the muscle is able to perform more than double the amount of mechanical work which it would do if it worked to the point of exhaustion with the most favourable conditions for repose.

Every one who has made the ascent of a mountain is familiar with the fact that the last part of the climb, when the summit is almost attained, demands a much greater effort than that necessitated by greater difficulties when one was less fatigued. Our body is not constructed like a locomotive which consumes the same quantity of carbon for every kilogrammetre of work. When the body is fatigued even a small amount of work produces disastrous effects. In the preceding chapter I have already shown that the cause of this must be sought in the fact that in its first contractions the muscle does not consume the same substances as when it is fatigued. In the same way, on the first day of a fast we consume materials which we have in our organism and which are entirely different from those which we borrow from our tissues during the final days.

I have stated that our organism is more injured by work when it is already fatigued. One of the causes of this is that the muscle having consumed in normal labour all the energy at its disposal finds itself compelled by additional work to trench upon other provisions of energy which it has held in reserve ; and thus it happens that the nervous system lends its aid with a greater intensity of nervous action. But although the nervous energy comes more into play, the contractions of the fatigued muscle are weak.

In raising a weight we must take account of two factors, both susceptible of fatigue. The first is of central origin and purely nervous in character—

namely, the will ; the second is peripheral, and is the chemical force which is transformed in the muscular fibres into mechanical work. Kronecker had already shown that it is not the weight which brings about fatigue, but the stimulus. I desired to try whether this law which was discovered in the frog holds good for man likewise.

To the ergograph I fitted a screw, V (Fig. 5, Chapter IV), passing from the further side of the support, I, between the two steel bars on which the runner moves. By turning this screw a point of support nearer to the hand is given to the weight, and thus the middle finger is freed from it at the beginning of its contraction. If we turn the screw whilst the muscle is contracting in order to write a fatigue tracing, we may so arrange it that the heights through which the finger raises the weight gradually decrease. When this is done, we find that in the beginning, when the muscle is fresh, no difference is perceived.

When the muscle is in full possession of its energy, therefore, it appears indifferent to the weight it raises. The muscle having once received the order to contract, shortens itself as much as possible, whether the weight has to be raised during the whole, or only during a part of the contraction. This first part of my experiments goes to confirm what Kronecker had observed in the frog.

When a muscle has its energy diminished by fatigue, it feels relief on being freed from a part of the weight. If any one after being fatigued raises fifty kilogrammes with difficulty, he will find one extra too heavy. But if he is not fatigued and can raise eighty or a hundred, one or two beyond the fiftieth will pass unnoticed.

We shall have occasion to examine this fact more closely; in the meantime what I have said enables us to compare the movements with the sensations. We find here a fact analogous to what we have all experienced in a concert, where we cannot tell whether there are thirty-five or forty violins in the orchestra. Similarly on entering a brilliantly-lighted hall we cannot tell whether the lights number ninety or a hundred; but if in either case there were only two, we should notice at once if one violin ceased to sound or one light were extinguished. We hence perceive a primary law of fatigue and of sensation, namely that their intensity is not at all proportional to the intensity of the external cause which produces them.

II

On an examination of what takes place in fatigue, two series of phenomena demand our attention. The first is the diminution of the muscular force. The second is fatigue as a sensation. That is to say, we have a physical fact which can be measured and compared, and a psychic fact which eludes measurement. With regard to the feeling of fatigue, the same thing takes place as happens in the case of every stimulus which acts upon our nerves; we begin to perceive it only when it has attained a certain intensity.

Light, sound, odour, all require to reach a certain intensity before we become aware of them. Besides this, the sensation produced in us at any moment continually decreases in force, notwithstanding that the external cause which produces it remains the same. Delboeuf has well expressed this fundamental principle when he says—[1]

"The intensity of sensation does not depend only on the intensity of the stimulus, but rather on the total mass of sensibility, or the energy possessed at the time by the organs affected."

One might almost say that at its second impact the stimulus acts on an individual whose sensibility is different from what it was at first.

There are two physiological conditions which render us insensible to fatigue. The first of these is habit. Thus when we are in a room with a great number of persons we do not perceive the profound alteration which the atmosphere undergoes.

The second is the gradual diminution of the excitability as the fatigue increases. The eye which gazes on a flame at first feels the stimulus of the light in its full intensity; its sensibility then diminishes rapidly, and what remains after this first period of fatigue is past continues to diminish more slowly.

Ocular fatigue thus follows a course resembling that of the exhaustion of force in the muscles. The difficulty consists in determining the laws which these phenomena follow, the nature of which is probably the same whether for brain or for muscle.

I shall endeavour to collect and arrange the greater part of the observations I have been able to make regarding this subject, and for the sake of brevity, I shall sum up under the title *law of exhaustion* all the complex types—certainly incomplete as regards their

[1] J. Delboeuf, *Eléments des Psychophysique*, p. 41. Paris, 1883.

explanation—according to which we shall see the excitability and the aptitude to motion diminish during fatigue.

A post-office clerk once told me that in the morning he could easily tell if a letter weighed fifteen grammes and a half instead of fifteen ; but that in the evening when he was fatigued he could no longer distinguish with certainty this difference of half a gramme. And I satisfied myself that this was true.

We shall have occasion later to give other examples, which show that fatigue in most cases diminishes the sensibility. Let this indication in the meantime suffice to show that what at first sight might appear an imperfection of our body, is on the contrary one of its most marvellous perfections. The fatigue increasing more rapidly than the amount of work done saves us from the injury which lesser sensibility would involve for the organism.

Delboeuf declares : "We have found the formula for exhaustion restive under experiment."[1] Certainly the formula of the relation between fatigue and work is an extremely complex thing owing to the multiplicity of the factors involved and to the almost inextricable intricacy of the different curves with which these factors vary according as the work surpasses the normal limits ; nevertheless we cannot doubt that an investigation carried on by exact methods, an examination of this problem regarded under its multiple aspects should lead to the determination of the resultant representing the law of exhaustion.

[1] *Op. Cit.*, p. 92.

This law, moreover, cannot be separated from the study of the restoration of force. Whilst work consumes the organism, a beneficial vital tendency cares for the renewal of its energy. Matteucci has observed that the greater the excitability of a nerve, the more quickly it is recovered. The weak are thus doubly handicapped.

The workman that persists in his task when he is already fatigued not only produces less effective work, but receives greater injury to his organism.

The intervals of repose between one effort and another should be longer when one is tired, because one's energy is restored less rapidly, the excitability of nerve and muscle having been diminished by fatigue.

The nervous stimulus which in the beginning serves to shorten the muscle by about one-third of its length, no longer produces this effect after we are fatigued, and we may easily perceive this difficulty, despite the increase of nervous effort, from the way in which we drag our feet after a fatiguing walk.

III

Infant mortality is greater among the poor than among people in easy circumstances, and children born and bred in poverty are never so strong as those more happily situated, either because their food is insufficient, or because they suffer from the effects of the fatigue undergone by their mothers during pregnancy.

Since the celebrated investigations of Quetelet on the growth of children, several physiologists have given us important measurements bearing on the development of the organism. Amongst these I may mention the fundamental works of Pagliani, Bowditch, and Key. Professor Pagliani made in Turin a series of anthropometric measurements comparing the weight, the height, the circumference of the chest, the vital capacity, and the muscular force, of poor children with those of children comfortably circumstanced.[1]

The rate of growth of our body is not always uniform, and there are certain years, as for instance those between ten and fifteen, in which the effects of insufficient nutrition are much more injurious. The investigations of Professor Pagliani show that poor children weigh less, the difference reaching an average of three kilogrammes in the period between sixteen and nineteen years of age. A comparison of heights shows that boys who are well off are taller than those who are poor, the difference being such that the latter at the age of seventeen have the stature of the former at the age of fourteen.

Similar differences are found in the *vital capacity*, or the quantity of air which can be taken into the lungs. The *vital capacity* of the rich at nineteen years of age is about eight hundred cubic centimetres greater than that of the poor.

The ruin which the exhaustion of fatigue brings about in man appears clearly in the degeneration of our race in some parts of Italy. In the province of Caltanissetta, for example, in the four years between

[1] L. Pagliani, *Sopra alcuni fattori dello sviluppo umano*. Atti. R. Accademia delle Scienze di Torino, 1876.

1881 and 1884, out of 3,672 sulphur workers who presented themselves for examination, only 203 were declared fit for military service ; 1,634 were rejected ; 1,835 remanded for another examination ; 1,249 were rejected as under the regulation height ; 69 for deficiency of chest measurement ; 64 for constitutional weakness ; 25 for malformation of the chest ; 43 for hernia ; 48 for spinal curvature ; 20 for other physical deformities ; 7 for varicocele ; 18 for malarial cachexia ; 18 for blindness ; and 73 for various causes.[1] Here then is a province under the lovely sky of Italy, with a fruitful soil and in a land rich in natural talent, which out of 3,672 youths of twenty years of age, counts only 203 able to bear arms. And when we think of our country, it is with great sorrow and uneasiness that we read these figures.

In the other provinces of Sicily at the same time, about twelve per cent. were rejected for deficiency in height. Out of 3,672 conscripts there would therefore be about 440 rejected on this account, whereas in Caltanissetta there were 1,249, that is to say, about three times as many.

The first time I went to Sicily I was sent thither in the capacity of army surgeon, and the conduct of the levy in the interior of the island was entrusted to me. I still remember as if it had been to-day a tiny church in which close to the altar stood the inspectors, the lieutenant of the carabineers, and the noisy crowd

[1] *Rivista del servizio minerario.* Annali del Ministero di agricoltura, 1885. Vittorio Savorini, *Condizioni-economiche e morali dei lavoratori delle minere di zolfo e degli agricoltori nella provincia di Girgenti*, Girgenti, Stamperia di S. Montes, 1881.

beyond the balustrade. I went to see the conscripts behind the high altar in the choir, and found there a line of youths, thin, naked, and blackened, and mingled with these, others who were fat, plump, and fair, as though they belonged to a different race. These were the poor and the rich. Sometimes there passed before me all the conscripts of entire communes, among whom not one could be found fit to bear arms, so much had toil and fatigue deformed and weakened the population.

The inspectors were humiliated by so much degradation. "They are *carusi*," they told me; that is to say, men who from childhood have worked as sulphur carriers.

Long after I had come out of this church, my heart remained full of bitterness. The beauty and serenity of the heavens, the brilliant sun giving birth to a tropical vegetation, orange trees, vines, gigantic oleanders covered with flowers—all told me that nature was no accomplice in this terrible disparity among men, which affected not nutrition alone, but also the muscles, and the sacred rights of life. I remembered that Sicily had been the granary of Italy in the times of the Roman Republic.

The fame of the fertility of this island, however, is unfortunately united with the sad record of the ancient wars waged by the slaves. And I thought of the misery and the suffering which must have accumulated for a rebellion to have broken forth in which there were seventy thousand slaves under arms; for the social war in Sicily to have become so vast as to discomfit four praetors and a consul despatched from

Rome; for it to have taken three years to stifle this revolt in blood; for Sicily to have given the first example of a war, which beginning with the slaves, more than two thousand years ago, threatens even now, under different forms and conditions, to disturb the peace of other countries of Europe.

With a feeling of sorrow I write these words as they are dictated to me by a painful recollection, and I am certain that none of the unfortunate sufferers will ever read them.

Sicily is not a poor country. The province of Caltanissetta, with which, together with that of Messina, I am best acquainted, has an excellent and temperate climate. There is no comparison between this province and certain districts of Germany and England, so much more favoured by nature are these people of ours. Yet in spite of that they live in wretchedness. Here among us there is wanting a rational system of agriculture, because the ground belongs to a few proprietors, who have neither practical nor scientific knowledge of how to render the soil fruitful. They are, moreover, without the money necessary for the improvement of their farms; and even if they had the means, their want of instruction makes them indifferent to all progress. I have seen these things with my own eyes; but in order that I may not be thought to exaggerate, I shall make some extracts from the detailed report published by Government on the condition of the agricultural class—[1]

[1] *Atti della Giunta per la inchiesta agraria*, vol. xiii, tomo ii. fascicolo iv., p. 3.

"Eleven per cent. of the district is not under cultivation. The oil and the wine have a disagreeable flavour, because they are made by primitive processes. The domestic animals are degraded in type and full of defects owing to the excessive labour to which they are subjected in their youth, and the meagre nature of their food. There are large holdings termed *ex-feudi*, because they originated in feudal times, some of which run to more than two thousand acres in extent. The taxes take from thirty-two to fifty per cent. of the net returns of these holdings. The major part of the population is a proletariate, which lives crowded together in towns and villages, and must every day journey many miles to arrive at the farms where they labour.

"The daily wage of a grown man is one lira or at most two, with which he must provide for food, lodging, and the needs of his family ; and often even at this rate of payment no work is to be had. The food and habitations of these poor creatures are most miserable. A single room communicates directly with the stable, or rather itself serves as a stable, and the whole family live along with their cattle in these fearful cabins. The peasant is by nature sober, industrious, intelligent, patient, and religious, but ignorant."

Again at page 18 the agrarian inquiry says : "The progress made in agriculture since the establishment of the unity of Italy has been nil or almost nil, and the Government has done nothing to promote it." This is a sad and painful confession, because agricultural labour is that which is most suited to the nobility of human nature ; it conduces most to the enrichment of the country and the morality of the people.

IV.

The most serious drain upon the energy and the hardest drudgery do not take place in the country districts, but in the sulphur mines. Pasquale Villari, the celebrated historian, author of the Biography of Girolamo Savonarola and of that of Niccolo Machiavelli, wrote a book on the social question in southern Italy.[1]

"Human beings," he says, "are subjected to labour, which described every day, seems every day more cruel and almost impossible. Hundreds upon hundreds of boys and girls descend by precipitous slopes or difficult stairways dug out of crumbling earth, which is frequently wet. Arrived at the bottom of the mine, they are loaded with the mineral, which they must carry up on their backs, in danger, if they stumble on this steep and treacherous ground, of falling down and losing their lives. It is known to every one, and has been a thousand times repeated, that this kind of work makes indescribable ravages upon these people. Many of them die, very many are maimed, deformed, or diseased throughout life. It is a thing to strike terror to one's heart."

Villari wrote these words in 1875. Five years later the Government wished to introduce a law regulating the labour of women and children. The prefects, the owners, the mining engineers, the societies for mutual aid, and the operatives were invited to give their opinion and to describe the con-

[1] P. Villari, *Lettere meridionali*, Florence, 1878, p. 21.

ditions of the industry. From the volume published by the Minister of Agriculture and Commerce, I take the following extract, in order that the reader may learn the state of affairs from official documents.[1]

The provincial Deputation of Caltanissetta sent to the Government by its Prefect the following report (p. 698)—

"The Deputation has ascertained that in the sulphur mines existing in great numbers in this territory, there are employed children even under the age of eleven. It is of opinion that the daily labour to which these children are subjected, under the direction of the contractors employed in the extraction of the sulphur, is beyond their strength; that the hardships undergone by these children not only obstruct their physical development, but co-operate in substantially altering their organic constitution, and prepare the way for a generation little fit for labour; that, however, were the labour of these children forbidden, immediately on the passing of the law the closure of several of these mines would be inevitable, as they are kept at work by proprietors who possess scant pecuniary means. Nor could mechanical contrivances be substituted for manual labour, because the mine would not give a return proportionate to the capital employed, and on the other hand, adult labour would be too expensive.

"It is of opinion, etc. . . ." And the report concludes by proposing transitory measures, which would do little to change the state of affairs, and

1 *Annali dell' industria e del commercio*, 1880, N. 15, *Sui lavori dei fanciulli e delle donne*. Roma, 1880.

which resemble the famous maxim of the Manchester school : *laisser faire, laisser passer.*

But the Sanitary Council refused to shirk the question in this way, and Doctor Lombardo wrote an account, approved by his colleagues, which shows the disgraceful character of this traffic, and makes one blush that things so cruel and monstrous still take place in Italy.

"In our province alone there are at least five thousand child workers employed in the extraction of sulphur from the mines.

"I know that in one single sulphur mine in Caltanissetta three hundred children are at work. The method adopted by the overseers to urge on the children in their task of carrying the sulphur begins with the most cruel pinching such as leaves the flesh black and blue for days ; they then burn their legs with lighted lamps, or make their companions do so, even to the production of scars on the skin. I have been summoned several times by the inspectors and prefects to report on the nature and cause of such sores. I can give evidence as to them upon oath.

"Nevertheless these methods of treatment, brutal as they are, have no lasting consequences and pass unobserved. What is indeed deplorable in the unhappy lot of these children in our mines is this : that the weights which they have to carry on their backs are out of all proportion to their years and strength. Their delicate bones give way and become curved and twisted, so that the poor creatures remain deformed and lame throughout life. The bones most liable to deviate from the normal form and direction are those of the shoulders, the scapulae, and those of the vertebral column. Most of the children have one shoulder lower than the other, some have humps on the breast, others on the back; all have the thoracic cavity more or less injured. But the evil is not confined to the external appearance and direction of the bones. The organs contained in the thorax, especially those of respiration and circulation, are compressed, more or less displaced, and impeded in their function and their development. . . ."

The following is the opinion of the Council—

"The Council finding the preceding relation conformable to truth and justice, and no more than is demanded by humanity in the interests of this class of unhappy child victims, who before their natural physical development is complete come to labour in our mines and manufactories like so many slaves, expresses unanimous approval of the project under consideration; although it also supports the wish expressed not long since in the Provincial Council by the Prefect, that with the sum of 50,000 lire which is spent by the province and the communes on the maintenance of foundlings, there be erected an institution for the recovery of the said children, who by the system at present flourishing in these provinces are after their seventh year thrown on their own resources, and are usually recruited by the miners to bear fatigues which are far beyond their stage of development."

There follow other accounts which make one shudder, so repugnant are they both to our reason and to our feelings. On reading these facts I ask myself whether we ought not to blush at our own inertia in face of such cruel slavery.

Some in the easy quiescence of their sentimentalism perhaps may say that now there is a law the third article of which prescribes "that no children under the age of eleven shall be employed in nocturnal or unhealthy subterranean work, and that the daily labour of children between the ages of nine and eleven shall not exceed eight hours, or else six hours without a rest."

Our law is not sufficient; at the least we should have copied the English one of 1878, which is much more physiological than ours. The masters merely increase the weight on the shoulders of the children, and make them move their legs a little quicker—that is all. Every miner still works with three or four children in attendance whom he brutally forces to run along the subterranean passages and up the steps until their strength is exhausted; and the same abuses continue to exist.

And these unhappy children, perhaps as long as they live, and at the time when societies for the protection of animals do their work and increase in number, continue to be enslaved, mutilated, and brutalized by premature labour. The majority of these foundlings die; those who survive become wicked, villainous, and cruel; no sentiment of humanity can grow in the galley to which these children are condemned, and it is they who through hunger will become the destroyers of other poor *carusi*. And such injustice remains unavenged; there are other victims destined to die under the weight of this labour, tortured, killed by these cruelties. For these innocents this life is worse than slavery, worse than the dungeon.

V

If we turn to the history of past centuries, we see that every nation has been dominated by one fixed idea, namely, how to render more effective the work of brain and hand.

By constant increase in the rate of movement, by instruments ever better adapted to their ends, modern society endeavours to multiply and render more productive the work both of muscle and of mind. The prodigious extension of the arts and the increasing velocity of machinery combine to hurry us onward; our haste will grow from more to more, till it reaches an extreme point at which the law of exhaustion sets an insuperable barrier to the greed of gain.

The same thing has happened in the realm of mechanics as in the realm of literature. At first books were made in order to aid the memory, and appeared to be a great invention; because legend, song, and history no longer required to be handed down from father to son by an effort of memory. But the arts of writing and of printing, instead of giving rest to the memory, have themselves gradually become most powerful causes of mental fatigue, instruments of torture for the human brain.

The bas-reliefs of Thebes show us that during three thousand years the life of the artizan underwent but little change; the tools employed in the time of the Pharaohs, hammers, axes, saws, looms, differ very slightly from those employed at the beginning of our own century.

And nowadays all is so changed that comparison is no longer possible. The employment of steam has created a new epoch in the history of man. Mechanics, mathematics, and most of all chemistry have created modern industry, and have given such an impulse to the organization of labour as to produce new conditions among civilized races. The operative who works at home in the midst of his family, bringing up his children, and resting on Sunday, will gradually disappear ; for modest matrons and bashful children, for the peace of the family there is preparing a gloomy future, one certainly far from tranquil and full of the most grievous fatigue. The artizan at home, within his own walls, will not long survive, because with his arms he cannot compete with the titanic labour of machinery. He will struggle for some time yet, redoubling his toil and diminishing his gain, but he is bound at last to disappear.

The machinery in our factories is ever becoming more ponderous ; it is increasing in size, velocity of motion, and productivity, and this increase still continues despite the fact that we have already surpassed the furthest limit set at first by our imagination.

The heaviest hammers which were in use up to the beginning of last century were such as are still seen in smithies, and the heads of these weighed about ten kilogrammes. Only in some forges were to be seen sledgehammers of 5,000 kilogrammes moved by water power. Nowadays in the forges of Terni a hammer weighs 100,000 kilogrammes, and its every stroke equals the force of 10,000 men; and as this hammer falls through a height of five metres, whilst the smith's hammer falls through barely a metre and a half, every such stroke produces 500,000 kilogrammetres of work. A man working for a whole day at raising a weight can do 73,000; thus the Terni hammer at a single blow does more work than six men working for a whole day. Now this hammer, of which the motive power is steam, moves far more swiftly than the smith's arms, seeing that it can make 100 strokes per minute, and if we consider that it knows no fatigue and can work both day and night, so long as the coal which feeds it lasts, we stand dumbfounded at the power of such machines.

Not alone in force and in speed but also in dexterity of execution has machinery made incredible progress. With a machine a man can make in one day as many stockings as the best knitter in a month; and the sewing machine takes 1,200 to 1,500 stitches per minute, whilst a skilful seamstress only takes 50.

The impression which one receives on visiting a great factory for the first time is one of profound bewilderment. From a distance the monotonous appearance of the building, the uninteresting outline of the enormous chimneys, do not suggest the prodigious activity which goes on within the blackened walls. Immediately on entry one is amazed at the boundless wealth of force. The furnaces whose light flashes forth in the midst of the smoke, the mighty arms of the pistons in motion, the giddy whirl of the fly-wheels, the transmission of the force by means of axles, belts, and steel cables, the cylinders and the whirling wheels, the din of the machinery, the whole fantastic mechanic skeleton which seems to be alive and to move to and fro in response to the will of man—all these things fill us with admiration for modern industry.

One very quickly perceives, however, that those machines are not made to lessen human fatigue, as poets were wont to dream. The velocity of the flying wheels, the whirling of the hammers, and the furious speed at which everything moves, these things tell us that time is an important factor in the progress of industry, and that here in the factory the activity of the workers must conquer the forces of nature. Beside these roaring machines are seen half-naked men, covered with sweat, hurriedly pursuing enormous weights, which whirl round as if a mysterious hand were raising them. The hiss of the steam, the rattling of the pulleys, the shaking of the joints, the snorting of these gigantic automata, all warn us that they are inexorable in their motion, that man is condemned to follow them without a moment's rest, because every minute wasted consumes time which is worth money, seeing that it renders useless the fuel and the movement of these colossi. The least distraction, the least mistake may drag the workers between the grinding teeth of the wheels; and the imagination recoils horrorstruck before the mutilations, the deaths, with which these monsters punish the slightest carelessness, the slightest hesitation, on the part of those who direct them.

VI

A machine recognises no limit to its speed save the weakness of man in performing his part as assistant. Now the capacity for action of human energy is in inverse ratio to the time through which it acts. But books on political economy contain very little exact information on this point. That same Marx, who has certainly written the most remarkable book of the socialist literature, does not give in his work on *Capital* serious and unassailable proofs of the exhaustion which machines produce in the operative. The statistics of the numerous official Commissions of Inquiry which have appeared during the last forty years are from the scientific point of view inadequate to demonstrate the injurious effect of work on women and children.[1]

Fresh investigations are necessary, made by independent men, by physiologists free from all pre-

[1] Among the best investigations which have been published on this subject, that of Fr. Erismann, Professor of Hygiene at Moscow, is deserving of special mention. *Untersuchungen über die körperliche Entwickelung der Fabriksarbeiter in Central-Russland; Einfluss der Beschäftigungsart. VII Internationaler Congress für Hygiene und Demographie zu Wien*, 1887. *Ergänzungen zu den Heften ibis xxxiii*, p. 118. In this work are collected 100,000 observations on persons of both sexes, between the ages of eight and eighty, employed as factory workers. Professor Erismann examined the development of these 100,000 persons in stature, weight, thoracic circumference, and muscular force.

conceptions whether political, humanitarian, or social. Other inquiries should be undertaken by medical men to discover the data, the measurements and equivalents which are wanted, and this subject should be studied with more attention to scientific scruples, with all the exactitude of a physiological research.

Marx, in his celebrated work,[1] devotes a chapter to machinery, and arrives at the following conclusions—that all our inventions have not diminished human fatigue, but simply the price of commodities ; that machinery has rendered worse the condition of the worker, because by rendering strength of no avail it has entailed the employment of women and children, instead of shortening the working-day it has prolonged it, instead of reducing fatigue it has rendered it more dangerous and injurious ; that to the accumulation of riches corresponds an increase of poverty ; that owing to machinery society is receding further and further from its ideal ; that the reality has not corresponded to our hopes.

Machinery does indeed tend to concentrate fortune and comfort in the hands of the few, instead of conducing to the equality of all men. The weak become the servants and victims of those who can substitute the forces of nature for those of man. The powerful automata of mechanics want nothing but intelligence and a nervous system ; this want a child or a woman can supply and guide the blind giants by the hand. It is a grave accusation to launch against science, that in making herself

[1] *Le Capital*, Karl Marx, p. 161.

mistress of the forces of nature she tends to establish a monopoly for machinery, to make labour the slave of capital. There are, moreover, those who fear that human fatigue will come to be less and less regarded, and that the workers will be gradually eliminated and dismissed without means of subsistence; that the intelligence of the people is deteriorating, because the greater the perfection of the machine, the less the skill and ability required from the worker. We all deplore the fact that the necessity for concentrating industries in factories has destroyed the social life and the tranquillity and freedom of the operatives, and has created unhealthy moral and hygienic conditions; that the iron necessity of keeping the machines at work during the night as well as the day causes exhaustion and deterioration in the nature of man.

Certain it is that society is at present undergoing a profound and rapid evolution, the extent of which it is impossible to foresee. But we shall never attain to an organization of society in which man will no longer know fatigue, and in which those who work with their hands shall be indistinguishable from those who work with their heads.

Even at birth men are physiologically diverse. However far we look back into the mists of antiquity, there are found men who toil for a bare living, and men who to increase their own enjoyment of life cause others to toil. Even if a law were to place all men in the same conditions, it would be immediately broken; seeing that a law could never be stronger than nature, and society would at once be disorganized once more owing to the different dispositions received by men at birth. It is a law of nature that the weak should obey the strong, and the strong be guided by those who have most skill and cunning. The man that is born with most talent and judgment will always be the man that commands; seeing that circumspection, perseverance, prudence, temperance, adaptability, and alertness of mind are not gifts which nature has bestowed on all men, and he who is born with them will know how to make himself obeyed.

The disappearance of social differences is unfortunately a dream still more beyond our reach than the universal brotherhood of nations. Nevertheless in the midst of the growing unrest which some would precipitate towards social revolution, we must admit that the well-being of the proletariate has everywhere increased upon the whole, or at least has in no way diminished. The population of Europe has doubled during the century,[1] and the average length of life has increased. In diet, education, hygiene, everywhere progress has been made. The fear of the artizan that machinery would take his place and deprive him of the means of subsistence has not been justified. The demand for labour instead of diminishing has increased. And machinery has brought within the reach of the people many commodities which were at first reserved for the rich. The greater pretensions of the artizan of the present day spring from this: that he has a higher ideal of life,

[1] In 1810 the population of Europe was calculated at 180 millions, in 1886 at 347 millions.

and that civilization has created in him needs which formerly were totally unknown to him.

Toil is to-day respected by all. With the advance of civilization the desire for labour would increase, as the means of satisfying increased needs and mitigating the injustices of fortune.

The ancient world arose upon the enslavement of labour, and not one of the great thinkers of Greece or Rome ever opposed himself to this; because human fatigue was put on a par with animal fatigue, and the slave was not a citizen, but a thing.

It was Christianity which proclaimed the equality of men, and for the first time gave us a glimpse of the community of goods. As civil progress has been accomplished, men have advanced steadily towards equality till a privileged nobility has disappeared. But the onward march of humanity is not arrested, and to-day we are tormented by the grave and fearful problem of a more radical equality. This is the great difficulty, on which all are engaged who have at heart the liberty and the dignity of man. It is no longer a party question, no longer a cry raised to overthrow governments; it is a profound conviction, a sacred moral sentiment, which spurs us on to seek out means by which property may be divided without violence, without bloodshed; by which he who gives employment may give it in virtue of humane laws, and he who receives it not become a slave, nor the human race degenerate under the usury of fatigue.

CHAPTER VIII

Attention and its Physical Conditions

Charles Darwin considered attention as the most important of all the faculties for the development of the human intelligence. He tells a story of a man who used to purchase monkeys from the Zoological Society in London at the price of five pounds for each. This man's trade was to train monkeys to act in plays, and he offered to give double the price if he were allowed to keep three or four of them for a few days in order to select one. When he was asked how he could tell in so short a time whether a monkey would turn out a good actor, he replied that it all depended on the degree of attention which the animal gave to what was done in its presence. If, when he was teaching it anything, its attention was easily distracted, as by a fly or any other trivial cause, all hope of instructing it had to be given up.[1] This shows how much animals of the same species differ from birth in their mental endowments.

In a book by Romanes [2] there is a record of observa-

[1] Darwin, *The Descent of Man*, vol. i, p. 44.

[2] Romanes, *Animal Intelligence*.

tions taken down day by day of the life and doings of an ape procured at the Zoological Gardens in London. To the students of psychology this is a most interesting volume—one which I recommend to all who wish to investigate the evolution of mind. If there were no other reasons to compel us to admit a relationship between the ape and man, the sight of the attention paid by these animals would be sufficient to lead us to recognise a certain affinity between them and ourselves.

"Much the most striking feature in the psychology of this animal," says Romanes, "was the tireless spirit of investigation. The hours and hours of patient industry which this poor monkey has spent in ascertaining all that his monkey-intelligence could of the sundry unfamiliar objects that fell into his hands, might well read a lesson in carefulness to many a hasty observer. And the keen satisfaction which he displayed when he had succeeded in making any little discovery, such as that of the mechanical principle of the screw, repeating the results of his newly earned knowledge over and over again, till one could not but marvel at the intent abstraction of the 'dumb brute'—this was so different from anything to be met with in any other animal, that I confess I should not have believed what I saw unless I had repeatedly seen it with my own eyes."

In Fechner's Psycho-physik this process is studied for the first time from the physiological point of view. We have already said that a sense stimulus must reach a certain intensity before it is perceived;

the instant at which it begins to be perceived is termed the threshold (Schwelle.)

"Provided it be true," says Fechner, "that the soul possesses an extended seat, it must be possible that the psychophysical activity, instead of sinking under the threshold all at once, should sink under it now here now there, and that man therefore should be able to be partially asleep and partially awake.

"Every time we turn our attention upon a sense is as if that sense awakened; and every time that we turn our attention from it is as if it fell asleep. When a man is so profoundly buried in thought that he neither sees nor hears what is passing around him, then the sphere of all the external senses sleeps just as in real sleep. And there are cases of ecstasy in which a man with his eyes open remains insensible to every stimulus from the outside world. And *vice versa* the whole sphere of the activity of the inner representations may fall asleep. In waking the vertex of the psychic activity changes place, and when the psychic activity rises in one place, it sinks elsewhere deeper below the threshold, and with this the sleep elsewhere becomes more profound."[1]

This passage from Fechner will, I hope, suffice to show that in his opinion in ordinary mental activity there is a partial sleep of some parts of the brain whilst others are active. Attention and the partial sleep Fechner places in the same chapter. When any one

[1] G. T. Fechner, *Elemente der Psychophysik*, 1860, p. 450.

is speaking close to us and we neither hear nor understand a word, it is because that part of the brain which deals with such impressions remains asleep. When a stronger impression awakens it, the attention is likewise aroused, and can often succeed in catching some of the former impressions before they are erased.

The intellectual life of man then, according to Fechner, oscillates between sleep and waking, and even in waking there are regions of the brain which are asleep.

Since Fechner, the man who has shed most light upon this subject by his investigations of attention, is Wundt, the physiologist ; but I should exceed the limits of a popular work were I even to mention the important facts regarding attention which were discovered in the psychological school of Leipzig.[1]

In this chapter I shall content myself with examining the modifications which take place in the organism when we are attentive. The state of slight stimulation which occurs in the brain to permit of better work and the prolonged retention of the images of objects, is a phenomenon in which all the organs of the body take part. For the physiologist the study of these modifications is of great importance,

[1] I recommend the reader who desires to become better acquainted with the recent work done on attention by the Leipzig School to consult the work of W. Wundt, *Grundzüge der physiologischen Psychologie.* An excellent popular book has been written by Th. Ribot, regarding the mechanism of attention, *Psychologie de l'attention,* Paris, 1889.

because it renders evident the physical fact which accompanies the psychic activity of the brain.

In my work on *Fear* I have already shown, with the aid of the plethysmograph and the balance, how the act of thinking about something drives the blood towards the brain.[1]

II

Respiration is modified during attention : of this fact I sought to convince myself by placing round the thorax an apparatus which registers the respiratory movements. But a modification often fails to occur, because many persons are excited by the mere fact of being subjected to experiment. More to be depended on is the alteration observed in those who pass from a state of dispersed attention or profound tranquillity to one of active thought.

In two papers on respiration, I have published [2] tracings taken from myself during complete dispersion of mind. The movements of the abdomen and the thorax were recorded. According as my peace of mind became more complete, the frequency of the respiratory movements became greater and the diaphragmatic respiration less strong. Of the two partners in respiration, the thorax and the diaphragm, the latter showed a tendency to repose. I considered myself in a state of dispersed attention, when in my consciousness appeared ideas of which I did

[1] *La Paura*, chap. v.

[2] A. Mosso, *La respirazione periodica e la respirazione di lusso.* Memorie della R. Accademia dei Lincei, 1885. *I movimenti respiratori del torace e del diaframma.* Mem. Accad. R. delle Scienze di Torino, 1903,

not know the origin nor the connection with the preceding ideas. They were images which forced themselves upon my mind in spite of the fact that my intention had been at the beginning to keep it blank; and with these images there appeared scenes from life which I should regard as the beginning of a dream had so much of my consciousness not been still awake as to be able to keep watch over myself, and to recall from time to time the aim of my repose. At this moment I pressed a button which I held in my hand, and a mark was made on the revolving cylinder on which the respiratory movements continued to be recorded. Scarcely was this mark made when my respiration became deeper and slower. When attention re-awakens, a modification in the functions of thorax and diaphragm takes place. Whilst the attention is dispersed the diaphragm contracts less and tends to repose, and the movements of the thorax are more ample and slightly irregular. As soon as full consciousness is restored the respiration changes in type, and becomes slower. The movements of the diaphragm become stronger, and the dilatations of the thorax diminish in amplitude.

I often continued thus for hours; and the same phenomena were always repeated each time that the attention became dispersed or that it reawakened.

I have, however, found that there are persons in whom the respiratory movements cease to be uniform and become periodic as soon as their attention wanders and they become drowsy. This phenomenon is very marked in Dr. Rondelli. I have already noted in Chapter V that periods in respiration may be observed even in fish, when they are perfectly still, and I gave a tracing of them in Fig. 14. These experiments succeed best in summer at the hours when a state of dispersed attention readily passes into sleep.

Dr. Rondelli was seated in a comfortable arm-chair reading, while in the background we recorded his respiratory movements on a cylinder by means of a pneumograph. As long as he was attentive the tracing was normal; but as soon as his attention began to wander, irregularities appeared, and as soon as he half closed his eyes and allowed his book to tremble in his hands, his respiration assumed a periodic form. That is to say, there were moments in which the respiration became very superficial and seemed almost to cease, and others in which it became gradually stronger and then diminished with great regularity.

In my own case I feel my heart beating more strongly every time I begin to think of something after having been in a state of dispersed attention. If a little noise occurs when I am dozing, or if I awake of myself, the beating of my heart suddenly becomes so strong as to force itself on my consciousness. Shortly afterwards the palpitation disappears. The primary cause of this stronger impulse must I believe be sought in the contraction of the blood-vessels, as I have already pointed out in my book on *Fear*. We see therefore that attention involves modifications of a complex nature. In metaphorical language we may say that the brain has not the sensitiveness of a photographic plate which, if kept in the dark, is always ready to receive impressions of objects; but the whole organism takes part in preparing the conditions of more active cerebration.

III

With reference to the influence which the circulation of the blood exerts on the activity of the nervous system, I shall cite an observation of J. Müller's:—[1]

"When with closed eyes I had observed for a long time the dark field of vision, I often ended by seeing a feeble light which from one point diffused itself rhythmically over the entire field, and then again disappeared. These luminous phenomena were synchronous with the expiratory movements, and could have no other cause than the more copious afflux of blood to the brain during expiration and the accelerated movement of the blood in the nervous substance appropriated to vision."

Experiments have shown that attention is not a continuous but an intermittent process proceeding almost by bounds. These intervals have been carefully studied by Wundt and more especially by Lange.[2]

Leumann[3] would maintain that the periodic oscillations of attention studied by Lange and others

[1] J. Müller, *Ueber die phantastischen Gesichterscheinungen*, p. 15.

[2] N. Lange, *Beiträge zur Theorie der sinnlichen Aufmerksamkeit und der activen Apperception.* Philosophischen Studien iv, 395.

[3] E. Leumann, *Die Seelenthätigkeit in ihrem Verhältniss zu Blutumlauf und Athmung*. Philos. Studien v, 618, 1889.

were synchronous with the respiratory periods. If this should be the case, we should have to admit that in every case of increase of excitability produced by the afflux of blood to the brain, corresponding periods in the intensity of attention arise.

That there are other causes besides respiration capable of producing periods in the functions of the nervous centres we have just seen, since respiration itself becomes periodic when our attention wanders. In profound sleep the respiratory activity may be interrupted at regular intervals by pauses which may last as long as half a minute.

Similar periods occur, moreover, in the tonicity of the blood vessels, and in the functioning of the heart. As long ago as January, 1884, in a work on periodic respiration which I presented to the *Accademia dei Lincei*, I said: "I maintain it to be a condition natural to the life of the nervous centres that when they are awakened from repose, they do not at once fall back into their primitive state, but return to it by a series of oscillations, in which the excitability increases and diminishes by degrees."

When we are falling asleep (or when we wake up and doze off again) we have all noticed that there are ideas and images which oscillate in the field of consciousness, which appear and disappear until they vanish completely. Many people, when during the night they listen to the ticks of a watch or the noise of a waterfall, perceive periods in the intensity of the sound. Nor does changing the watch change the duration of these periods, because the cause is in the brain. When I was studying the circulation of the blood in the human brain, I observed analogous augmentations and diminutions in the quantity of blood which flows to the brain.

In sleep our respiration is regular, but a slight noise is sufficient to cause an arrest ; a deep inspiration follows, and thereafter for some minutes the respirations gradually increase in force and then diminish, forming a curve on the tracing like the cusp of the pipes of an organ ; then there is a slight pause followed by a second period, then by a third and fourth, after which the respiration becomes uniform. To this phenomenon I have given the name of successive oscillations. The energy of the nervous centres is not always set free in a continuous manner, but has a tendency to periods of greater or less activity. When the equilibrium of the nervous centres is disturbed undulations arise which die away by degrees, or rather become the source of other undulations of increasing force ; just as in sounding a heavy bell each pull of the rope accumulates energy, and thus the oscillations become more and more violent. What I have said with regard to respiration applies likewise to attention and fatigue. To convince ourselves of this it is sufficient to look fixedly at the sun or even at an artificial light, in order to exhaust part of the retina and obtain an after image which is the effect of fatigue. On looking at this image we see it disappear and reappear ; and these oscillations continue for some time until at last they disappear completely.

The same oscillations are also perceived in the other senses. When one places one's forehead against a cold piece of glass—the window pane, for instance—one feels the impression of cold for a certain time after contact with the glass has ceased. The intensity of this sensation does not decrease uniformly, but one has alternate sensations of heat and cold; the intensity of the sensation is reinforced three or four times, then it ceases altogether.[1]

I have spoken at some length on these periods because they let us perceive with what rapidity the nervous centres are fatigued. I regard it as very probable that fatigue appears in a nerve cell of the brain after only three or four seconds of work. The prolonged activity of the brain, in spite of this very rapid exhaustion of its elements, is explained by the consideration that we have in the cerebral convolutions two thousand million cells which can do duty for each other.

So long ago as 1874, in a series of observations which I made in Leipzig with Dr. Schön, I had discovered that if one darkens one eye, and, without focussing on any special point, looks with the other at any uniformly coloured surface, such as the sky, a cloud, or a white-washed wall, the field of vision shows regular periods of obscurity and clearness. When obscure it is of a greenish yellow colour, sometimes azure, often indefinite. These obscurations have different durations in different people, and are repeated on an average from five to twelve times per minute.[2]

[1] Beaunis, *Physiologie humaine*, 1888, vol. ii, p. 593.

[2] A. Mosso, *Sull'alternarsi del campo della visione.* Giornale della R. Accademia di medicina di Torino, 1875, vol. xvii, p. 124.

IV

Haller denied that man can direct his attention according to his will;[1] and, as a matter of fact, we do know that the power varies greatly in different individuals and at different times. We shall see later that we may sometimes fail in fixing the attention in spite of every effort of the will. In weak and nervous persons, especially in women, a very prolonged strain on the attention may give rise to serious ailments.

It sometimes happens that when a man has been made to map out his field of vision at an eye clinique, or at a photographer's has been in front of the lens of the camera, he becomes after a short time completely hypnotized and remains immobile.

The amusement of thought-reading is generally known. Those who, with eyes blindfolded, are able by great concentration of will to discover the purpose of another whose hand they hold, are guided by his very slight involuntary movements. Some women feel the strain of this amusement so much that after some time they become dizzy and may even swoon. It is, moreover, a well-known fact that attention produces the hypnotic state. This special form of attention the English call expectant.

Very excitable persons, when they look attentively at any object whatever for several consecutive minutes or when their mind is immersed in mystic thought, such as religious contemplation, fall without being

[1] *Haller*, vol. v, p. 553.

aware of it into a peculiar sleep, which is called hypnotic or ecstatic.

In the church of St. Dominic at Siena there are some frescoes by Sodoma representing St. Catherine. No other artist has ever illustrated in such masterly fashion the sublimity of that attention which in the contemplation of a divine image transcends the bounds of ordinary nature. I believe that in verisimilitude of expression these pictures are among the most marvellous in Italian art. It is several years since I saw them, yet my memory of them is as vivid as if it had been only yesterday.

Perhaps it was the surroundings which had prepared me to experience such emotion. Towards evening I was alone in the church ; from the windows under the ancient woodwork of the roof the twilight lit the great central nave, and the last rays of the sun reflected around added to the majesty of the solitude. I had visited the chapel of the German students, and on its walls had read the Latin inscriptions, by which these youths who had come in ancient times to study at the University of Siena were wont to send even from the tomb a greeting to their distant fatherland. Afterwards I had looked from the balcony of the church, and before me as in a fantastic vision had appeared that city with its ancient towers and reddened walls, its acute arches and marble-columned windows, and its gardens descending like festoons towards the valley.

With the warm rays of spring the sun illumined this magnificent panorama, and I felt as if I were spending this lovely evening in a city of the Middle

Ages. When I roused myself from this reverie, I went to the altar where Sodoma's frescoes are to be found. On the right is the ecstasy, on the left the swoon of the Saint. Both pictures represent the effects of attention and of fervour. Sodoma has reproduced nature with such accuracy, yet with such sublime idealism, that never elsewhere have I seen such a marvellous work of art.

In the fresco on the right of the altar St. Catherine is represented in ecstasy; her eyes are wide open and turned upward, her countenance is that of one in a trance; in her look there is no longer any human expression, the shimmer of a tear alone betokens life. The Saint is on her knees with arms outspread and hands extended, but rigid from a convulsion made evident in the inclination of the long and delicate fingers. In the colouring of the face and the posture of the body is depicted the nervous nature of a hysterical attack produced by the intensity of her religious meditation.

On the other side of the altar St. Catherine is represented in the more serious morbid phase of attention—the swoon. The pallor of the countenance, the abandonment of the limbs, the closed eyes, the head leaning to one side, the complete relaxation of the body, the hands irresponsive and inanimate as those of a corpse, all show that she has suddenly lost consciousness and that her heart has almost ceased to beat whilst she was praying on her knees.

The attitudes of surprise and grief in the two followers who have arrived in time to support the Saint before she falls are marvellously exact to the most minute details of movement and emotion. The pale diffused light which descends from above on these two groups of figures, the virgin purity of the white robes, the love-inspired beauty of one of the nuns, the mystic expression of the subject together with the historical nature of the incident, produce an effect so replete with poetry that it is impossible to dismiss it from the mind.

V

When animals (such as cats) lie in wait for their prey, the concentration of their attention so silences all the other senses, that hunters often make use of this psychic state of insensibility in order to approach them. A dog when pointing is in this state.

In his *Life*, Cardiano writes : " No state is more constant in me than meditation. My subject of contemplation so absorbs me that I cannot dismiss the thought of it either at table or at recreation ; I know not what I eat ; I become insensible to pain."

The great difficulty is to understand the mechanism by which the activity of some parts of the brain becomes more intense whilst that of other parts seems to diminish.

Physiologists think to explain these phenomena by saying that in the physiological process of attention there is an inhibition. There are, however, numerous evident indications that it is rather excitation which prevails. The very attitude of any one who expectantly awaits a sound or a signal, the movements of his head and the expression of his face, show that attention is closely connected with motor phenomena.

Some very excitable individuals suffer from a convulsive twitch, which contracts the muscles of the forehead and knits the eyebrows, or the muscles of the face may contract spasmodically ; in such people emotion and attention render the contractions of the muscles stronger and much more frequent.

The excitability in the motor sphere is sometimes so great as to be embarrassing every time attention is required. I have known surgeons begin to tremble at the critical moment of an operation, although they had no fear whatever. In the practical work done by students in my laboratory I have often noticed a similar phenomenon ; if one warns them to be very careful, when they are handling some delicate instrument or measuring a certain number of drops, then their hand at once begins to tremble, and all is lost. Some people, women and children especially, make grimaces when they concentrate their attention on any task, pouting their lips and knitting their brows ; others scratch their head, or shut one eye.

Fechner has described a sensation of tension in the head, particularly in the occipital region, when one is doing hard intellectual work. A friend of mine, who had certainly never heard of this sensation described by Fechner, told me that this discomfort in the occiput often obliged him to abandon work, and that with mental rest it always disappeared.

In attention there are two distinct factors : the first consists in the reinforcement of the internal representations, the second in the prevention of any impressions from the outside world reaching consciousness. It is possible to work amidst noise, but it certainly entails more fatigue not to allow ourselves to be disturbed in the work of reflection. Neither the one nor the other of those fundamental facts can we explain. Possibly it is least difficult to understand how we can silence other stronger impressions which act on the nervous system while we are concentrating our attention on something else. But we cannot yet decide whether it is the external impression which decreases in strength, or whether it is not rather the internal representation on which the attention is concentrated which is reinforced. Certainly the organs of sense function in the same way when the attention is dispersed as when it is concentrated. A colour at which we are looking fixedly will seem neither brighter nor darker however great the effort of attention. We are here dealing with changes which take place in the secret recesses of the brain, and we must hope to be successful in throwing a little light on these phenomena, which are the foundation of our psychic life.

Bain,[1] Sully, Lange, and others regard attention as a motor phenomenon, and they base this hypothesis on the close connexion which exists between muscular and mental activity.

Ribot has also considered this important problem; and the following quotation shows what he holds to be the function of movements in attention. "Is it the case that the movements of the face, body, limbs, and the respiratory modifications which

[1] Bain, *The Psycho-physical Process in Attention*, 1890. Pt. ii. p. 154.

accompany attention are, as is ordinarily supposed, effects, signs? Or, on the contrary, are they the *necessary conditions*, the *constitutive elements*, the *indispensable factors of attention?* We accept this second hypothesis without hesitation. If the movements were entirely suppressed, so likewise would attention be suppressed."[1]

When we shut our eyes and think of a pencil, says Lange,[2] we make first a slight movement of the eyes corresponding to a straight line, and frequently we are aware of a slight change in the innervation of the hand, as if we were touching the surface of the pencil. Lange found in his own case that whenever he thought of a circle, a movement of the eye corresponding to this figure always took place; whence he affirmed without qualification that only by means of muscular contractions is thought rendered possible. With regard to abstractions, Stricker had previously demonstrated the existence of the word image. A little observation will indeed convince every one that when we think of an abstraction we silently pronounce the word which represents it, or at least feel an inclination to do so.

VI

Much importance has been attached to the circulation of the blood in the phenomena of attention. I am among those who had a predilection for investigating the movement of the blood in the human brain, and I showed the mechanism by which the

[1] Ribot, *Psychologie de l'attention*, p. 32.
[2] Lange, op. cit., p. 415.

afflux of blood to the brain is increased during attention. Continuing such investigations in a work which I have not yet published, I was able further to convince myself that the blood is not the first and most important factor in psychic activity. The brain cells contain substances sufficient to provide for the operations of consciousness without there taking place any sudden modification in the afflux of blood. Indeed, observation during sleep of persons who had an aperture in the cranium showed me that consciousness is established before any alteration takes place in the circulation of the blood within the brain.

Attention, which at first sight appears to be a strain on the intellect, turns out, on the contrary, to be a marvellous saving of energy. What would happen to us, or to the animals, if all the impressions from the external world were to remain impressed upon the memory at the same time and with equal intensity? A mechanism to enable us to limit such impressions and to make a selection of those we wished to retain was a necessity. We are present at the constant change of the contents of our mind without their leaving any trace which fatigues us permanently.

There are many other organs which have to function intermittently like the brain. The salivary glands, the glands of the stomach, the pancreas, etc., function only at intervals. There are special nerves which, independently of the blood current, accelerate and strengthen the processes of life in these organs, when they are to secrete.

As we have an exact knowledge of the state of the cells of the salivary, stomachic, and pancreatic glands when in repose, and can give an exact description of the changes which they must undergo in order to function, so is it probable that in the brain also the appearance and intimate composition of the cells is different when they think and when they repose. Analogy, which is of such value in the interpretation of the facts of nature, suggests that it must be so, nor do I know of any fact opposed to such a supposition.

Just as we have nerves charged with providing for the secretions of the glands, I regard it as probable that there are also in the brain nerves charged with stirring up and rendering more active the life of its cells. If this opinion of mine be true, attention would be a reflex movement.

Just as one turns pale or sheds tears or trembles, just as the secretions of the salivary and other glands are arrested or resumed, so do we involuntarily cause the cells of some regions of the brain to undergo a transformation by which they become better adapted to receive impressions from the external world, or are prepared and adjusted for more active changes, for a more intimate relation with other regions. This supposition of mine explains why the more abundant afflux of blood to the brain is insufficient to make it function more actively. The smell of the fumes of nitrite of amyl is sufficient to produce considerable hyperaemia of the brain ; but every one who has tried the experiment is aware that the play of ideas does not on this account become more active. The same thing takes place in the glands; it is not sufficient to promote a secretion which increases the flow of blood in the glands, it is necessary to stimulate the secretory nerves: this then is the fundamental condition, the hyperaemia is a secondary fact.

The differences in civilization apparent in different races, the differences in intellectual power apparent in different individuals of the same race, would depend on the ease and intensity with which the chemical processes of life are modified by means of this reflex action, and the cells in the various parts of the brain made to function more actively and to retain more clearly the impressions made by the phenomena of the external world. The more quickly our brain can consume and repair itself, the more powerful it is. These supposed nerves of attention would, like the secretory nerves, have the power of stimulating the destructive processes in the cells of the cerebral hemispheres so as to transform energy and produce thought. Attention would, like the periodic functioning of the glands, be a mechanism for economizing the energy of the organs, which have to function only at the precise moment when their consumption is necessary.

VII

There are many facts which show the material nature of the organic process on which attention depends. For instance, we are familiar with its obstruction. Often, in turning over the leaves of a book, we are aware of having read only one word, although we have glanced through the whole page on which it was written. Or, when walking along the street, we become aware of having seen something in a window when we are some steps past it; or, in a conversation, of having heard a name some seconds after it was pronounced.

When we wish to keep our attention fixed on a thought, our mind by degrees shows a tendency to wander; there are moments in which a cloud comes between us and the thought, so that, in spite of every effort, we can no longer retain it; other images and other thoughts crowd in, and we feel an increasing need of repose. If we hold something in our hand and stretch out our arm, there takes place in the muscles a series of phenomena analogous to what we observe in the brain during an intellectual effort. At first the contraction of the muscles appears not to fatigue us, but shortly afterwards we feel the fatigue increase rapidly, till finally our arm trembles and then gives way.

If the brain is fatigued, it is almost impossible to be attentive. Galton studied the movements which take place in a large audience when a lecture has been prolonged so much as to fatigue the listeners. The art of class teaching consists chiefly in knowing how long and in what way one can retain the attention of the students. The best masters are those who never fatigue too much any one region of their pupils' brains, so that their attention, being directed now here, now there, obtains some rest, and is better able to grapple with the main subject of the lesson.

Beard, the author of a recent work on American nervousness, says that nowadays in America "no lecturer can attract very large crowds unless he be a humorist and makes his hearers laugh as well as cry ; and the lectures of the humorists—now a class by themselves—are more required than those of philosophers or men of science or of fame in literature. Americans, who are themselves capable of originating thought in science or letters, scholarly, sober, and mature, prefer nonsense to science for an evening's employment." This, according to Beard, "is an inevitable reaction from the excessive strain of mental and physical life ; people who toil and worry less have less need than we for abandonment—of nonsense, exaggeration, and fun." Beard is convinced that in no other country is nervous exhaustion so common as in the United States ; that in no other country are there so many varieties and so many symptoms of nervous debility.

Mirth is like a safety valve, and we can understand that in the art of oratory humour should be one of the rules for speaking to a wearied audience. In Parliamentary debates one can observe the effect produced by certain speakers who know how to rest the attention of their hearers, and how to make it work in physiological periods without fatigue. Physiology will be of great assistance to oratory, when human psychology is better known.

However little attention we may have given to the subject, we are all aware that after too long a walk, or after any violent exercise, such as gymnastics, fencing, or rowing, we are less fit for study. It is true that sometimes after moderate exercise intellectual work seems to become easier ; this arises from the stimulating effect of muscular work, which we shall have occasion later to consider at length. The best example of the incapacity for attention produced by muscular fatigue is given by Alpine ascents. Only with great difficulty could Saussure do a little intellectual work on Mont Blanc. "When I wished to fix my attention for a few consecutive moments, I had to stop and take breath for two or three minutes."

In my own case I have observed that great muscular fatigue takes away all power of attention and weakens the memory. I have made several ascents. I have been once on the summit of Monte Viso and twice on that of Monte Rosa, yet I do not remember anything of what I saw from those summits. My recollection of the incidents of the ascents becomes more and more dim in proportion to the height attained. It seems that the physical conditions of thought and memory become less favourable as the blood is poisoned by the products of fatigue, and the energy of the nervous system consumed. This is the more singular in my case because I have a good memory for places.

Several Alpinists whom I consulted agreed with me that the last part of an ascent was least distinctly remembered. Vaccarone, the barrister, well known for his daring ascents, one of the most distinguished writers belonging to the Italian Alpine Club, told me that he was obliged to take notes during an ascent, because on his return in the evening he remembered almost nothing. The following day, when the fatigue had passed off, many particulars recurred to his memory which he believed he had entirely forgotten.

The incompatibility existing between physical and intellectual work, the limits which should be observed in physical exercise in order that it may be useful and not harmful to cerebral activity, are questions which should be seriously studied by educationists.

Professor Gibelli told me that in botanical excursions his memory diminishes as soon as he begins to be fatigued, and eventually he becomes unable to recall the names of even the commonest plants. Rest very soon causes this phenomenon of fatigue to disappear. Delboeuf, in his very valuable study on the measurement of sensations, calls to mind the fact that short-sighted persons wear spectacles in order to see better, because thus they diminish the fatigue arising from confused vision.[1]

VIII

A characteristic indication of the fatigue of attention is yawning. Every one knows what this is; nevertheless, I may say that it arises from a deep, slow, and involuntary inspiration by which the lungs are filled with air, which is then slowly expired, the mouth being held open and the glottis slightly shut so as to produce that strange characteristic noise which is the dread of orators.

To make myself clear I should have to write a chapter upon yawning, and I hope to do so in one of

[1] Delboeuf, *Eléments de Psycho-physique*, Paris, 1883, p. 52

my next books upon the physiology of sleep. For the present I shall limit myself to what is necessary for the study of fatigue.

Yawning is produced by a slight passing anaemia of the brain. When we are tired or bored, the blood vessels are gradually dilated, and the blood remains, so to say, stagnant in the small veins of the body. This dilatation is favoured by a high temperature, and the blood circulating under decreased pressure renders us less fit for brain work, and the phenomena of fatigue appear more quickly. Patients who suffer from cerebral anaemia or from certain affections of the medulla oblongata often yawn continually. When we say that yawning is contagious, we mean that the weariness is general, and therefore every one is inclined to yawn. Yawning may be regarded as an indication of fatigue and weakness; those who suffer most from it are hysterical women.

Yawning is usually accompanied by a contraction of the muscles, to which one gives way whenever possible, because it brings relief; repressing it in public requires a certain effort which one cannot always succeed in making. The relief which follows the stretching of the arms results from the fact that by contracting the muscles we set in motion a certain quantity of blood which was stagnating in the veins. This increases the pressure of the blood and renders the pulsations of the heart stronger, and thus carries off our depression. Yawning and stretching is not an acquired habit; babies are very often seen to yawn and stretch themselves even in the very first days of life.

IX

Nowadays chronometers are constructed which mark the thousandth part of a second. One of those most employed by physiologists in their experiments on attention is that made by Hipp, of the telegraph department at Neuchâtel, and bearing his name. With these chronometers one can easily measure, by opening and closing an electric current, the time taken by a ball to pass along the bore of a cannon, or the velocity of a projectile at any point of its course. With them we measure the time which elapses between the production of a sound and the notification of its perception. Physiologists, especially the pupils of Wundt, have extended to all the senses their investigations of the phenomena of attention. One of the most singular facts—one of which we have all had practical demonstration when fencing or playing at ball or at any game of skill—is that attention increases the promptitude of reaction ; when we are off our guard we require a longer time to get into the proper position and hit back.

The shortening of muscular reaction time as the effect of attention may depend on either of two factors : the movement itself may be executed more rapidly in consequence of the preparation for it ; or the beginning of the movement may take place sooner, because the representation of the stimulus in consciousness does not require to attain to the intensity ordinarily necessary for the production of movement, nor does the attention require to make the transit from the representation of the stimulus to the representation of the movement. The second hypothesis Martius regards as the more probable.[1]

The difference is not in the rapidity of the movement, but in that of the psychic processes. The time of physiological reaction or simply physiological time is the name given to the interval between the occurrence of an electric spark, for instance, and our giving some sign of having perceived it, say, by touching an electric button on which our hand rests. This short space of time varies in different individuals, and represents the delay which takes place before we take account of one of the most simple forms of perception. Great individual differences are found in this as well as in the more complex forms of perception. Proof of this variation is readily obtained by reading a column of a newspaper or a page of a book along with some one else. Fatigue has a great influence on the duration of this reaction time. When such measurements are repeated without an interval for rest, the time before the response is given gradually increases.

Most people take about 134 thousandths of a second before responding with the hand to a touch on the foot ; but fatigue of the attention may prolong the interval to 200 or 250 thousandths of a second.

Obersteiner showed that noises and all causes which tend to distract the attention lengthen the time of physiological reaction. One example will suffice to show how much better our brain functions

[1] Götz Martius, *Ueber die muskuläre Reaction und die Aufmerksamkeit. Philosophische Studien.* Wundt, vi, Bd. 2 Heft, 1890, p. 214.

in silence. Obersteiner had an organ placed in the room where, by means of Hipp's chronometer, he was measuring reaction time. When there was silence, the subject of the experiment took 100 thousandths of a second before with his right hand he gave a sign of having felt a touch on his left; but when the organ was played, the time was prolonged to 140 or even 144 thousandths of a second. This retardation took place in spite of the greater intensity of the attention, and whenever the music ceased the time of physiological reaction became as before.[1]

The physiologist Exner,[2] who has investigated this subject, had previously found that the work of attention increases the secretion of perspiration. My brother investigated the influence of cocaine on the phenomena of attention. It was already known that certain stimulants, such as alcohol and coffee, shorten reaction time. My brother found that cocaine produces the same effect.[3] About half an hour after taking from five to ten centigrammes of cocaine, one experiences a sensation of excitement and well-being, which lasts about an hour. In this interval one reacts with greater promptitude to external stimuli, and perception takes place more rapidly.

Fechner had already established the fact that attention does not depend on the better functioning

[1] Obersteiner, *Experimental researches on attention*, Brain,i, p. 439.

[2] S. Exner, Hermann's *Handbuch der Physiologie*, ii. B., ii. Th, p. 288.

[3] Ugolino Mosso, *Azione della cocain sull'uomo*, R. Accademia di medicina di Torino, 1899.

of our senses. The eye, as we have already said, does not through attention become more sensitive; objects do not appear more distinct, nor are the after images, due to fatigue, more lasting. Attention, as Exner says, acts on parts of the brain where the sense impressions are already elaborated up to a certain point.

X

In the most ancient books of philosophy and medicine, in the works of Aristotle and Galen, the differences existing in the natural endowments of different races are commented upon; and we constantly hear it said that the people of the south have a more lively sense of music and of colour, a more vivid imagination, greater muscular mobility, and a more excitable nervous system. Civilization tends to make this difference between the northern and the southern nations disappear, in that it presents a complex of causes and effects, not the least of which is wealth. Nowadays the north no longer envies the south the glories of poetry, of music, and of art.

The difference between the people of the south and those of the north is, however, still so great that, as a rule, one would never take the mind of a Frenchman for that of a German, or the mind of an Italian for that of an Englishman.

Professor Gaule,[1] in a recent paper on *Physiology as an Educative Science*, says: "Can education accelerate our thought and the action of our nerves?

[1] F. Gaule, *Von der Physiologie als erziehender Wissen schaft. Schweiz. Pädagogische Zeitschrift.* Heft. i, 1891.

Before you answer, I beg you to observe a crowded street on a holiday or market day. You will easily distinguish the peasant by the disturbance he makes and the awkward way he runs against you. All foreigners complain of us, and praise the character of the Italians, who, even in the densest crowd, never come in collision with any one. Do not believe, however, that this arises from any defect of character. Our people are as kind-hearted as those of any other country. They do not get out of the way because they cannot. Their brain does not act with sufficient rapidity for them to give prompt orders to their muscles to avoid every new figure that unexpectedly appears on their field of vision. They cannot change their direction swiftly—a thing which comes easily to an Italian of no more or even less education. And why is this? Because with us the crowded city is a product of modern times; because with us the people come down from the mountains and from distant hills where there is no throng penned up in little space. The Italian on the other hand is the heir of a culture which has flourished for thousands of years, which has been developed in cities; he possesses the nerves of his progenitors, and is prepared for rapid changes because his nerves act more quickly."

I am convinced that my friend Gaule is right. Should another proof be necessary, I may recall to mind the fact that the Italians and the French to this day surpass all other nations in the art of fencing. In this, great concentration of attention, which reduces to a minimum the time of the physiological reaction is precisely what is required; the essentials are great swiftness of perception and resolve and the highest agility in the muscles because the best fencer is the quickest. It is certainly a singular fact that even now the Germans and English, who surpass us in so many more important things, cannot compete with the most skilful fencers of the Latin race.

CHAPTER IX

INTELLECTUAL FATIGUE

I

We do not know the nature of thought, and it might be better not to discuss it; but physiology, as Du Bois-Reymond says, "is the only one of the natural sciences which necessitates our speaking of things of which we know nothing."[1]

In the physiological class-room we speak of many organs of whose function we are ignorant, such as the spleen, the thymus, the thyroid gland, the supra-renal capsules; and of as many others regarding which we can say nothing positive and must content ourselves with warning our hearers that the entire truth is still unknown to us, and that we are only trying to discover it.

Thus we are convinced that for the production of thought, emotion, or feeling a transformation of energy is required, but the palpable proof of this we cannot yet give. The principle of causality is the expression of a postulate.

Of thought memory is a fundamental factor, and

[1] *Reden* von E. Du Bois-Reymond, Zweite Folge, 1887 p. 199.

it has certainly a material basis in the cells of the brain. Even yet we do not understand the mechanism by which external objects succeed in producing by means of the nerves traces on the brain ; but that our relations with the external world do produce a central organic alteration is seen in the way the strength of the impression varies with the intensity of the stimulus and the physiological or pathological conditions of the brain. The various methods of learning by heart, repetition or reading aloud (as children do in preparing a lesson) make us think of the mechanical methods of impression as we see them in certain industries. In making a water-colour sketch one likewise works in this way. Certain images seem to be imprinted on the memory in light colours which gradually fade, so that from time to time they need to be touched up lest they disappear altogether.

The continuous nature of our recollections, the resounding and unceasing echo awakened within us by the vibrations and chemical processes produced in the brain by the stimuli of the external world, the persistent uninterrupted memory which psychic states and emotions leave in the cells of the brain, this is what constitutes our identity, this is the material basis of that *ego* so much discussed by philosophers. The disposition of the nerve cells to retain impressions is one of their most characteristic properties. I can conceive a plant without memory ; but as soon as I think of an animal which moves, of an organism which is no longer an automaton, and see that it adapts itself to its environment, that it makes complicated reflex movements, I must suppose that there are cells in its body in which memory shows itself in an elementary form. By degrees the disposition to retain impressions and to modify movement in accordance with them will become greater; instinct, association of ideas, impressionability undergo elaboration as we ascend the zoological scale. But the nature of the process is always the same; the quantity of memory is multiplied with the multiplication of cells, the quality remains identical. And this wonderful power possessed by the cells of the cerebral convolutions which, like a mysterious phosphorescence in the obscurity of the ego, can revivify the impressions and emotions which disturbed their equilibrium, is the origin, the foundation, and the principal condition of consciousness.

Besides the power we possess of seeing and feeling external things, we possess a power of seeing and feeling the impressions which external objects have left within our brain. Consciousness is, as Wundt[1] says, the sum of all the representations contemporaneously present and active. It is not a mysterious and transparent vessel which contains the images of the memory and imagination; it is these very images themselves in their constant reanimations; it is the content and not the container which makes on us the impression of our ego.

II

Imagination is of the same nature as sensation. It is an echo, a simulacrum, a phantasm awaking spon-

[1] Op. cit., p. 230.

taneously without provocation from without. It is a resurrection which reaches the intensity, clearness, and persistence of the original impression ; and which can be mingled with other memories or changed and touched up so that from it is born, as it were, another image of reality. What we call imagination and vivacity of mind is the power of reviving quickly any sensation simple or complex, representations, emotions —in a word, any psychic state which after having left its trace on the brain had remained, so to speak, drowsy or half exhausted.

There are many facts which prove to us that this re-animation of images takes place in the same nervous constituents on which the external impressions primarily acted. If we observe a person who is afraid of tickling, we shall see that whenever we pretend to touch him he prepares to defend himself, and assumes an attitude which indicates that all the phenomena which accompany tickling are reproduced in his mind along with the idea.

Montaigne has written an interesting chapter on the force of imagination, in which he says—

"We sweat, we shake, we grow pale, and we blush at the motions of our imaginations ; and wallowing in our beds we feele our bodies agitated and turmoiled at their apprehensions, yea in such a manner as sometimes we are ready to yeeld up the spirit. And burning youth (although asleepe) is often therewith so possessed and enfolded, that dreaming it doth satisfy and enjoy her amorous desires." [1]

Imagination directs the eyes of the mind within to

[1] Montaigne's *Essays*, chap. xx, Florio's translation.

contemplate the impressions which past objects and emotions have left on the memory. We call those who can see these images best poets and artists. In some people this inward vision is almost entirely wanting, whilst in others the power of reviving and studying such memory images is very considerable.

A great profusion of images, memories, ideas, would be of little practical use had we not also the power of selection and arrangement. It is, however, difficult to say how this selection is made, for this is one of the regions in which modern psychology has made little progress.

We are all agreed that sometimes the phenomena of memory take place independently of or even against our will, so that we are entirely passive ; whilst at other times it is by our mental exertions that the ideas are awakened and associated together.

Münsterberg[1] says : " It is possible that the reproduction of images, when it is active no less than when it is passive, is always a physically produced association, and that theoretically the two cases are not diverse, but only appear so, because with the one is mingled a complex of sensations which we call will, which is wanting in the other ; this complex of sensations might, however, itself be only a passive association, physically produced, the cause of which is not different from that of other associations."

This problem cannot be resolved directly. From the researches made by Professor Münsterberg in order to find a solution indirectly it follows that

[1] H. Münsterberg, *Beiträge zur experimentellen Psychologie*, Heft i, pp. 67 and 72.

"there is no boundary which divides the psycho-physical processes from those which are simply physical: the most complex phenomena of voluntary selection are themselves only reflex phenomena; and the psychic phenomena which accompany them have no appreciable influence. The process would follow the same course even if we were not conscious of the intermediate links; all that we should know would equally be a passive sensation and a passive reproduction of sensations, which our consciousness perceives without being able to intervene in their succession."

All this is true; but we must confess frankly that there is still a great gap in our knowledge which modern psychology does not know how to fill up.

Every one who pays any attention to what takes place within him when he thinks will agree that he is not simply present at the appearance of images in the field of consciousness, but that he can himself rearrange them, can reject some ideas and call up others, and order them all in logical fashion. The ease with which we can let down one scene, raise it and put another in its place, is one of the most difficult things to explain in the mechanism of our cerebral functions. And more marvellous still is the power we have of occasionally suspending all this representation and obtaining a pause which lasts for some minutes. What the explanation of these changes may be we have not to this day the remotest idea.

In Spencer's view the rational action arises out of the instinctive action. He says: "That the commonly assumed line of demarcation between Reason and Instinct has no existence, is clearly implied not only in the argument of the last few chapters, but also in those more general arguments elaborated in preceding parts of this work. Proving, as the Special Analysis did, that there exists a unity of composition throughout all mental processes, from the most abstract reasoning down to the lowest conceivable type of psychological action—proving, as it did, that the lowest forms of animal life are made possible only by a classification of impressions fundamentally the same as that which constitutes the most elaborate thinking of the civilized man ; it involved the conclusion, that our ordinary psychological divisions are simply conventional. The General Synthesis again, by showing that all intelligent action whatever is the establishment of a correspondence between internal changes and external co-existences and sequences ; and by showing that this continuous adjustment of inner to outer relations progresses in Space, in Time, in Speciality, in Generality, and in Complexity, through insensible gradations, similarly implied that the highest forms of psychological activity arise little by little out of the lowest, and, scientifically considered, cannot be separated from them. So that not only does the recently enunciated doctrine, that the growth of intelligence is throughout determined by the repetition of experiences, involve the continuity of Reason with Instinct ; but this continuity is involved in previously enunciated doctrines." [1]

We believe ourselves lords of our ego and of our

[1] Spencer's *Principles of Psychology*, Part iv, chap. viii.

determinations, because we are ignorant of the unconscious psychic phenomena which precede and determine our thought. Whenever we feel that the power of selecting among the various ideas which present themselves to our mind has ceased, then we cease to be conscious of the process of representation leading us to a psychic result; whenever an idea persists till at last we feel ourselves impotent and passive with regard to it, then we are mad.

III

In order to show how much intimate association with nature may enrich the language of a people, Alexander Humboldt tells us that the Arabs have more than twenty words to designate the desert. We have only one single word to express fatigue. The reason of this difference is easily perceived. A desert may be flat, undulating, mountainous, covered with sand or gravel or rocks, dry or marshy, sterile throughout or with some pasturage—in one word the idea desert may be conjoined with the most varying topographical attributes; but fatigue is an internal sensation, which does not present features sufficiently characteristic to express the varieties of its physiognomy.

When one says fatigue, pleasure, hunger, thirst, every one understands what is meant, and we can also, by means of adjectives, express the greater or less intensity of the sensation; but in precision we cannot compare the idea thus awakened with that produced in us by the sight of the desert. What we want when we speak of our sensations is weight and measurement ; there are shades and gradations which we cannot express, little differences which we cannot appreciate at their just value ; and worst of all, we cannot even attempt to describe these phenomena so as to compare them with those experienced by others, without falling into the greatest lack of precision.

In muscular fatigue, if the work was light, we feel a little weariness ; if the fatigue was excessive, we experience an uncomfortable and painful sensation which lasts for several days. The need of rest after brain work, or the weakness we feel after great emotion or intense pain, is something more vague and more indescribable than the local pain produced by muscular fatigue.

What renders this study still more complex is that nervous fatigue does not affect every one in the same way, and consequently we can never be certain, when we speak to any one of sensations that we have experienced, that he has felt them in similar fashion.

The fact that the same cause gives rise to pain or pleasure in another as in myself may make me suppose that the sensations are equal in us both, but of this there is no proof. Similarly in the case of intellectual work, we must consider not how much others can do, but how much we ourselves can do without fatigue ; just as the water of a bath may feel cold to one and hot to another.

We do not feel our internal organs. It commonly happens that even educated people are ignorant of the position of the viscera in the abdomen and the chest. Nor should this surprise us, because, unless these organs are inflamed, their nerves never reach the degree of sensibility necessary to excite the nervous centres. The stomach, the intestines (except the end of the rectum), and the uterus are quite insensible to temperature ; they can be burned or cut without our feeling it. And it is the same with the brain. Galen long ago pointed out that its substance could be touched without causing pain. From numerous observations both of men and of animals, we are perfectly certain that the brain can be cut stratum by stratum without the least pain being felt. The surgery of the brain, which has recently made great progress, has established the fact that even in man the brain is insensitive. We can wound the liver, the muscles, the spleen, the kidneys, without causing any pain. The sensory nerves are found chiefly in the skin, and our sensibility is intended to defend us against the action of the external world, to procure for us the pleasurable or painful stimuli which conduce to our preservation.

Our inability to judge of internal sensations is often clearly shown when we are feverish. When we put our finger or hand into warm water of a temperature between 33° and 37° C., we can distinguish a difference of $\frac{1}{5}$ of a degree. On the other hand, when we become feverish we may not be aware of a difference in our temperature of even a degree and a half or two degrees, nor can we tell exactly what the internal temperature is without employing the thermometer. We often say we are cold when our internal temperature is above normal.

Certain very serious infectious diseases which inevitably result in death have a period of incubation of which the victim is quite unconscious; just as certain poisons which have no taste can be secretly introduced into the organism and bring about a painless death. One of the most astonishing things to a student of poisons is the minute, almost imponderable quantity of certain substances, which is sufficient so to alter the life of the nerve cells as to abolish consciousness and sensibility, and produce death without the victim becoming aware of anything wrong.

Fatigue, which we must likewise regard as a poisoning, may alter the constitution of the blood and the conditions of life, without our being aware of it or giving the faintest sign of exhaustion.

It is an accidental fact (if I may be permitted the expression) that man has arrived at such a degree of civilization as to study himself and examine what takes place within him. It is a luxury in which uncivilized races might indulge; but primitive man, like the animals, was intended simply to struggle for life; and all his structure is adjusted to this end. Wherefore he judges with certainty only what takes place outside of himself. This was a necessity, and in the struggle for existence even the animals have attained so far. We must not therefore wonder if psychic facts are less suited to study, if subjective phenomena escape us, and language becomes pale and imperfect as soon as we seek to express or to measure a feeling. It is a good thing that we have little internal sensibility, so that the functioning of the organism does not give too much trouble to the nervous system, which is all intent on its struggle with the external world.

IV

It is difficult to describe precisely the symptoms of brain fatigue on account of the great individual differences in the power of resisting harmful agents. An example will make this clear. If a number of people are exposed to cold, in the same circumstances and at the same temperature, it may happen (let not the reader be alarmed if I make the cases serious) that one takes inflammation of the lungs, another tetany, a third facial paralysis, a fourth rheumatism, a fifth enteritis, a sixth a simple chill, a seventh some disease of the skin, and the others no harm at all. It is the same with intellectual fatigue.

The ancients classified the differences among men under four heads which they called temperaments. This classification was based on physiological ideas which were afterwards shown to be entirely false. Nevertheless the differences among men do still exist, although we cannot give the reasons for their nature and origin. Temperament does not depend on the bile, the blood, and the phlegm, as Hippocrates believed, but principally on the nervous system. It is very probable that the so-called nervous people, in whom the phenomena of fatigue easily arise, are born with a nervous system inadequate to the rest of their body. In such persons an arrest of the nervous system must take place, so that it preserves certain infantile characteristics.

Unfortunately we have no records comparing the weight of the brain, spinal cord and nerves with that of the muscles in persons whose psychology and intellectual abilities we know. Even the comparison between civilized and savage man has been scarcely begun, and the anthropological and ethnological material hitherto accumulated is not sufficient even for a physiological study.

It is a matter of everyday experience that men who seem to be prodigies of health and strength may suffer from great weakness of the nervous system, and may be without either capacity for or resistance towards intellectual work. On the other hand, there are those, such as Virgil, Pascal, Vico, Leopardi, to mention a few of the greatest, who though little favoured physically by nature, have yet done wonders by the strength of their brain.

When we think of the human brain we must recollect that at one end of the scale we have the great brains of such celebrated thinkers as Cuvier, Volta, Petrarch, Schiller and Byron, which weighed from 1,860 to 1,600 grammes. At the other end we have the brains of such microcephalous patients as those described by Professor Giacomini, which weigh only from 170 to 966 grammes.[1]

Dante's brain was smaller than that of the average man; whilst Gambetta's weighed scarcely 1,180 grammes, which is 140 grammes less than that of the average woman. This shows, without need of further comment, that besides the material difference of weight, there must be functional differences in the nerve cells of different brains. The anatomical dif-

[1] C. Giacomini, *I cervelli dei microcefali*. R. Accademia di medicina di Torino, 1889. *Archives italiennes de Biologie*, vol. xv, 1891.

ferences become negligeable in comparison with the chemical differences in the processes of life, in two groups of cells equal in number, identical in form, and similar in aspect.

Haller,[1] in his great work on physiology, compares the effects of study to those of love, which stimulates the circulation of the blood and promotes the perspiration. Buffon, who was in the habit of working twelve hours consecutively, used to say that the feeling that he was hot and flushed gave him warning of the commencement of fatigue.

In my book on *Fear* I have already spoken of the effect of intellectual work on the heart and blood vessels ; here I shall only recall the facts that fatigue renders the pulse weak, whilst the head becomes hot, the eyes bloodshot, and the feet cold ; some people experience also a buzzing in their ears.

These phenomena depend on the contraction of the blood vessels, which is needed to maintain a high blood pressure. This greater tonicity, as it is called, is produced even in organs with unstriated muscles, such as the bladder ; this explains why we require to pass water more frequently when we are studying than when we are resting or walking. These and other phenomena, such as the feeling of cold in the legs and of heat in the head, have all the same cause, namely, the contraction of the peripheral blood vessels

[1] Haller, *Elementa Physiologiae corporis humani*, tom. v, p. 582.

of the body, which produces a more copious flow of blood to the brain.

Dr. E. Gley,[1] in a paper upon the influence of intellectual work on the internal temperature of the body, observes that as soon as we sit down at the table to write or read, our immobility immediately results in a lowering of the temperature ; but this is a transitory phenomenon, and by degrees, if the intellectual labour is intense, the temperature of the body rises above normal.

A much more important phenomenon is palpitation of the heart. Two of my medical colleagues (otherwise in very good health) tell me that they never have palpitation when they are in the country on their holiday, but that as soon as they return to town and take up their work again, they suffer from it occasionally, particularly at the beginning of winter. Both are engaged all day in laboratory researches and the duties of their clientèle ; and when in the evening, after the fatigue of the day, they sit down to work, after two or three hours palpitation comes on and they are obliged to cease. If they continue, the trouble increases so much that it becomes difficult for them to obtain any sleep.

In such cases the question is whether the heart beats more strongly or the sensibility is increased. As a matter of fact it is both. In hysterical cases also it may happen that the cardiac systoles, although actually remaining constant in force, seem to become stronger only because previously they used to pass unnoticed.

[1] *Société de Biologie*, 26 avril, 1884.

Excessive brain work sometimes brings on irregularity and increased rapidity of the heart's action. Indeed, I have myself experienced this. Quite suddenly one feels short of breath and slightly stunned for no apparent cause. The respiration is unimpeded, all the senses are acting perfectly ; but one is aware that some unexpected change has taken place within. On feeling the pulse we find that the heart is beating more rapidly, so that it is difficult to count the number of pulsations. This lasts little more than half a minute, then the beats become slower and fall even below the normal, so much so that one barely occurs every two or three seconds ; this period of reaction in which the pulse is so slow lasts in my case about half a minute.

Charles Darwin found that excessive intellectual work was apt to produce vertigo, and I have seen Maurice Schiff also suffer from slight dizziness from the same cause. In the evenings he was dictating to me certain additions, for the second edition of his physiology of the nervous system, whilst during the day he was experimenting with marvellous persistence and intense concentration of attention. It sometimes happened that in stooping to take a book from a shelf, he would suddenly become giddy. Sometimes similar attacks would seize him even in the laboratory, or when he was seated. As soon as he had finished his work and the book was published, these attacks ceased. To active brain workers these phenomena will not appear strange.

VI

In a letter to a friend, written when he was composing his inaugural address, Foscolo says: "I am working until I can neither eat nor digest."[1] A bad digestion, as we shall see in the sequel, is one of the most frequent complaints of those who work with the brain; so much so that Tissot says, "He who thinks most is he who digests worst."

Yet the observations which I have collected among healthy subjects do not always confirm this saying; since I have found that in certain cases intense intellectual labour, so long as it is not excessive, actually whets the appetite.

In his book on nutrition Moleschott[2] says—

"In artists and scientists the material change promoted by their intellectual exertions is again moderated by their sedentary life. Nevertheless we find in them as effects of their activity of mind a more abundant secretion of the urinary salts, increase of bodily temperature, and greater need of nourishment. And it is a well-known fact that artists and scientists, in spite of their sedentary life, rarely suffer from excess of fat."

The distinction which we have made with respect to appetite must be repeated with respect to sleep; moderate work which fatigues without exhausting, conduces to sleep; exhaustion of the brain, on the contrary, produces insomnia.

If we try to continue our work in the evening after

[1] Foscolo, *Lettere* i. p. 192.
[2] Jac. Moleschott, *Lehre der Nahrungsmittel*, 1858, p. 223.

a day of intense application, we find our ideas confused, our work burdensome, even our memory weak. A friend of mine, who is a poet, tells me that if he tries to compose in the evening when he is fatigued he is unable to find rhymes.

At times we all experience a certain difficulty in following an argument, an intellectual torpor, which gives warning of fatigue of the brain. Difficulties which in the morning we should laugh at appear insurmountable in the evening ; we lose all confidence in our mental forces, and even our will becomes slack. The letters of a manuscript or book dance before our eyes. Our eyes ache, the lids become heavy, we yawn, and finally cease work.

Francis Galton,[1] in a very valuable paper on mental fatigue, gives an account of experiments which show that some schoolboys cannot spell correctly when they are tired, and that they leave out words in writing.

In brain fatigue, phenomena are observed which bear a certain resemblance to those produced in the muscles by a long walk. We have all experienced that torpor in our legs which hinders our resuming our walk once we have sat down to rest. It is the same with the brain ; when we are tired by prolonged intellectual work, we cannot without great effort take up our task again.

One of my friends, who was lecturing on dramatic poetry, told me that often, when he had to work far into the night, he became aware of being fatigued by his increasing difficulty in reading English ; and that

[1] F. Galton, *Recherches sur la fatigue mentale. Revue scientifique*, 1889, i, p. 98.

sometimes after having run through some pages of a Spanish author, he was kept back and, as it were, fettered in his reading if he took up a German or an English writer.

The headache which succeeds intense brain-work corresponds to the inertia felt in the muscles of the legs after a long walk, or to the stiffness and discomfort felt in the muscles of the arm after a first game at balloon. We shall see later that a slight oedema and a little disturbance in the lymphatic circulation are sufficient to render us incapable of thought.

In my own case fatigue of the eyes precedes fatigue of the brain, and I am not good for more than four or five consecutive days' hard work at my desk. More than once in writing this book I have had the opportunity of convincing myself of this. During the University session, my daily lectures and my laboratory work present sufficient variety to prevent my feeling much brain fatigue ; because I very rarely study at night. But when the week's vacation comes, and I abandon myself to the passion of work for ten or twelve consecutive hours, after three or four days I am forced to rest. On the evening of the third or fourth day I have a headache, and, if walking, I feel a slight uncertainty in the movements of my legs, although the muscular contractions are accomplished as usual. My appetite continues good. My head is hot, and in various parts of my body I feel a slight tingling, accompanied by fleeting sensations of heat and cold. I feel a little weariness in the hips. At night, when I go to bed, I have to wait half an hour or sometimes an hour before falling asleep, a very unusual circumstance with me. Moreover, my sleep is bad, and I am awakened by dreams. In the morning my eyes are red and bleared ; I feel fatigued, the night's rest has not sufficed to refresh me. My muscles are indolent ; my hand quickly tires of writing ; I feel a certain heaviness in my head. Then I shut my books, set aside my papers, and after twenty-four hours' rest I find that I am cured.

VII

Fatigue of the eyes in the perception of colours has been thoroughly studied by Goethe. The genius of this immortal poet is especially apparent in his profound knowledge of nature even in its most minute details. He wrote a celebrated book of morphology on the metamorphoses of plants, and published some studies in comparative anatomy. Italy, which affected his thought and artistic inspiration so considerably, had also a very great influence on his scientific studies. On the shore of the Lido at Venice, he chanced to find a broken sheep's skull, and was examining it attentively when the thought flashed through his mind that the cranium might be simply a series of modified vertebrae. This thought, accepted later by anatomists, demonstrates the power of that intuition and philosophic acumen which made of this great poet the precursor of the Darwinian ideas.

His most elaborate scientific work is his four-volume treatise on the doctrine of colours.[1] In the

[1] Goethe, *Zur Farbenlehre,* 1812, p. 279.

fourth volume he tells us what led him to undertake this investigation.

" The more I considered," he says, " the works of art to be found in Northern Germany, and the more I talked with intelligent persons who had travelled, the more I felt in myself the want of a foundation for all my knowledge, and convinced myself that only from a tour in Italy could I hope for any satisfaction.

" And finally, when after so much hesitation I essayed to cross the Alps, I felt from the crowding in upon me of so many new objects that my aim must not be merely to fill up gaps and amass new treasures, but rather to divest myself of all preconceptions in order to search for truth in its most simple elements. One thing in particular I was unable to account for in the least: that was colour."

Goethe was convinced that nature has no secret so hidden that it cannot be discovered by attentive observation, and with youthful enthusiasm he launched himself on the study of the most arduous problems of physiological optics. From his work on colours I shall quote some paragraphs which deal specially with ocular fatigue.

We have all tried the experiment of looking at the sun, or gazing fixedly on the flame of a candle, and then shutting our eyes. We are all aware that the eye retains an image of a circle, which is at first bright with a pale-yellow centre, but quickly becomes rose-coloured round the edges.

" After a time, this red, increasing towards the centre, covers the whole circle, and at last the bright central point. No sooner, however, is the whole circle red than the edge begins to be blue, and the blue gradually encroaches inward on the red. When the whole is blue the edge becomes dark and colourless. This darker edge again slowly encroaches on the blue till the whole circle appears colourless. The image then becomes gradually fainter, and at the same time diminishes in size."[1]

I was in the arsenal of Turin when the first cannon of a hundred tons was cast, and saw the opening of the furnaces in order to run the metal into the mould. My eyes were so dazzled that half an hour afterwards when I closed them I still saw a luminous spot.

Goethe has likewise pointed out the effect of debility upon vision: "In passing from bright daylight to a dusky place we distinguish nothing at first: by degrees the eye recovers its susceptibility: strong eyes sooner than weak ones; the former in a minute, while the latter may require seven or eight minutes."

This observation of Goethe's as to the longer duration of fatigue phenomena in enfeebled persons is of great importance in our present study, as is also his treatment of colour images. "Just as uncoloured objects leave an impression on the eye, so also do coloured objects. If we hold a piece of bright-coloured paper or silk in front of a white surface, and after staring at it for some time draw it away without moving the eye, we shall at once see in its place the spectrum of a different colour. Thus yellow will give

[1] Goethe's *Theory of Colours*, Trans. by Eastlake.

place to violet, orange to blue, red to green, and *vice versa*."

Such phenomena appear in ordinary life much oftener than we should at first imagine ; indeed, any one who pays attention will see them continually, whilst uninstructed people regard them as a transitory defect of the eye, or, if they think seriously of them, as the precursory symptoms of some disease. Some important examples fall to be considered here.

" One evening," Goethe tells us, " I had gone into an inn, and as a well-favoured girl, with a brilliantly fair complexion, black hair and a scarlet bodice, came into the room, I looked attentively at her as she stood before me at some distance in half-shadow. As she presently afterwards turned away, I saw on the white wall, which was now before me, a black face surrounded with a bright light, while the dress of the perfectly distinct figure appeared of a beautiful sea green."

VIII

In certain diseases the retina presents abnormal sensibility. For example, patients who have undergone the operation for glaucoma, retain the image of an object on the eye after the object itself has disappeared. I remember a lady telling me that with her eyes shut she still perceived a cart of hay which she had just seen, and this vision lasted for about a minute.

When an astronomer, with whom I am acquainted, takes his eye from his telescope, he still sees the stars he has been observing, and at night they return to shine in his field of vision and will not let him fall asleep.

Fechner devotes a chapter[1] of his *Psycho-physics* to comparing such after-images with memory images; and he notes this fact: that enfeebled persons can for a long time retain the image of an object which they have seen, so that the after-image is superposed on the memory image. The difference between after-images on the one hand and memory or fancy pictures on the other, consists mainly in this: that the former are always accompanied by a feeling of receptivity, and of continuity with some sense impression; whereas the latter arise with a feeling of spontaneity long after the action of an external cause upon our senses, are produced involuntarily in part by the association of ideas and in part voluntarily called up, and are moreover capable of being modified or banished. Fechner remarks that in his own case memory and fancy pictures are always more indefinite and confused and less solid than after-images. He was unable to obtain any memory-image with clear and precise outlines, even of things which he saw every day; nor was he able to retain a memory-image before his mind's eye for even a short time; to look at it for long he had to be always producing afresh the constantly vanishing image. "But if I attempt," he says, "to reproduce it several times as clearly as at first, I am unsuccessful, because my attention or my capacity for production is quickly exhausted. This is, however, no exhaustion of memory in general; seeing that I am able to call up another memory-

[1] Fechner, Op. cit., p. 469.

image, as clearly as I ever can ; and when my attention or power of production is exhausted with respect to this one also, I can return to the first image and produce it with its original clearness." But in this internal vision which we call memory, in no case can objects assume relations diverse from those they have in reality ; nor can imagination, however great its creative power, transgress the limits of the field of vision. We cannot for example, represent to ourselves a man seen at once from in front and from behind. Such examples may suffice to indicate how modifications which have taken place in the nervous system are reproduced when we think, in the generation of other like images ; and to show that in this imaginative reproduction there is renewed the consumption of the organism which makes us experience intellectual fatigue.

In many people the mere thought of pressing a sponge or piece of cloth between the teeth gives rise to the same sensation as the reality. The scratching of the nails on slate or glass, the grating of a saw on iron, or the sound of the pick when a pavement is being taken up, these sounds all give rise to an unpleasant sensation accompanied by a contraction of the blood vessels ; and the sensation is reproduced every time we call the sound to mind, or even when we simply see the hand approach the glass or the saw the iron.

IX

Some people tell me that when they are greatly fatigued by brain work, they are subject to passing hallucinations, similar to those which are sometimes experienced toward the end of an exhausting walk. To some degree these open-eyed dreams are, I believe, produced in all slightly nervous subjects who have somewhat over-fatigued their brain. More especially in the evening, but sometimes also during the day if we are tired, our mind begins to wander in our reading, and visual images arise. These disappear, leaving only the memory of their passage, as soon as attention reawakens; and then for a little we are allowed to resume work. A fresh distraction supervenes, the same or another image appearing quite clearly; occasionally it is some one we know or a landscape we have seen. And this takes place when we are convinced that we are not asleep. In the morning when we are fresh and fit for work, such images hardly ever appear.

An able dramatic writer once told me that when he composes he has to shut himself up in his study, because he is obliged to make his characters continually talk aloud. He receives them as if on the stage, shakes hands with them, offers them a chair, follows them in every little gesture, laughs or cries with them as occasion demands. When he writes he always hears the voices of his actors, but faintly. If they become loud, he at once stops writing and goes for a walk. Experience has taught him that this is a premonitory symptom of fatigue, and that he must cease working if he does not wish to spend a sleepless night. When he was writing one of his dramas, the composition of which exhausted him greatly, he fell into such a morbid state that he not only heard his actors talk when he summoned them in order to write or revise the scenes, but he found that some of them would not be quiet again. He did not trouble himself much about this phenomenon, being convinced that it was simply the result of fatigue; he went off for a little holiday and the hallucinations completely disappeared.

All my investigations on fatigue are directed towards the comparison of muscular with cerebral fatigue, and later I shall have to speak at length on this subject. In the meantime I shall give a preliminary sketch of the more important phenomena of intellectual fatigue.

Fatigue, fasting, and all debilitating causes tend to render us more sensitive. After a long walk we become more irritable. The smallest troubles seem insupportable, and our impressionability is increased. Jolly found in patients suffering from auditory hallucinations a greater sensibility (or hyperaesthesia, as it is called), not only of the brain, but also of the auditory nerve. This example serves to show that the increase of irritability is produced not only in the nervous centres, but also within the nerves by means of which the brain communicates with the external world.

During the two or three years I have spent in collecting material for this work, I have often questioned my colleagues and friends regarding the phenomena of fatigue. I addressed myself mainly to doctors and others who might be supposed to have experienced the symptoms of intellectual fatigue. Now four of the persons thus interrogated declared that fatigue stimulated them. The question I usually put to them was : " How do you know when you are fatigued ? " Four of my friends replied that along with other sensations they found themselves more disposed to sexual pleasures. This frank and spontaneous response makes me believe that this phenomenon is much more common than one would at first suppose.

The reason of this will appear in the following chapter, in which we shall see that a great difference is found in the muscular force before and after intellectual work. In many persons fatigue is preceded by a phase of excitation which may last for a long time. In others intellectual fatigue is accompanied by a rapid depression of force, the period of excitation in these cases being of the shortest. Of them it may be said with certainty that intense brain work will lower the activity of the sexual organs.

X

As long as we are in good health, we are little aware of intellectual fatigue ; but as soon as ill health comes upon us, we find how exhausting brain work is. The source of thought and the power of attention are dried up, and the flow of ideas is sluggish. When we are recovering from illness even conversation fatigues us ; we have occasionally to stop talking, and, taking our head between our hands, close our eyes in order to rest and gather strength to continue, and we find great difficulty in recalling a name or date which is perfectly familiar to us. The same thing happens with the brain as with the muscles. As long as they are vigorous, they are not fatigued by repeated efforts; but when they are weak, the signs of fatigue appear at once.

We sometimes hear it said that in the case of intellectual fatigue change of occupation is sufficient rest. This is true in certain cases, when we have fatigued a limited area of the brain by a monotonous piece of work. But it is true only when we are in good health, not when we are weakened in any way. Quite lately I have had proof of this. I was in the midst of writing the final chapters of this book, when I was attacked by influenza and was confined to bed for several days. I had been up for about a week, and although not feeling quite myself, had resumed my writing, and was getting on fairly well, though slowly, when a friend of mine—a German professor, who had come to Italy in order to learn Italian—was shown in. Naturally I could not dismiss him, and he began to talk in Italian, instead of, às usual, making use of German. It would seem that I ought not to have been fatigued, for the conversation was kept perforce within the limits of the most simple and easy sentences. All I had to do was to make a little effort to understand and correct him—nothing more. But my suffering, my exhaustion, no one can conceive who has not experienced the like. After half an hour I proposed that we should go for a little walk, and thus escaped to my own room for a moment's rest. I hoped that the fresh air would do me good; but I found myself in worse case than before, for my friend kept continually asking me the name of everything he saw.

If these lines ever fall under his eyes, I trust he will pardon me—for he also is a doctor—and understand that once I had begun to try an experiment on myself he is innocent of my stubbornness. After an hour of this conversation, which in ordinary circumstances would not have fatigued me at all, I returned home quite worn out, and was forced to lie down and refuse to see any one ; I was so exhausted that I felt myself on the verge of an attack of vertigo.

Extreme fatigue, whether intellectual or muscular, produces a change in our temper, causing us to become more irritable ; it seems to consume our noblest qualities—those which distinguish the brain of civilized from that of savage man. When we are fatigued we can no longer govern ourselves, and our passions attain to such violence that we can no longer master them by reason.

Education, which is wont to curb our reflex movements, slackens the reins, and we seem to sink several degrees in the social hierarchy. We lose the ability to bear intellectual work, the curiosity, and the power of attention, which are the most important distinguishing characteristics of the superior races of man.

Persons who suffer from chronic affections of the nervous system are usually irascible. We shall see later that hysteria is a condition of the nervous system comparable to that produced by fatigue. Expressive physiognomy, vivacious gesture, intensity of look, and the nervous condition which characterizes artists, melancholia or excessive merriment, and certain mannerisms which may seem strange to some people, all in great part arise from want of resistance in the nervous system, from a kind of exhaustion or hysteria produced by continued brain fatigue.

Corresponding to the ultra-sensibility noted in some people, there is found in others a depression of the sensibility. These resemble, one might say, a tired horse which no longer responds to the spur. A long walk affects many people in this way. Fatigue, the first period of excitation being past, is gradually transformed into an exhaustion which renders us insensible; which produces in us a pleasurable emotion, and causes us to marvel that we no longer feel the exertion of walking, but continue to advance mechanically. In the *Journal des Goncourt* this phenomenon is described :—

"Excessive work produces a not unpleasant dullness, a feeling in the head which prevents one thinking of anything disagreeable, an incredible indifference to the pin-pricks of life, a detachment from reality, a want of interest in the most important matters such that urgent business letters are put away in a drawer without ever being opened."

CHAPTER X

LECTURES AND EXAMINATIONS

I

CICERO says that " even the best orators, those who speak with the greatest ease and elegance, feel some apprehension when they are preparing to speak, and are nervous during their exordium." In some men this emotion is so powerful that they never succeed in mastering themselves sufficiently to speak in public. Darwin suffered such discomfort on finding himself the object of any one's attention, that only very rarely could he make up his mind to take part in any public ceremony.

I am acquainted with professors who have renounced the advantages of promotion to one of the large Universities on account of their insuperable aversion to presenting themselves before a large assemblage of students. The joy with which many professors greet the announcement of an unexpected holiday is thus excusable.

The phenomenon is one which our will is powerless to conquer. There are celebrated professors who even in old age feel the same nervousness on any public appearance as beset them at the beginning of their career. I might mention several examples, but there would be no advantage in so doing, because the question is not here of the number of persons, but of the nature of the phenomena which they exemplify. I have seen Paul Mantegazza confused and nervous at the beginning of his lectures. Once I even wondered whether he had come unprepared, so uncertain and bewildered were his first few words. The hesitation, however, was momentary. He became animated as he proceeded, and it soon appeared that we had to do with a master. Warming to his work more and more he became eloquent, and by the expression of his countenance and by his improvisation, accompanied as it was by measured but vigorous gestures, he produced all the effects of magnificent oratory, so much so that I confess I have heard few professors attain such a degree of polish and elegance in their lectures.

The timidity and uncertainty felt by great orators at the beginning of a speech is one element in their success. The more they magnify their theme and feel the importance of what they have to say, the more skilful will they be in communicating their thoughts, and the more thorough in thrashing out their subject. For an orator a nervous temperament is a pre-requisite of success ; the state of quivering excitement, in appearance a weakness of the organism, becomes positively an advantage, seeing that true eloquence has its source in feeling rather than in thought. More than any other orator did Cicero suffer from this agitation. He writes : " Very often I feel myself become pale at the beginning of a speech, and quake with my whole mind and in every limb."

Mantegazza once told me that after thirty years' teaching he cannot take his breakfast in peace till after he has delivered his lecture, that he always experiences great uneasiness, intense thirst, an absolute inability to think of any subject not connected with that which he is about to treat, and other symptoms of which the most serious are vomiting and nausea, which sometimes attack him just when he is about to deliver an important lecture.

I know professors who come from their class-rooms so exhausted that they will see no one until they have rested at least a quarter of an hour. One of my teachers shut himself in his own room immediately after his lecture, so as to be certain that no one would disturb him. In winter one can easily tell whether some professors have lectured or not by watching them as they come from the University ; in the former case their faces are flushed, they wrap their cloaks closely round them like preachers, or have a comforter wound about their necks, and they rush homewards with hasty steps.

But all this is nothing in comparison with the excitement or prostration suffered by great orators. In his book on Brutus, Cicero tells us that Lelius had defended the cause of the tax collectors with so much eloquence that the consuls had deferred judgment. Their supporters having maintained that Galba would have defended their case even better, the tax collectors commissioned him to speak. Cicero says that Galba shut himself up in his house until the time of the trial, " and that when he came forth his face and eyes were so inflamed that he looked as if he had already conducted the case instead of having only thought about it." This shows, says Cicero, that Galba excited himself violently not only in conducting a case, but even in meditating upon it.

II

Some authorities maintain that our body has many reservoirs of energy, diverse one from another, and adapted to the diverse needs of life, and that these magazines of energy can be drawn upon independently of one another. They believe, for example, that the amount of force at our disposal for muscular movement may be exhausted by walking or other muscular contraction, while the provision of energy which the nervous system holds in reserve for the work of the brain is left intact. And this provision of energy may remain distinct from that which serves, for example, for the genital functions.

I do not believe that our organism is made in this fashion. The nervous system is the sole source of energy; and although we must admit a certain amount of localization, this is not of such a nature as to prevent the neighbouring organs feeling any loss through the great activity of any one organ. The exhaustion of energy is general; and all the magazines of energy can be drained by the exaggeration of any activity whatever of the organism. The conclusion to which we are led by my experiments is that there exists only one kind of fatigue, namely, nervous fatigue; this is the preponderating phenomenon, and muscular fatigue also is at bottom an exhaustion of the nervous system.

The complexity of the subject arises mainly from the fact that the organism is not consumed in the same way in every individual. Some people are more, some less, sensitive to the products generated in fatigue. By comparing the muscular energy before and after lecturing of several of my colleagues, I have been able to convince myself of the immense difference existing in this respect. In Professor Aducco, for example, lecturing produces a nervous excitement which increases the force of his muscles.

We had observed this increase several times when he did duty for me in my class-room, but as I was going to publish these experiments I begged him to give me a record of his first lecture. On being elected Professor of Physiology at the University of Siena, he began, three days before his inaugural address, to make tracings with the ergograph of his fatigue curve, raising three kilogrammes every two seconds with the middle finger of his left hand. These tracings he made four times a day, at 9 and at 11 a.m., when he went to breakfast, after which he returned at 1 and at 4 p.m. to take the other tracings.

Figures 17 and 18 represent his normal curve, and were taken at 11 a.m. and at 1 p.m. on January 11, 1891. They resemble those of the previous day in the profile of the curve, which shows the mode in which the muscular force is exhausted.

The slight increase observed in the afternoon is partly due to the strengthening influence of breakfast, and is a constant phenomenon.

At 11 a.m. he made twenty-five contractions and the work done in kilogrammetres is 2·469.

At 1 p.m. he made thirty-one contractions and the work done in kilogrammetres is 3·294.

Figure 19 shows the 11 a.m. tracing of the following day; there are twenty-five contractions representing 2·685 kilogrammetres of work. The breakfast which followed was the same as on the preceding days. At

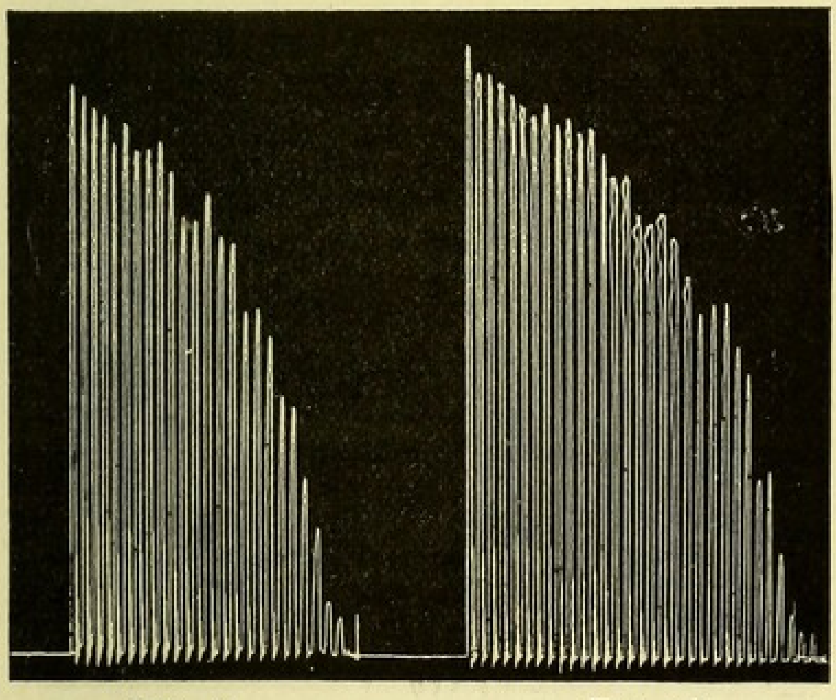

FIG. 17 FIG. 18

11 a.m. 1 p.m.

Fatigue tracings written by Professor Aducco the day before he delivered his inaugural address in Siena University.

12 his inaugural address in the great hall of the University of Siena began. His lecture, which was on the physiological action of light, had been written at Turin, so that he had nothing to do but to read it in presence of his colleagues and the students who had assembled in large numbers to hear the new Professor of Physiology.

Immediately on the conclusion of the address Professor Aducco went to the laboratory which is over the hall, and inscribed Tracing 20.

Here there are thirty-three contractions, the work done being 3·879 kilogrammetres.

A comparison of this with Tracing 18 shows at once that the profile is different. The amount of work done by the flexor muscles surpasses that of the

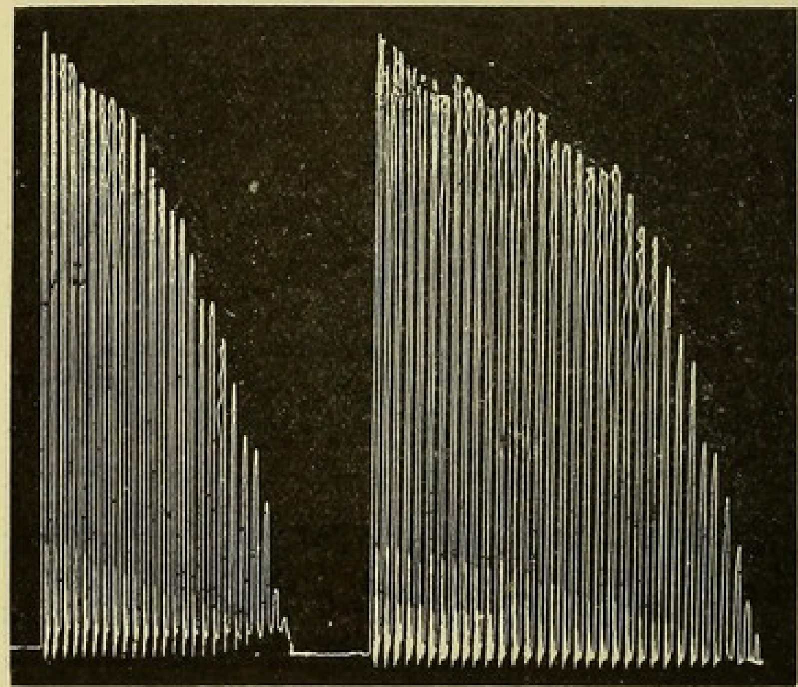

Fig. 19 Fig. 20

11 a.m. 1 p.m.

Fatigue tracings written by Professor Aducco on January 12, 1891, when he delivered his inaugural address in Siena University.

previous day by 0·585 kilogrammetres. The height of the contractions diminishes less rapidly, showing that the resistance to fatigue is greater. The nineteenth contraction is the same height as the thirteenth in Fig. 18—namely 41 millimetres. This increase in Doctor Aducco's muscular force confirms what we had previously observed at Turin.

In sending me these tracings Professor Aducco writes—

"All the experiments were tried in the presence of several of my colleagues, who were much surprised at the result. I was greatly excited and felt heated and flushed. In the evening of the day on which the lecture was delivered I was much fatigued, suffering from pain in my legs and a slight headache."

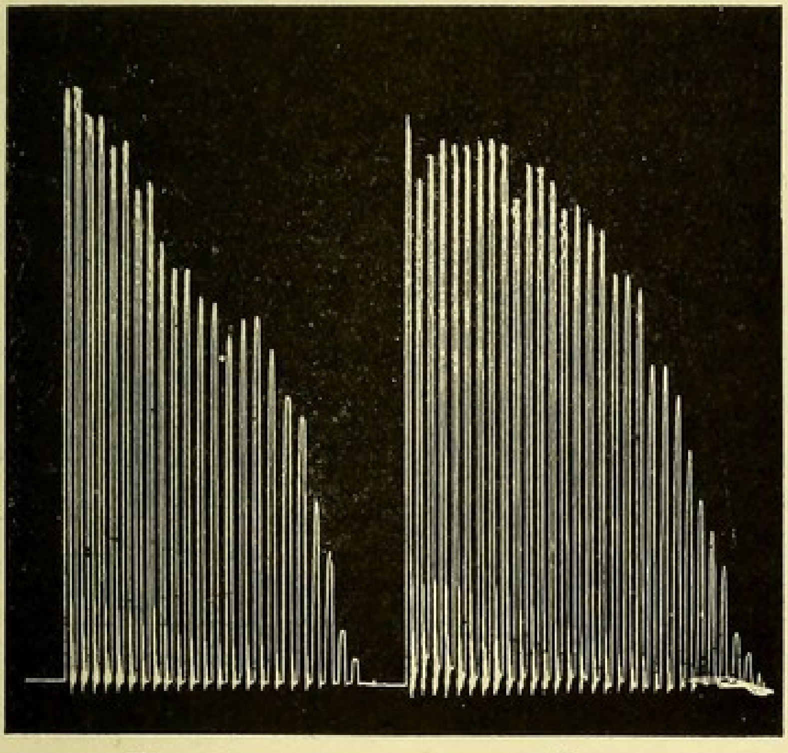

FIG. 21 — 11 a.m. FIG. 22 — 1 p.m.

Fatigue tracings written by Professor Aducco the day after his inaugural address.

The following day Professor Aducco again made two tracings, one at 11 a.m. and the other at 1 p.m. (Figs. 21 and 22). Comparing Fig. 22 with Figs. 20 and 18, we see that it resembles the latter, which represents Professor Aducco's force when he is not excited by intellectual labour.

At 11 o'clock he made twenty-three contractions, at 1 o'clock thirty. The amount of work done at 11 was 2·304 kilogrammetres; at 1 it was 3·006 kilogrammetres. This is slightly less than the normal force as shown by previous tracings (Figs. 17 and 18), and this diminution must be regarded as an effect of the emotion experienced on the previous day.

It was at the International Congress at Berlin that I found with the ergograph the most remarkable diminution in Professor Aducco's power of resistance to muscular labour. He was very well and was delighted with Berlin; only in the evening he complained of being tired in consequence of speaking German and taking part in the discussions. I should never have imagined that the labours of the Congress, of which so many made a jest, could have taken so much out of him. On the day when I exhibited my ergograph to my colleagues I begged Professor Aducco to make a tracing; and we both saw to our amazement that he had only done about half what he was wont to do at Turin.

Professor Aducco's absorption in his work when entering on his professorial duties is apparent in the Siena tracings. He assured me that he was well, and had a good appetite; but between these tracings and those of Turin there is a considerable difference. The normal tracings of Siena resemble the normal tracings of Berlin. These two episodes in Professor Aducco's mental life have a profound resemblance to one another, on account of the continued emotion and intellectual fatigue, which had gradually diminished his force, although he assured me that he was unaware of any change.

The result of the experiments here collected is that, in the case of Professor Aducco, emotion such as that aroused by delivering a formal speech or lecture, generates an excitement of the nervous system which increases the force of the muscles, whilst prolonged emotion and intellectual fatigue diminish that force; and finally that the increase of force is succeeded on the following day by a depression.[1]

III

Doctor Maggiora, who is of the same age as Professor Aducco, and whose mode of life is similar, represents a second physiological type in his reaction to intellectual fatigue. In him the period of excitation and increased force is very short, the period of depression setting in almost at once. Fig. 23 represents Dr. Maggiora's fatigue curve in April, 1890, at 12 o'clock—that is, one hour before his lecture. By a preliminary series of experiments we knew that six tracings all exactly alike could be obtained be-

[1] [An apposite illustration of the increase of force produced by the excitement of lecturing is afforded by James Melville's account of John Knox's preaching, "I saw him," he says, "every day of his doctrine, go hulie and fear, with a furring of marticks about his neck, a staff in the an hand, and gud godlie Richart Ballanden, his servand, halding up the uther oxter, from the abbey to the parish kirk, and be the said Richart, and another servant, lifted up to the pulpit, whar he behovit to lean, at his first entrie; bot, er he haid done with his sermone, he was sae active and vigorous, that he was lyk to ding the pulpit in blads, and flie out of it." Quoted from M'Cries' *Life of Knox*.—*Tr.*]

tween the hours of 8 a.m. and 6 p.m., by allowing the muscles two hours' rest every time. On the days when Dr. Maggiora had to give his lectures on hygiene the tracings made at 2 p.m., immediately after his

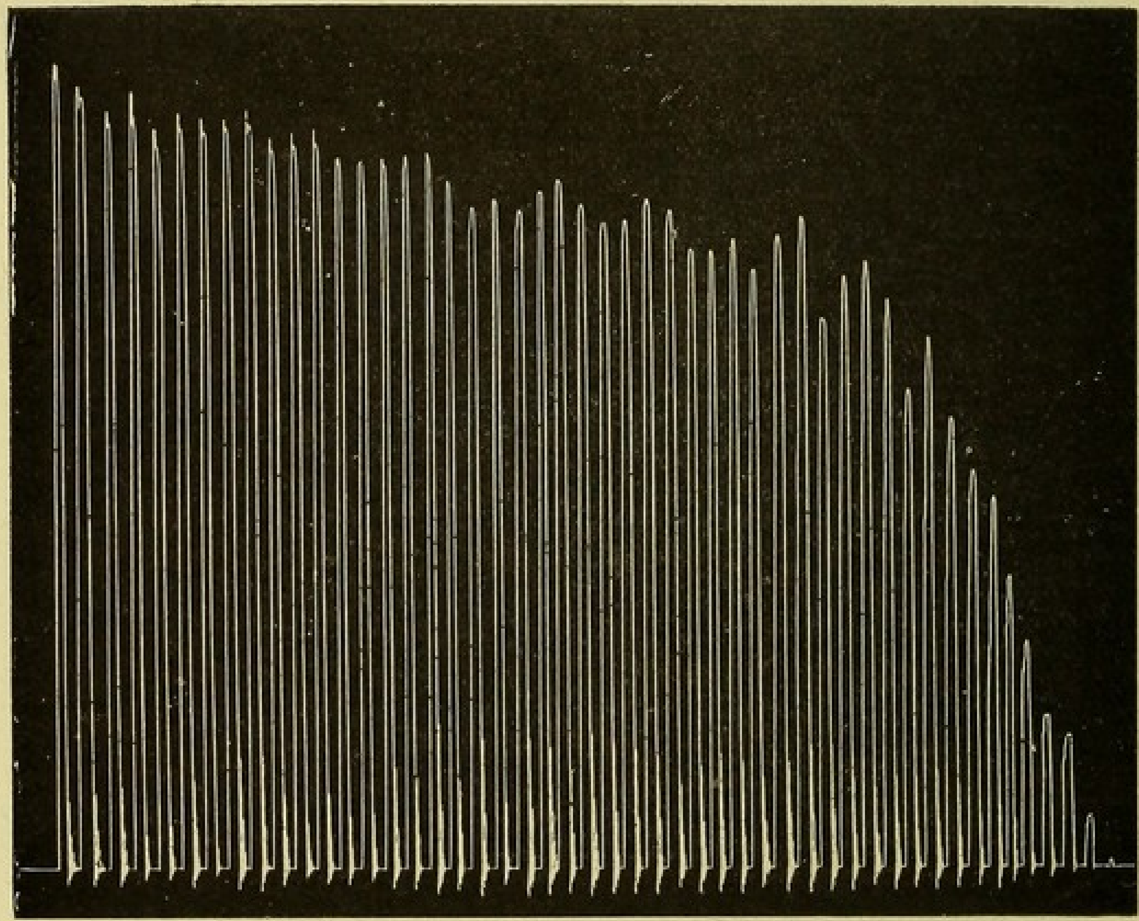

FIG. 23 Dr. Maggiora.—Normal fatigue tracing written at 12 o'clock, April 25, 1890. Weight, 3 kilogrammes. Rhythm, 2 seconds.

lecture, are always shorter than the others, as is shown in Fig. 24.

On the day before his lecture Dr. Maggiora, raising a weight of 3 kilogrammes every two seconds, makes 48 contractions, the work done being 7·161 kilogrammetres; but at the same hour after lecturing, the force of his flexor muscles is so diminished that he makes only 38 contractions (see Fig. 24), the work done being 5·055 kilogrammetres.

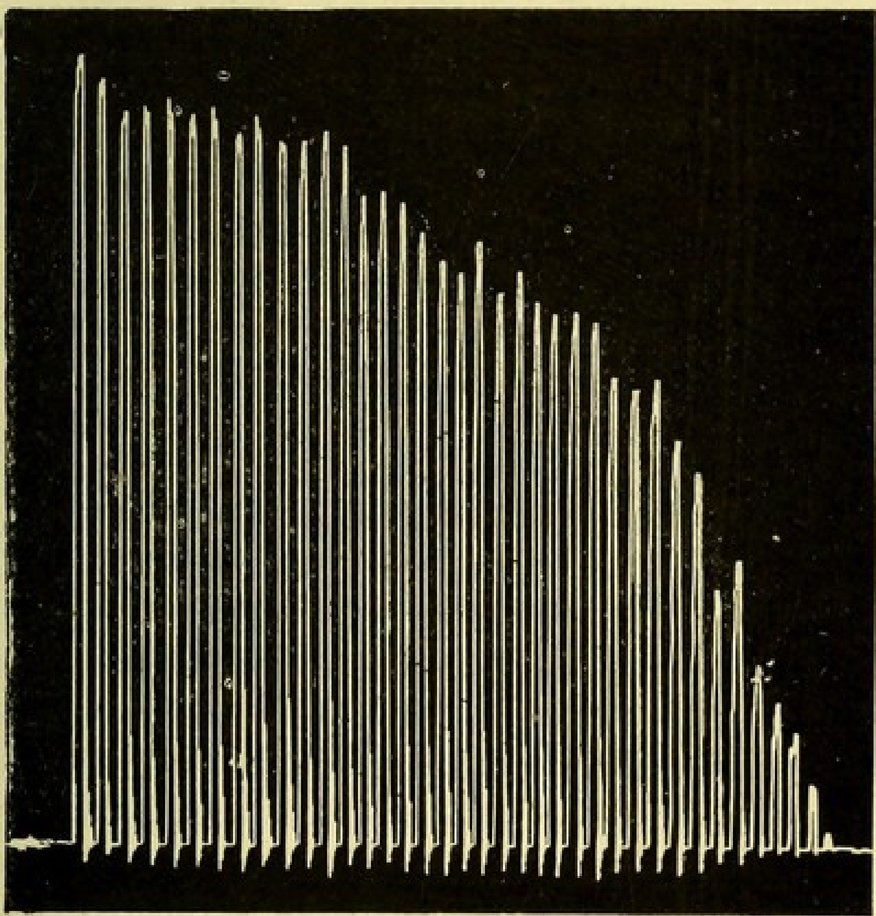

FIG. 24 Dr. Maggiora, after lecturing. — Fatigue tracing written at 12 o'clock, April 26, 1890. Weight, 3 kilogrammes. Rhythm, 2 seconds.

IV

In the fatigue produced by lecturing there are two factors, the one intellectual, the other emotional; but the one cannot be separated from the other either in its nature or in its effects. Experience shows us that very strong emotions diminish intellectual strength, just as great intellectual application diminishes pain and the passions. A strong emotion fatigues us in exactly the same way as intellectual work exhausts the brain.

I myself daily experience the effect of a numerous audience in producing fatigue. I give two courses of lectures on physiology. The one is for medical students, and during these lectures the amphitheatre is full, there being over two hundred enrolled in the class. The other, delivered on alternate days, is for students of natural history, philosophy, and veterinary surgery, who number about thirty in all. The matter of the two courses is much the same, but in the second course the nature of my audience, many of whom have never studied anatomy, obliges me to resort to a more synthetic form of exposition. These lectures are thus more troublesome to give, and ought to be more fatiguing on account of the difficulty of making myself understood ; yet on account of the smaller audience they are, as a matter of fact, much less fatiguing.

The same difference has been felt by every one who has done duty for me. It is not an affair of the imagination, but a difference which can be translated into figures, by studying the modifications which take place in the action of the heart, in the pressure of the blood, in the temperature of the body, and in the respiration.

Teaching accompanied by experiments performed before a large audience causes great preoccupation of mind. When the experiments are delicate, very great fatigue results. Nor is it sufficient to be well prepared, for one feels continual apprehension on account of the thousand-and-one deviations or accidents which may take place and embarrass one in presence of the students. Many professors before entering their class room have already decided to abandon some experiment owing to their fear that something may go wrong. Any one who has had to repeat in public an experiment which has missed fire, however little he may suffer from nervousness, suddenly feels that his hands are trembling, and that he no longer has either the coolness, or the certainty of movement, or the keenness of vision which were his when he made the experiment alone.

Most of the fatigue of lecturing does not arise from the preparatory work, but from the matter and delivery. Those who tire themselves most are those who cling to elegance of form, wealth of quotations, names, dates, etc. The more formal a lecture is, the more the emotional element predominates. Those who tire themselves least are those who adopt a familiar style, and place themselves most closely *en rapport* with their students.

I have studied in my own case the changes in the organism produced by lecturing, but I obtained less striking results than some of my colleagues. This partly depends on my constitution, but more especially on the fact that I am fond of teaching.

At the beginning of my work on *Fear* I have, however, described the serious affections which even I experience on important occasions. I remember spending sleepless nights after having delivered a lecture or conducted a conference, and I know the torments induced by such agitation. Sometimes when obliged to write immediately after a lecture, I have noticed a slight change in my caligraphy, the letters being larger and the lines less firm than usual. During the session, except for a slight weakness in my legs after my lectures, which I deliver standing, I am not conscious of any phenomena of fatigue. Only at the first and sometimes at the last lecture of my course do I feel any phenomena of excitation; my face is flushed, my voice trembles, and I suffer subsequently from headache.

Many observations have been made on the influence which the activity of the nervous system exerts on the temperature of the body. The best known are those of John Davy and the more recent ones of Speck [1]; but no author who has hitherto treated the subject has recorded such marked increases of temperature as I have observed in myself and my assistants.

I have several times taken my own temperature in exceptional circumstances before and after lecturing, and I have always found a difference of about half a degree. Once after a conference which had fatigued me greatly, owing to the emotion produced by a select and numerous audience, I found a rectal temperature of 38·2. A slight fever, which ceased after midnight, had thus been brought on simply by delivering the lecture.

It was, however, when my assistants took a class that I had the opportunity of observing the highest

[1] Speck, *Untersuchungen über die Beziehungen der geistigen Thätigkeit zum Stoffwechsel.—Archiv. für exp. Pathologie und Pharmak.* xv, 1882, p. 88.

temperatures. Every time other duties or illness have prevented my lecturing, I have requested one of my assistants to supply my place. I have thus been able gradually to collect a number of important observations bearing upon this question, and to see that feverish augmentations of temperature through nervous action are much greater than one would have believed.

I shall record one of those observations : that made on Dr. Mariano Patrizi, when he gave his first lecture from my chair. He had been engrossed for more than a week in a research, studying with great attention the changes of his internal temperature in the normal condition, when I unexpectedly requested him to give his first lecture in my stead, as I had to go to Rome. As the subject was one with which he was well acquainted, he agreed, although only three days remained for him to prepare for his début. It was scarcely a year since his graduation, but he had so much ability that I did not fear putting him to this trial in presence of a large audience. From the evidence of colleagues who were present at this first lecture of his, I may say that my hopes were fully satisfied, and that he acquitted himself well.

For the sake of accuracy in this psychological investigation, I quote a passage from the letter which Dr. Patrizi subsequently wrote to me at Rome—

"I have but too plainly seen that I am not to be numbered among those privileged beings who sleep soundly on the eve of a battle ; on the night before June 3 I felt the necessity of revising my work for my lecture, and did not go to bed till one o'clock. I was awake at five, nor was the shortness of my rest made up for by calm and continuous slumber. The thermometer betrayed my agitation, my rectal temperature at six a.m. being 37·8°, whereas in ordinary circumstances at the same hour it is never above 36·9°.

"I rose, and sought to conceal from myself my increasing emotion, and by giving the final touches to some drawings which were to show the students the development and localization of the centres of language, to cheat the four interminable hours which separated me from the solemn moment. But in vain I endeavoured to overcome the trembling of my hand, and my lines were shaky and unequal. I succeeded, however, by a great effort, in mastering the constant impulse to micturate, which tormented me.

"At 10 o'clock my temperature was still 37·8°. My respiratory movements were eighteen per minute, one above the normal for this hour. I took a pulse tracing from the right forearm with the hydrosphygmograph. A comparison of this tracing with the normal taken at the same hour on other days shows not only the greater frequency of the pulsations (105 instead of 78), but also the more decided verticality of the systolic ascent, the steep descent of the diastole, and the most manifest dicrotism. These differences from the normal were greatly accentuated after the lecture, seeing that the dicrotism was then at its height: a certain indication of the relaxation of the walls of the blood vessels.

"At 10.27, a few moments before I entered the hall, the cardiac pulsations rose to 136, and the respiratory movements to 34 per minute. I experienced a sense of pressure and constriction at the epigastrium, and I noted an increase in salivation which obliged me to expectorate every few minutes.

"I entered. After having spoken for seventy minutes, walking about and gesticulating vigorously, partly to conceal my embarrassment, I left the hall at 11.40 covered with perspiration, and drew a long breath which gave me relief. I took my pulse again as before with the hydrosphygmograph, and found that it had decreased to 106 per minute.

"My temperature had gone up to 38·7°, whereas about midday it is wont to oscillate between 37·2° and 37·3°.

"With the ergograph I took a fatigue tracing, raising a weight of three kilogrammes every two seconds with the middle finger of my right hand. The mechanical work done was 4·50 kilogrammetres, whereas two hours before, when my agitation was at its height, I had done 5·95 kilogrammetres. I had evidently not yet entered upon the period of depression of force, since the amount of work done is still superior to the normal for that hour, which is 4·35 kilogrammetres. Subjectively I was aware that the excitement was about to vanish and give place to depression. I dragged my limbs as if I had had a long walk; and in the afternoon, having stretched myself on a sofa in order to read a little more comfortably than usual, I fell into a sound sleep which lasted two hours and restored my energies."

V

There are many modes of lecturing, which vary according as the lecture is theoretical or accompanied by experiments. Some professors trust entirely to their memories, others again make use of notes, which they employ in very various ways. Thus some keep their notes before them, but make no use of them ; others cannot say two consecutive sentences without glancing at them. Some make very brief jottings, others so many that it is as if the whole lecture were written, and whilst they gesticulate with one hand, with the index finger of the other they follow the lines of their manuscript so as not to lose their place. Sometimes a whole lecture is committed to memory by a new professor, or by one who comes to his class *en grande toilette*, as a colleague from Paris said to me in telling me of a professor who was in the habit of repeating his lectures before a mirror. Professors who recite their lectures by heart are easily recognized by their monotonous voice, lifeless gestures, and expressionless eye. It is evident the minute they speak that they are not alive to their surroundings, that they are afraid of distractions, that they are not *en rapport* with their audience. With the rarest exceptions their mode of exposition is unequal ; their delivery is hurried, and without light and shade. They are, as a rule, young professors who have little oratorical talent, and no practice in teaching ; they have to help themselves along by writing numbers, names, and notes on the blackboard ; they often turn round to look at these, and remain gazing at them for some minutes with their back turned to their audience, so great is their fear of letting go the thread which is to conduct them out of the labyrinth.

I have heard of celebrated professors who at the beginning of their career were so afraid of forgetting a number, a formula, a date, or a name, that they would write it on their nails or on their cuffs before entering the classroom. They did not make use of these notes, but they served to give them courage. As a rule, young professors are tormented by the fear that the material they have prepared will be exhausted before the end of the hour. Nothing but long practice gives the sense of time, and the knowledge of exactly how much can be explained in one lecture ; old professors have no need to look at their watch to know exactly when they should be drawing to a conclusion.

VI

One of the least studied points in human psychology is disposition. Under this term are included phenomena which we observe every day, but which have not yet been analysed scientifically. In the morning we rise feeling well, but, without being able to tell why, we discover that we are not in a good mood. At other times we believe we are in a bad mood, but when we sit down to our desk we work better than usual. So likewise in giving a lecture I can never tell beforehand how it will go. Sometimes I cannot find words to treat a subject on which I thought myself certain to give a good lecture ; whilst at other times I express myself with great facility when I thought I was not so well prepared.

Without doubt the conditions of nutrition in the brain must be of the most complex nature. Of some of them we are now beginning to have some slight knowledge ; whilst of others, which certainly exist, we have not yet the remotest idea. The poisonous substances, which are continually being produced, and as continually being destroyed in our organism, must be the cause of these variations. The stomach and intestines are probably the principal seats of the changes affecting the disposition of our mind. This idea is as old as medicine, the very word *melancholy* signifying in Greek black bile. One does not need to be a physician to have known persons whose temperament is melancholic, and who are afraid without knowing why. A careful examination does not reveal any disease, and yet they are depressed, tearful, and uneasy. One of my friends, Professor A. Budge, by whose untimely death a few years ago science lost a valuable worker, suffered from severe melancholia. I shall always remember the painful impression I received when he revealed to me the great trouble of his daily life. I was visiting him at Greifswald, and we had taken a long walk together in the forests on the shores of the Baltic Sea. On our return he took me to his laboratory, and opening the door of his class-room said : " Look at these few steps which I have to take in order to reach my chair ; every day these make me wish to give up teaching. When the students are there I feel as if I were walking at the edge of a high tower. My heart palpitates, and I tremble. Sometimes I have felt quite giddy on entering the classroom, and I always grope my way without distinguishing anything. My assistant knows this, and I have requested him always to stand near me until I am seated, because I am afraid of falling."

But let us leave this sad story. I believe that Professor Budge was suffering from a mild form of the malady to which Westphal gave the name of *agoraphobia*. But when I suggested this to him, he informed me that he could cross the streets without feeling any anxiety, and that he was in the habit of walking about the town quite alone.

As a rule, when a professor is preparing a lecture he makes some notes on a sheet of paper. One word suffices to indicate a whole series of facts. Even those who have had long practice in teaching cannot do without these jottings. One of my colleagues was in the habit of drawing extraordinary figures—a species of hieroglyphics—which made one laugh heartily, and which he alone understood. He said to me: "Although it is in my pocket, I see my sheet of paper faintly but distinctly, and I know exactly point by point how I am to conduct myself, even to the intonation of my voice. So well do I remember it, that I know when I have reached the foot of a page and must turn over."

Finally, there are professors who sometimes improvise their lectures, when they are dealing with those departments of science of which they have made a special study. The most delightful hours in the career of a teacher are those in which he can set forth his own ideas and abandon himself to the current of thoughts over which he has long pondered. The only uncertainty he feels is that he does not know how he is going to finish his lecture. But your audience perceives at once when you have abandoned the dull earth of text-books to launch yourself in the upper regions of science ; and you are aware of the fact that all eyes are gazing on you more intently, and that your pupils have become more immobile. Your hearers share your emotion, because they perceive that they have reached the spring where a new doctrine has its source. They understand that your hesitation arises from no vagueness of thought ; that the rush of your ideas embarrasses while it animates ; that you only seek the most perfect form in which to clothe your ideas, to adorn by your words a thought long cherished.

Such moments, in which you glow with the sacred inspiration of the teacher, are moments which renew your youth ; it is in such moments that you know that treatises or books could never supply your place or equal your power as an educator. The new ideas expressed by you at such a time in a voice which you feel resounding through the hall, will open up new horizons in the minds of the young men who listen, and will remain with some of them as an inspiring influence through life ; and you rejoice in the hope that in the future from one of these youthful foreheads will perhaps radiate the fame to which you have yourself in vain aspired.

VII

There have been orators of slender build and short stature, such as Thiers and Guizot, who were wont to speak for three consecutive hours, making every one marvel at the power of their lungs and the strength of their brains. But the improvisations of great orators, the harangues which hold assemblies spell-bound, cannot last beyond a few minutes. It was thus with Mirabeau, who exhausted himself very quickly ; but who, in any case, would have known to bridle his eloquence, for emotion loses effect when too prolonged.

In parliament and courts of justice speeches of three or four consecutive hours are sometimes made ; but no professor lectures for more than two hours, except in Germany, where some professors of Pandects continue for three hours. In such cases, however, at Leipsic, I have seen the students eagerly munching rolls in any interval which was sufficiently long. At Leipsic I myself tried some two hour courses, but they wearied me terribly ; and I attended them only because I had had to pay for them in advance.

In Italy professors rarely lecture for an hour and a half or two hours. I am, however, acquainted with some who give three lectures consecutively of one hour each ; and I pity them, because for my own part I confess that I could not speak for more than one hour without being excessively fatigued. One of them told me that after speaking for two hours he felt an irresistible desire to be silent, and a sense of oppression on the chest. Besides his distaste for speaking, I observe that when listening to others he is apt to doze. As these phenomena do not appear till some minutes after he has finished his lecture he attributed it to hyperaemia of the lungs and subsequent anaemia of the brain. I believe he was right, for he sometimes complained of slight vertigo and a feeling of light-headedness.

One of my colleagues, who sometimes forgets the time, as he says, feels great weakness of vision after having given too long a lecture. This phenomenon appears especially at the beginning of summer, when the excessive heat affects his digestion. Any slight brain fatigue, particularly a lecture of an hour and a half, is then sufficient to obscure his sight so much that he can no longer read. This asthenopia arises from exhaustion of the nervous system, and disappears a few hours after he has finished lecturing.

VIII

Dr. Ignazio Salvioli, who did duty for me several times, made a series of observations on the modifications which take place in the pressure of the blood, the pulse, the respiration, and the temperature. According to a memorandum which he has been kind enough to write for me, he did not sleep so well as usual on the night preceding a lecture, and he woke spontaneously at an early hour. On his arrival at the laboratory he was aware of being excited and nervous, whilst he was preparing his specimens for the lecture. The bladder and intestines betrayed his internal agitation ; but no sooner did he enter the class-room than all sense of indisposition ceased, and after half an hour's lecturing a feeling of pleasurable excitement took its place. I now quote the notes with which he favoured me—

March 13, 1891.

8.30 a.m., pulse	60
10.30 a.m., a few minutes before entering the class-room, pulse . . .	98
11.35 a.m., ten minutes after the conclusion of the lecture, pulse . .	60

From the average of the observations made by Doctor Salvioli on himself, it would appear, however, that his pulse remains a little above normal even after the lecture is finished.

A

B

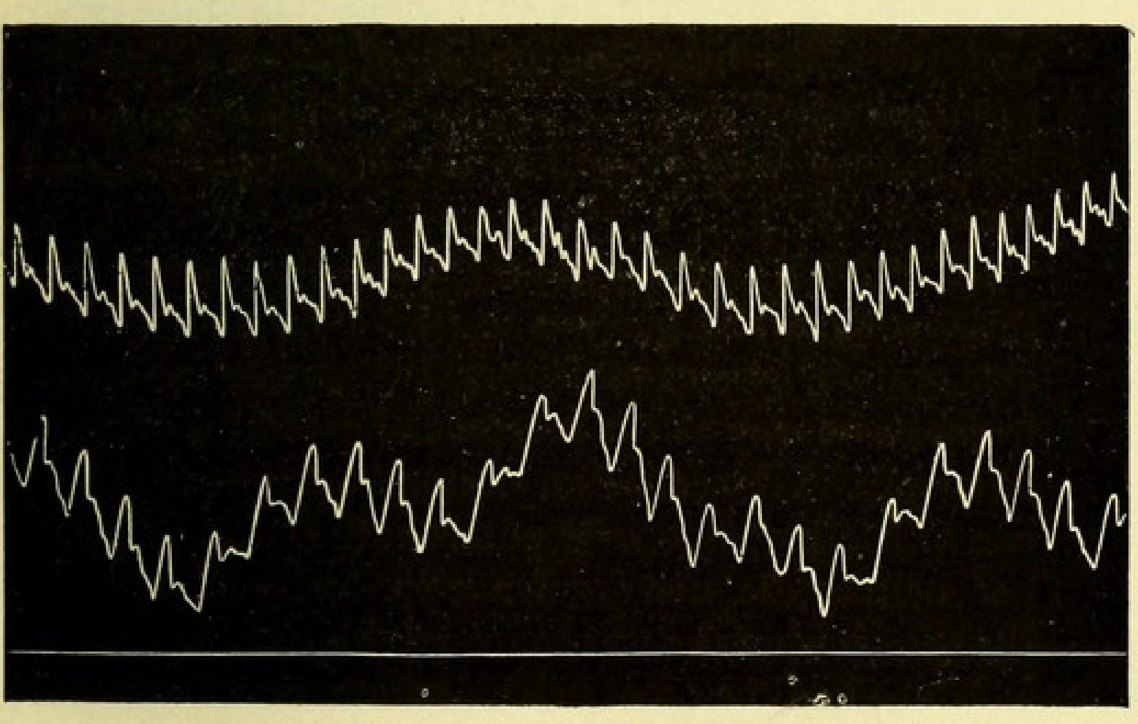

FIG. 25. Dr. I. Salvioli.—Changes in the pulse produced by a lecture on physiology. Curve A was written before, curve B after the lecture.

In Fig. 25 curve A represents the pulse tracing taken by Doctor Salvioli with my hydrosphygmograph immediately before he entered the lecture room. His heart was beating 116 times per minute, and in the curve there are to be seen undulations which correspond to the slow changes of tonicity which take place periodically in the blood vessels. The influence of the respiration is practically nil in this tracing.

Immediately on the conclusion of the lecture, Dr. Salvioli took the tracing B with the hydrosphygmograph. The pulse is less frequent, having fallen from 116 to 92; but it is still above the normal, which for several consecutive days, during which he was not lecturing, was at the same hour only 69. The form of tracing B differs from that of tracing A in such a way as to show that the tonicity of the blood vessels has diminished, and the influence of the respiration has become very evident in the oscillations of the curve.

Dr. Salvioli told me that his appetite before lecturing was not so good as usual. I have seen very able orators, famous professors, find themselves upset in the same way at the prospect of reading a printed discourse. I remember an electoral banquet at which one of the best known deputies in the Italian Chamber neither ate nor drank till he had run through the speech which he was to read to his electors, and of which he had the proof in his pocket; and I was told that such was always his custom. With all the admiration I feel for the courage with which he beards his opponents in the Chamber, I cannot help smiling when I read the reports of his fiery interruptions and recall the fear which he experienced in presence of the electors.

IX

The men who suffer most severely from lecturing are the officers who teach in the military schools. Judging from the information I have collected in Italy and elsewhere, the effects observed are indeed serious. I know two cases of military instructors who after two months have been obliged to suspend their lectures. The first effect of the cerebral exhaustion was a failure of memory such that they no longer understood what they were reading, and they suffered from a pain in the loins which neither rest nor sleep ameliorated. One of these officers, while he was in a very excitable state, suffered from great depression and loss of appetite, and constant heat flushes in his face. Later he became so much worse that he had veritable hallucinations at night, which disappeared as soon as he went on furlough.

There are several reasons for this aggravation of fatigue in such lecturers. The first is the want of exercise. Very frequently officers, simply because they are distinguished for their diligence and capacity, are suddenly taken from the healthy life of their quarters and their drill, to endure the confinement of schools and libraries.

Many of them have not even had opportunity or time to prepare, for they have to begin their lectures at a few weeks', often at a few days', notice. Military discipline, harsher than university discipline, demands greater subordination from the pupils ; whereas the difference in age between teacher and scholars being generally greater in the latter case makes the authority of a university professor more natural. At the university we do not force any one to listen to us. The students come of their own free will, and some of them even go away before the end of the lecture. In military schools the iron discipline to which subalterns are subjected predisposes them against their instructors ; and the superior officer knows that in the circumstances the criticism passed on his lecture, though silent, cannot but be very severe. The fatigue of teaching is thus increased by a very important factor which is wanting at the universities.

X

Examinations are a source of great fatigue both for the students and for the professors. The continuous attention required during the viva voce questioning, the monotony, the great responsibility, the sorrow one feels at rejecting any candidate, the sense of being criticized by the public—in a word, all the worst conditions for intellectual work are concentrated in an examination. The most powerful cause of fatigue is the having to ransack every corner of one's memory so as not to repeat the same questions continually. Nor is the questioning the only difficulty, for the answers are often defective and confused, and one has to search out any trace of truth, any glimmer of knowledge of the fact required. If the candidate does not answer at all, one must present the question under another form, change the words, decompose the problem into parts, so that he may at least attempt some of them. When the student is timid, one must encourage him by asking easy questions at first, and sometimes speak in his stead, for silence would add to his confusion. At other times youths present themselves who are over-bold, who have a ready tongue and an accurate memory. Some of these know how to turn every question so as to bring in some material they have committed to memory; they obstinately evade the point and overleap the essentials, so that one has to manage them like a fiery steed, and lead them gently back to that solid foundation of fact on which all instruction is based.

If the members of an examining board have not great facility in distracting their thoughts, they soon feel the effects of intellectual exhaustion. No one who is taking part can remain impassive, and the thousand vicissitudes of an examination fatigue even the examiner. It is not only that the responsibility of decision rests with him, but fresh curiosity seizes him with the approach of every fresh candidate: there are comparisons to be made; incidents amusing or pitiful take place; his attention is never allowed a moment's rest. Woe to those who allow ennui to overtake them, because to them the examinations will become the most grievous of their professorial duties. I do not know a single one of my colleagues at the University of Turin who does not entirely cease or at least moderate considerably his own studies at examination time, regarding this period as a dead loss from the point of view of original work. Nor do I know any professor who, after examining for three or four hours, has the strength to return to his desk to work. To a greater or less degree there is produced in every professor some change in character which certainly does not contribute either to his amiability or to his gaiety.

To conduce to a right understanding of the conditions in which the experiments which I am now about to record were made, I may say that examinations are held in June and October. Every lecturer has to examine in the subject which he has taught, and every candidate is examined for at least twenty minutes. In large universities like that of Turin, more than a hundred students sometimes present themselves for examination. Dr. Maggiora, as *privat docent* in hygiene, was taking the place of Professor L. Pagliani, who had been summoned to Rome as Director-General of Public Health. The examining board, composed of Professor Bizzozero and Dr. Soave, was presided over by Dr. Maggiora, who put the questions. The physiological laboratory is close to the university so that as soon as the examination was concluded they could at once write their fatigue curves with the ergograph.

I have made various experiments on myself and my colleagues: I shall first give an account of the phenomena observed in Dr. Maggiora, because the effects of intellectual fatigue are more marked in him than in any of the others.

XI

On June 9, 1889, before entering the examination hall, Dr. Maggiora wrote the tracing of voluntary contraction with the middle finger of the left hand, raising a weight of two kilogrammes every two seconds. To economise space, I shall not here reproduce the tracing obtained, which I have already published elsewhere.[1] At 2 p.m. the examinations in hygiene began. Dr. Maggiora examined eleven candidates one after the other, his brain thus being active for three hours and a half. Besides the intellectual fatigue there was the teacher's emotion and responsibility, which he was feeling for the first time in presence of competent colleagues who were assisting as members of the examining board.

Immediately after these examinations Dr. Maggiora returned to the laboratory, and at 5.45 wrote his fatigue tracing under the same conditions as before. The first contraction was still strong; but those following decreased rapidly in height, and after only nine contractions the energy of the muscles was completely exhausted. It is unnecessary to say that Dr. Maggiora had not exerted his hand in any way except for these experiments. At six he dined; at seven he returned to the laboratory to write a third tracing, and this shows that the muscular energy has already to some degree increased, although it is still a long way below normal.

The first idea which strikes one on seeing such a considerable diminution of muscular force in consequence of intellectual work is that the fatigue here observed is of central origin, that is to say, that it is the will which is unable to act with its wonted power on the muscles, because the fatigue of the

[1] A. Mosso, *Archives italiennes de Biologie*. Tome xiii, p. 154, Fig. 37.

psychic centres has spread to the motor centres. The following experiment, however, shows that the phenomenon is much more complex.

The electric current is applied to the skin near the armpit so as to stimulate the brachial nerve, or the electrodes are applied directly to the muscles of the forearm in order to make them contract without the intervention of the will, and the tracings thus obtained

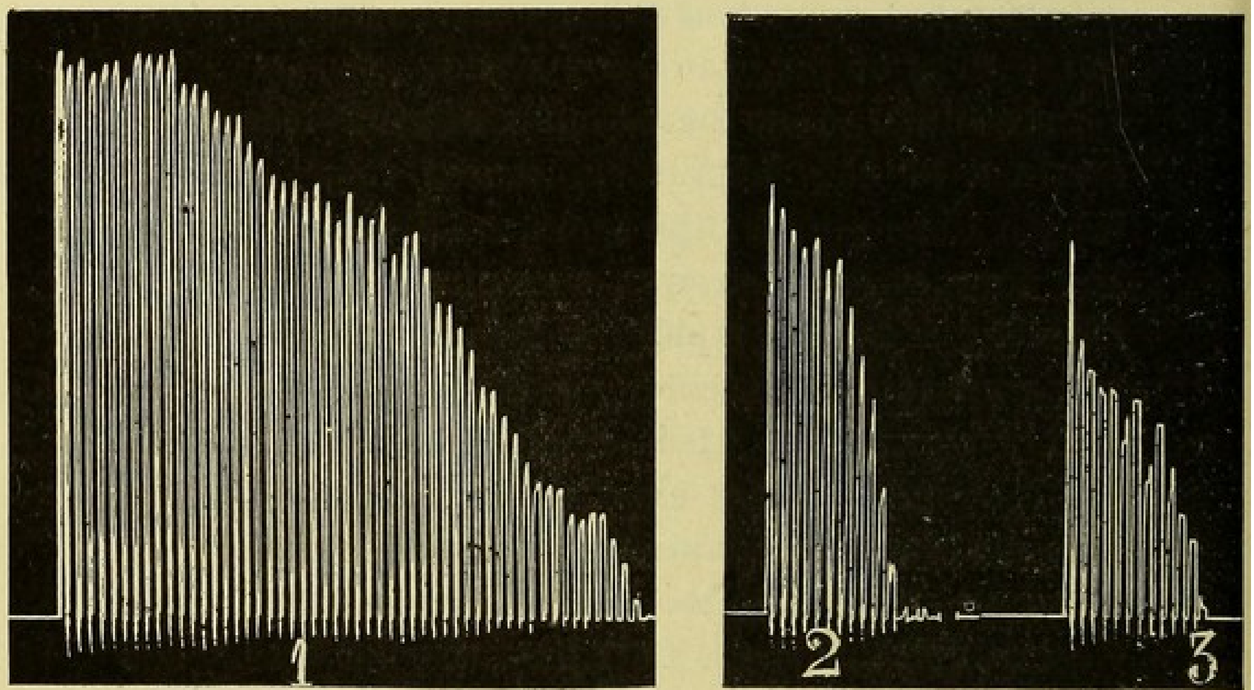

FIG. 26.—Dr. Maggiora. Involuntary contractions. Diminution in muscular force brought about by the examinations. The flexor muscles excited by an electric current every two seconds. 1. Written before the examinations. 2. Immediately after the examinations. 3. Two hours after the examinations.

are the same as those obtained when the will is brought into play.

The first tracing of Fig. 26 was written on the second day of the examinations about 9 a.m., the flexor muscles being stimulated directly. There were three tracings written and they are all equal. The stimulus was as usual applied every two seconds, and the middle finger of the left hand contracting involuntarily raised a weight of 500 grammes.

At two o'clock the examinations began, and Dr. Maggiora examined twelve students. At 5.30 he finished his work, and wrote Tracing 2 of Fig. 26, which shows that the force of the muscles is itself much diminished quite independently of the will. Previous to the examination the muscle performed fifty-three contractions before being exhausted; after the examination, with the same electric stimulus, it was exhausted in twelve contractions. After two hours' rest Tracing 3 of Fig. 26 was written, from which it appears that the fatigue has not yet passed away in spite of complete repose.

It is then not only the will, but also the nerves and the muscles which are fatigued in consequence of intense brain work. Let us remember this proof that fatigue due to intellectual labour affects the periphery of the body, and we shall shortly see the importance of these observations.

XII

Among all whom I have questioned, Edmondo de Amicis has noted most clearly the relation existing between cerebral and muscular fatigue. After intense intellectual labour prolonged through several days, he is aware of a slight uncertainty of movement in his limbs. Some years after he had told me of this fact I questioned him again; he answered that in this interval he had repeated his observation and that he was conscious of a very distinct difference in the movement of his arm, for when he stretched out his hand to open the door after four or five hours' hard work he felt this movement less secure than usual.

The tracings written by Dr. Maggiora represent what De Amicis had already felt in the muscles of his hand without needing any instrument. Dr. Maggiora's muscular force continued to decrease rapidly in consequence of the examinations. The night's rest was no longer sufficient to restore the organism to its normal conditions, and in the following voluntarily inscribed tracings I was obliged to reduce the weight from three to two kilogrammes. Dr. Maggiora did not sleep so well as usual when he was being thus over-fatigued in the examination hall.

Several of my colleagues were present at these experiments, and there is no doubt whatever that the diminution of muscular force is due to excessive brain work. Dr. Maggiora's appetite was as good as usual, nor did he present any abnormal symptoms save those due to brain fatigue. To remove all question of the possibility of the weakness arising from any other cause, I shall reproduce a tracing which shows that the muscular force after its rapid diminution returned to its normal state as soon as the examinations ceased.

On the morning of July 13, 1889, Dr. Maggiora wrote his fatigue curve, reproduced in Fig. 27, raising two kilogrammes every two seconds with the middle finger of his right hand. The number of the contractions is forty-four; the work done 1·762 kilogrammetres.

In the afternoon he gave the final examinations of the session, and as usual felt much exhausted.

In order to see the effect of complete intellectual rest we had agreed that he should go to the country as soon as the examinations were over. In fact, on

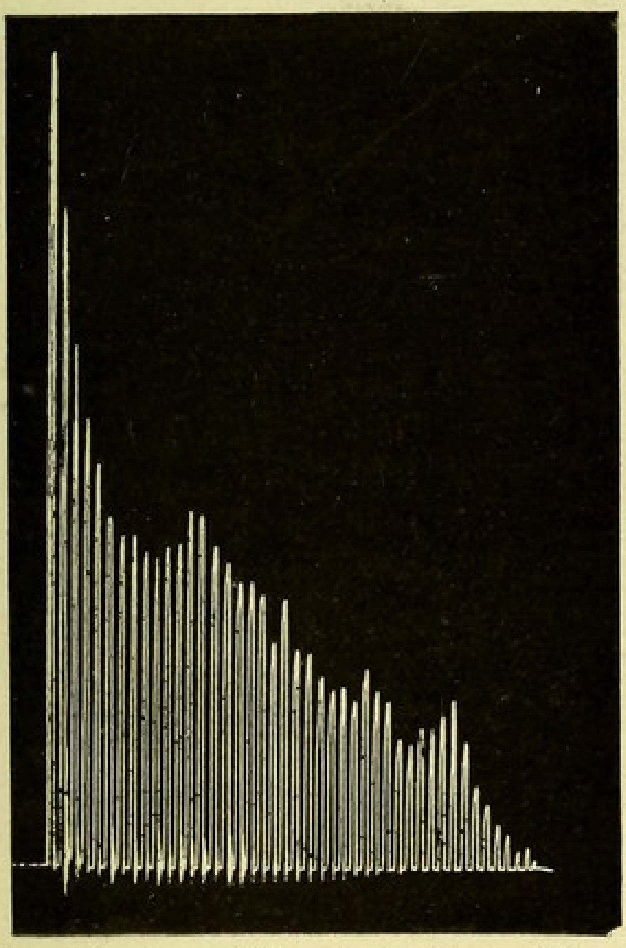

FIG. 27. Dr. Maggiora. Normal tracing written on the last day of the examinations, when his forces were exhausted by the intellectual work of the previous days.

that very evening he went with his family to Asti, in order that there might be no chance of his being disturbed, and remained a couple of days in the most complete idleness. On his return to Turin on the third day he wrote Tracing 28, which shows plainly how soon the muscular force was re-established. The two curves have a certain resemblance to one another in profile, but the amount of work performed in this last tracing is 4·634 kilogrammetres, whilst in the former it was only 1·762 kilogrammetres; and the number

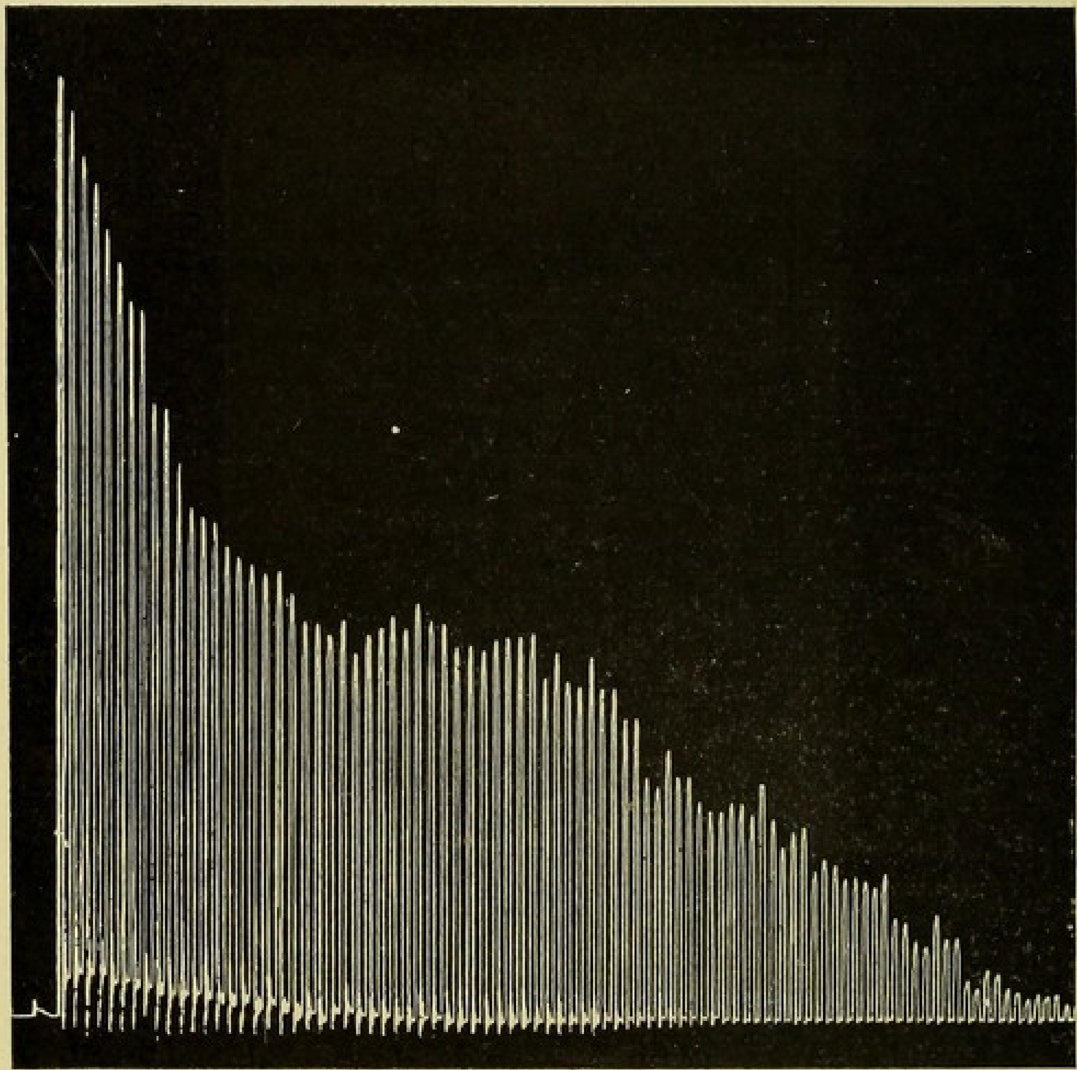

FIG. 28.—Dr. Maggiora. Tracing written after three days' rest following the examinations.

of contractions has risen from forty-four to ninety-one.[1]

[1] The results of these experiments I published in German. (*Ueber die Gesetze der Ermüdung—Archiv für Anatomie und Physiologie*, 1890), and subsequently in French in my *Archives italiennes de Biologie*, tome xiii. p. 154.

XIII

The alteration in muscular force in consequence of intellectual labour observed in Dr. Maggiora had surprised me so much that in the following year at examination time I begged him to let me make another series of observations. I take this opportunity of expressing my sincere thanks to him for his kindness and for the trouble he took.

On June 18, 1890, Dr. Maggiora wrote the normal tracing represented in Fig. 29, raising a weight of three kilogrammes every two seconds with the middle finger of his right hand. The reader who recollects the tracing of the previous year (Fig. 28), will at once remark the great difference which there is between the two curves both in the height of the contractions and in the profiles. This alteration in the type of curve corresponds to a great improvement in Dr. Maggiora's general health; he had increased in weight, and had become both stouter and stronger, so that he declared that he had never before felt so well. Observe that in these tracings Dr. Maggiora was raising three kilogrammes, whereas in the previous year he raised only two. The difference arises also from this being the first tracing taken after a long rest, whereas Figs. 27 and 28 represent tracings taken when Dr. Maggiora's strength was exhausted by the examinations, which was the reason why the weight had to be diminished from three to two kilogrammes.

On June 19, 1890, the examinations began. The tracings taken in the morning are the same as those of the preceding day. Fig. 29, 1, represents the

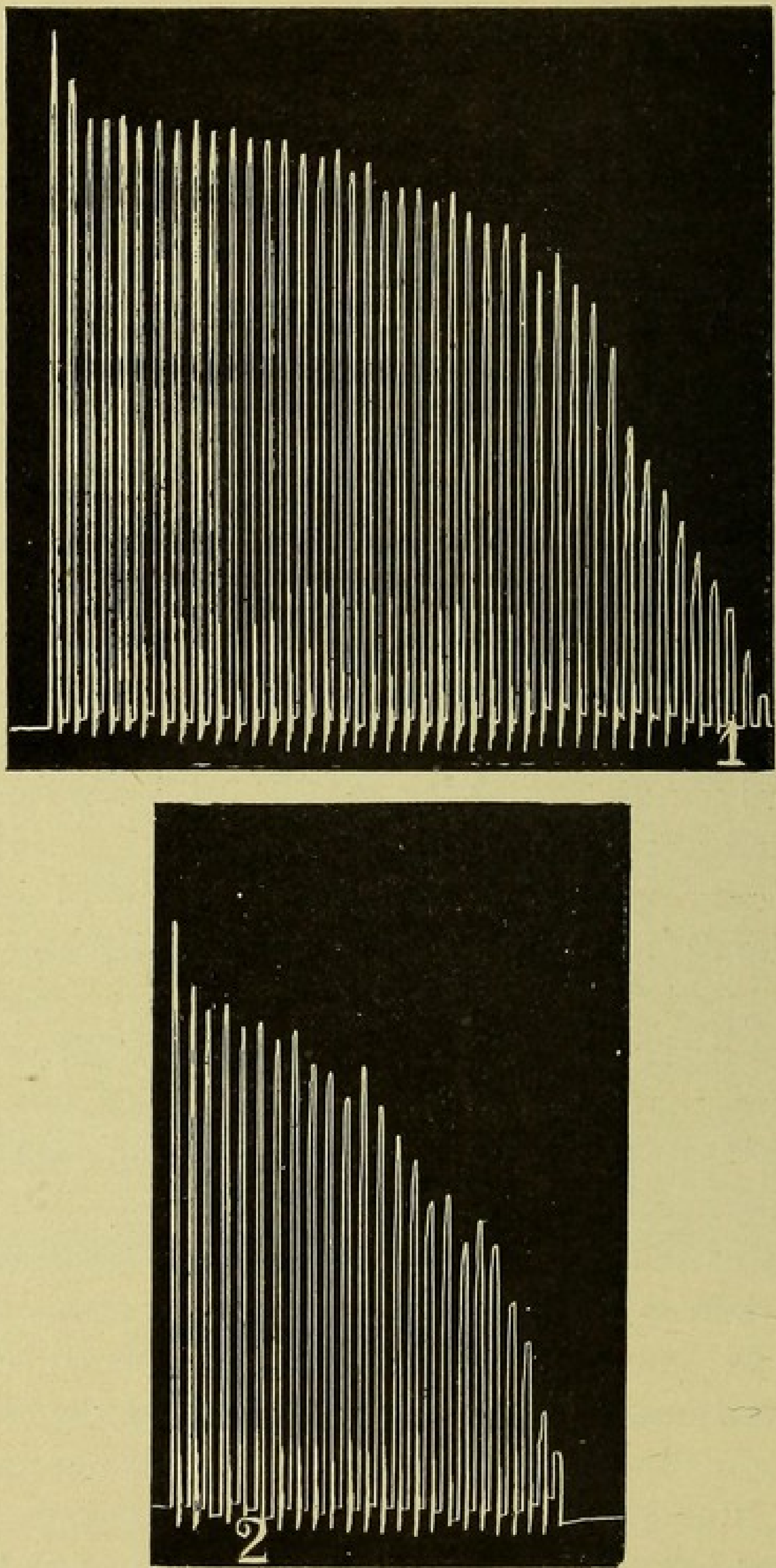

FIG. 29.—Dr. Maggiora's Tracings, June, 1890. 1. Before examining. 2. After examining fourteen candidates.

normal tracing. The number of contractions is forty, the work done 6·087 kilogrammetres. After fourteen examinations Dr. Maggiora wrote his fatigue tracing with the same hand, and obtained Fig. 29, 2, whence it appears that there is a great diminution of force although the difference is somewhat less than in the previous year. The number of contractions is twenty-

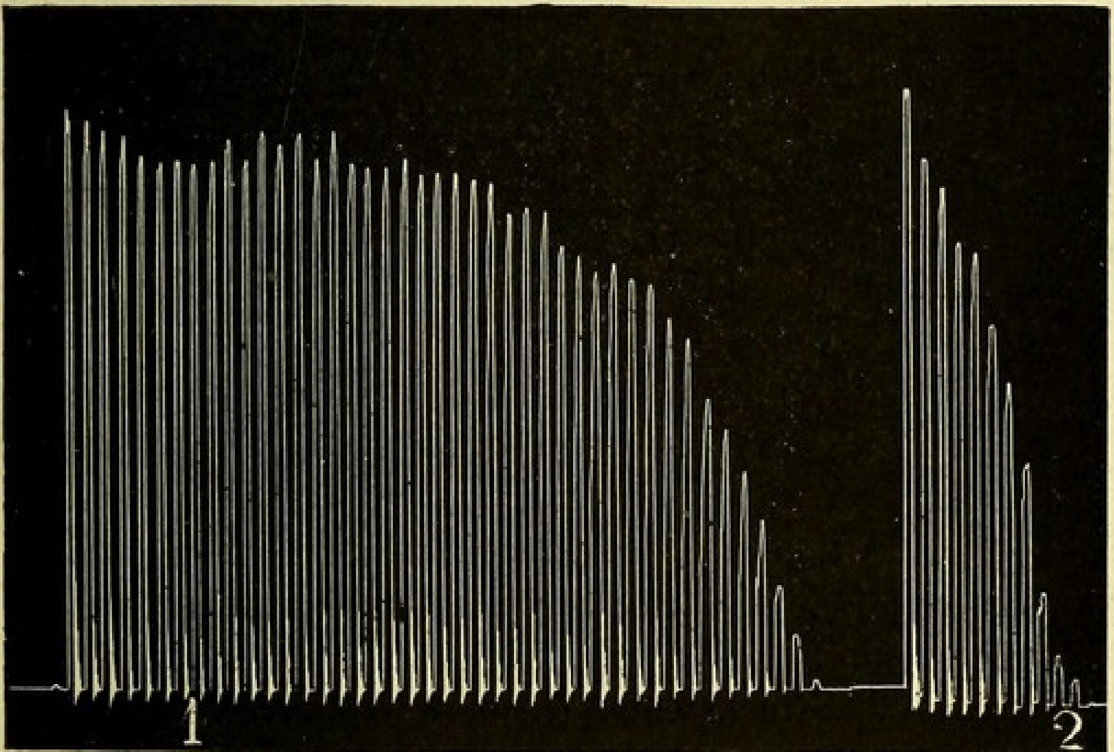

Fig. 30.—Dr. Maggiora's tracings written on the last day of the examinations, July, 1890. 1. Before examining. 2. After examining nineteen candidates.

four, the work done 2·745 kilogrammetres. I repeated the experiments with direct stimulation of the muscles and with stimulation of the nerve, and obtained the same results as before.

Fig. 30, 1, is the normal curve written with the right hand, the middle finger raising a weight of three kilogrammes every two seconds. The number of contractions is forty-three, the work done 5·694 kilogrammetres. At 6.15, after nineteen examinations, Dr, Maggiora returned much exhausted to the laboratory, and wrote Tracing 30, 2, which shows an extraordinary diminution in the power of resisting work, even although the first contraction is as high as the first of the rested muscle. The number of contractions is eleven, the work done 1·086 kilogrammetres.

Cerebral fatigue diminishes the force of the muscles, and with the ergograph we measure this phenomenon with exactitude. The need of rest after intense brain work arises then from the fact that the nervous centres are exhausted and the muscles weakened. The feeling of discomfort and the prostration which characterize intellectual fatigue are due to the fact that the brain, which is already exhausted, has to send stronger stimuli to the muscles in order to make them contract. The exhaustion is twofold: central and peripheral. This explains why after brain fatigue one feels one's energy exhausted by the slightest movement, and why every obstacle which we have to overcome seems to have grown more serious. In these circumstances violent exercises should be avoided, because they are injurious: fencing, gymnastics, or any muscular effort whatever aggravates the conditions of the organism.

It is therefore a physiological error to interrupt lessons to make children do gymnastics in the hope that this may diminish brain fatigue. To restore the forces of the organism when exhausted by intellectual labour there is no remedy other than immobility and letting one's thoughts wander. When we force the nervous system to muscular after cerebral effort, we find the muscles less fit for work ; and we add to the cerebral fatigue another fatigue which, as we shall see later, is of the same nature and is equally harmful to the nervous system. The best way to rest is to sit still and " think of nothing," and to let children play about and amuse themselves in the open air.

XIV

Between the muscles and the brain there are only two ways of communication : the nerves and the blood. In the present state of science we have no reason for supposing that when the muscles are resting and the brain working, the latter can send anything to the former by way of the nerves. If we regard the brain and the muscles as two telegraph offices, we can understand that the nerves which join them do not suffer from fatigue. But the central or psychical station may influence the peripheral or muscular station, even if the latter is not doing work, seeing that both brain and muscles are irrigated by the blood. The blood current may introduce into the muscles some injurious substance which has been produced in the brain as the effect of its activity. It is also possible that it takes useful substances from the muscles to convey them to the brain, which requires large supplies of energy for the work of thought. Let us examine this second hypothesis, since we have already considered the first in Chapter V.

We know that when we do not get sufficient food, we become thin. The first thing which disappears is fat ;

subsequently the muscles also are consumed, but above all it is the internal organs which are wasted.

In death from inanition the spleen and the liver lose more than half of their normal weight. In the muscles the loss is 30 per cent. The heart and the brain alone do not waste or become thin, if I may so express myself.

When in 1843 Chossat announced the fact that the brain to the very last resists the general wasting brought about by inanition, this was regarded as a great wonder by physiologists. Many could not believe that the brain was endowed with such resisting power as to survive all the other organs. But the repetition of Chossat's experiments forced upon them the conviction that in men and animals that die of inanition, the brain does not diminish in weight. If, however, the brain is the organ in which the most active change of material takes place, how can one explain the fact that it does not diminish in weight when all the rest of the body is wasting ?

To make clear the supremacy of the brain and the mechanism by which all the other organs of the body destroy themselves during inanition to nourish it, I shall record some observations which Professor Miescher of Bâle made upon salmon. In the month of March these fish, which inhabit the Atlantic Ocean and North Sea, seek out one of the great river mouths, and after having lingered there a little to accustom themselves to the fresh water, they begin to ascend the stream. The salmon ascend the Rhine as far as the Alps, but from the moment that they enter fresh water they eat nothing. Of about 2,000 salmon which in the course of four years Professor Miescher[1] examined at Bâle not one had any food in its stomach. It is perfectly certain that the salmon after entering the Rhine eat nothing until they have laid or fertilized their eggs. But during this time their organism undergoes profound internal modifications. When the salmon leave the sea, they are very fat; their flesh is red and very delicate; their skin dark with red spots; but when they return to the sea after some months' fast they are unrecognisable, so thin have they become. Their skin is lighter and their flesh, which has become pale, is less palatable and little esteemed. Whilst the salmon are ascending the thousand odd kilometres which bring them beyond Bâle, the ovaries in the body of the female become continually larger. At the end of July the ovaries weigh only 4 per cent. of the whole body; at the end of November they weigh 25 per cent. The fat and the muscles are gradually consumed, and their substance, after being liquefied, passes into the blood to be carried to the eggs; so that the ovaries become so enormously developed as to contain more than a third of the solid matter of the body.

An analogous modification takes place in the male. In winter the testes form only the thousandth part of the weight of the body; but as soon as the salmon have entered the fresh water, the blood flows so copiously to the gland that in August it appears inflamed, so great is the circulation in it. During

[1] Miescher, *Statistische und biologische Beiträge zur Kenntniss vom Leben des Rheinlachses*. Internationale Fischerei-Ausstellung zu Berlin, 1880.

this time the muscles continually diminish in volume and become wasted, their albuminoid matter serving as nutriment to the testis, which develops like the ovary and prepares for the work of reproduction. By September or October the testes have become fifty times larger than they were at the beginning; and in November they undergo further modification, changing from a grey and gelatinous to a white mass filled with a liquid resembling milk and full of spermatozoa.

The transformation of living matter in the interior of the salmon thus studied by Professor Miescher, and the transportation of albuminoid matter from the muscles to the organs of generation are facts of extreme importance; and science has reason to be very grateful to the illustrious physiologist of Bâle for his persevering investigation of these phenomena. The salmon which lives for several months in the impetuous current of the Rhine does not merely fast; it must use up part of the energy of its muscles and nervous system in the continued work of swimming.

According to the calculations of Professor Miescher, a salmon weighing ten kilogrammes loses about seven grammes of its weight per day.

In spite of this loss and in spite of the want of food, a most profound transformation is taking place within its body. By a number of experiments with the balance, Professor Miescher found that the muscles of the back waste as the ovaries increase; and the two phenomena are exactly proportional. One of the most important facts which results from this investigation is that from the albumen, the fat, and the phosphates of the muscles the organism can by means of special chemical actions form new and characteristic combinations, among which is *lecithine*. This substance is abundant not only in the ova of fish, but also in the human brain. And this is why I regard it as probable that, not only during a fast but also in cerebral exhaustion produced by excessive work, the muscles can give up part of their albuminous matter to the brain through the medium of the blood.

When the body is receiving no nutriment, the less important are sacrificed to the more important tissues in the combustion which must finally destroy life. To the very last moment as long as there is any possibility of life being saved, all the organs give of their substance, save the heart and the brain ; and even when the heart has been reduced by hunger to desperate straits and the temperature of the blood has fallen to 30°, the cardiac contractions having become both weaker and less frequent, even then this organ, which was the first to give any sign of life, will continue faithful to its duty till the end, and will collect the last remains of energy from the wasted organs to transmit them to the brain. And the final transference, the final cession of living material from the body to the brain will be made with the final systole of the heart. Marvellous example of an arrangement in which the supremacy of the intellect is respected and maintained to the last in the midst of that most terrible of destructions—death by starvation.

XV

At the beginning of this chapter we compared the tracings written by Professor Aducco and by Dr. Maggiora; we shall now make a similar comparison with respect to the intellectual fatigue produced by the examinations.

On October 16, 1890, Professor Aducco took my place as examiner in physiology, and also did me the favour of allowing me to study the changes produced in his curve of fatigue. At 1.30 p.m. he wrote a tracing with the ergograph, raising three kilogrammes every two seconds with the middle finger of his left hand. It took forty contractions to exhaust the energy of his flexor muscles.

The mechanical work (calculated by adding together the heights of all the contractions and then multiplying by three) is 4·416 kilogrammetres. At 2 p.m. the examinations began. On this first day sixteen students presented themselves, and Professor Aducco had to question them all. After the first seven examinations there was an interval of half an hour, during which Professor Aducco returned to the laboratory, and wrote another tracing with the ergograph.

Number of contractions . .	56
Work in kilogrammetres . .	5·106

We thus see here the same result as that brought about by lecturing; namely, that intellectual fatigue increases Professor Aducco's muscular force, and that there is in him a central excitation which makes up for the damage done to the muscles by fatigue.

On his return to the University the examinations recommenced, and went on till seven o'clock. After this arduous cerebral exertion, lasting five and a half hours, Professor Aducco wrote another tracing, but this time his force was beginning to diminish.

Number of contractions . . .	38
Work in kilogrammetres . . .	4·131

The increase in force is therefore transitory, and in Professor Aducco also diminution of muscular force is produced, when the brain work is sufficiently prolonged.

Other experiments on the effect produced on Professor Aducco by the examinations gave the same result. Space forbids my giving the details here, but I wish to record in conclusion one experiment in which the effects of intellectual labour and of emotion appear in conjunction.

On October 29, 1890, at 2 p.m., Professor Aducco wrote his normal tracing with the ergograph, raising three kilogrammes every two seconds with the middle finger of his left hand.

Number of contractions . .	38
Work in kilogrammetres . .	3·897

This figure is almost equal to that found in another tracing which he had written in the morning. The examinations began at 2 p.m. as usual, and there being only four candidates the intellectual work lasted one hour and twenty minutes; but unluckily for

Professor Aducco one of his friends presented himself and to his great regret he was obliged to pluck him. This last examination perturbed him greatly; he returned with flushed face to the laboratory and at 3.30 wrote this fatigue curve—

Number of contractions . . .	47
Work in kilogrammetres . . .	5·112

He returned again at 6 p.m. and wrote the following curve—

Number of contractions . . .	43
Work in kilogrammetres . . .	4·368

From this it is plain that the exciting effect of the emotion had not entirely disappeared even after three hours.

We must now consider why it is that the first effect of intellectual fatigue and emotion on the muscles is to increase their energy.

This is another instance of the marvellous perfection of our organism.

In proportion as the energy of the brain is consumed and our organism weakened, the excitability of the nervous system increases. Here we have an automatic means of defence of great efficacy which nature has provided to counteract enfeeblement. The senses become more acute and the nervous system more excitable, when in consequence of fasting or fatigue an animal becomes less fit for the struggle.

We have an example of this in the fact that persons who are not very strong are more sensitive than their robuster brethren. In serious illnesses the denutrition affects the nervous centres, producing great disturbance, shocks and convulsions. In the evening overmuch intellectual work gives rise to convulsive attacks in those who are predisposed to them. Some of the unfortunates who suffer from epilepsy hope to diminish the attacks of their malady by weakening their nervous system by some excess, particularly sexual excess, but experience has shown in an unmistakable manner that this only aggravates the evil, the attacks becoming both more frequent and more severe as the nervous system is exhausted.

I shall return to this subject in the next chapter; meantime we have seen that the difference between Professor Aducco and Dr. Maggiora in their mode of reaction in intellectual fatigue is more apparent than real. In Professor Aducco the first period of fatigue, namely excitation, lasts a long time, but at last enfeeblement of the muscles appears in him also. In Dr. Maggiora the period of excitation lasts a very short time and is succeeded almost immediately by exhaustion.

In the study of nervous phenomena we must attach little importance to intensity and duration, provided that the order and causal connexions of the phenomena remain constant.

The same remark may be applied to all therapeutic actions. In my laboratory it has been well tested; in support of it I shall quote only one experiment, which, although it treats of the most elementary facts in medicine, will yet serve perfectly to illustrate the general principle.

I was desirous of making some experiments on the heart and respiration during the action of chloroform. Several of my friends and colleagues with great devotion offered themselves for an investigation which was not without danger. Professor Pagliani assisted me, for I required some one in whom I had the greatest confidence to administer the chloroform, as during the experiment I required to give all my attention to my apparatus.

One day it happened that one of our friends lost consciousness after having inhaled at most only two grammes of chloroform. We were surprised; but we were aware that some very sensitive persons have died in consequence of a dose no larger; therefore we proceeded with the utmost caution.

On the following day Professor Daniele Bajardi kindly offered himself for experiment. The chloroform was the same, and of it he inhaled about fifty grammes without feeling any effect. We then asked him what was to be done, and he told us to continue to administer the drug until he fell asleep.

We continued for about half an hour; finally he lost consciousness and subsequently sensibility after he had inhaled another hundred grammes of chloroform. When he awakened on the conclusion of the experiment, so much chloroform was given off from his lungs that in talking with him one perceived the odour in his breath. When he returned home an hour later, his relatives complained of the smell which he had brought with him and for which they could not account.

CHAPTER XI

THE METHODS OF INTELLECTUAL WORK

To the subject of this chapter an entire book might be devoted. To set forth the mechanism of intellectual work, the art of making the best use of our time both for work and for repose, the methods of gathering our materials, the different modes of sketching out and writing a book, and all the devices practised to create something both novel and good: such might be the aim of a work of genuine usefulness, which I believe has not yet been written. The majority of students are unfortunate enough to have no assistance at the beginning of their career and to become disheartened because they doubt their own strength. Such would find in this volume counsel and also perhaps help, for they would discover that others weaker than they and less favoured by nature have yet succeeded in doing valuable work.

Instances abound of men who have made themselves immortal in spite of uncertain health; who by their own perseverance alone have attained unhoped for results. From among them all let us select the glorious example which Charles Darwin has given us of a struggle carried on day after day to the very end of his life. On his return from his voyage round the world, his health deteriorated so rapidly that he decided to abandon London for the solitude of a tiny village. Darwin has left us very interesting information regarding his mental faculties and his mode of work. In his Autobiography he says: "The school as a means of education to me was simply a blank. During my whole life I have been singularly incapable of mastering any language." [1]

"I have no great quickness of apprehension or wit, which is so remarkable in some clever men. I am a poor critic. . . . My power to follow a long and purely abstract train of thought is very limited; and therefore I could never have succeeded with metaphysics or mathematics. My memory is extensive, yet hazy; it suffices to make me cautious by vaguely telling me that I have observed or read something opposed to the conclusion which I am drawing, or on the other hand in favour of it. . . . So poor in one sense is my memory, that I have never been able to remember for more than a few days a single date or a line of poetry. . . .

"I have a fair share of invention, and of common sense or judgment, such as every fairly successful lawyer or doctor must have, but not, I believe, in any higher degree."

The man who estimated his intellectual powers so low has by forty years of assiduous work succeeded in changing the whole aspect of science. He was so much of an invalid that he could scarcely ever re-

[1] *Life and Letters of Charles Darwin,* by Francis Darwin, vol. i, p. 32.

ceive friends in his quiet country home, because every time he made the effort the excitement and fatigue he experienced brought on chills and nausea. Yet this man with his simple country life, his garden and his books his only occupations, has inspired philosophy with new life, and fertilised, if I may so express it, all the knowledge of our day. In the little village of Down, in the shade of the tall trees surrounding his house, he thought out and brought to a triumphant conclusion a gigantic undertaking. There new horizons were opened to thought ; there a new life for man's intellect had its birth. And Darwin, before he died, had the rare happiness of seeing the triumph of his ideas and the growth of the edifice of science on the foundations which he had laid.

"There seems to be a sort of fatality in my mind," says Darwin, "leading me to put at first my statement or proposition in a wrong or awkward form. Formerly I used to think about my sentences before writing them down ; but for several years I have found that it saves time to scribble in a vile hand whole pages as quickly as I possibly can, contracting half the words ; and then correct deliberately. Sentences thus scribbled down are often better than I could have written deliberately.

"Having said thus much about my manner of writing, I will add that with my large books I spend a good deal of time over the general arrangement of the matter. I first make the rudest outline in two or three pages, and then a larger one in several pages, a few words or one word standing for a whole discussion or series of facts. Each one of these headings is again enlarged and often transferred before I begin to write *in extenso*. As in several of my books facts observed by others have been very extensively used, and as I have always had several quite distinct subjects in hand at the same time, I may mention that I keep from thirty to forty large portfolios, in cabinets with labelled shelves, into which I can at once put a detached reference or memorandum. I have bought many books, and at their ends I make an index of all the facts which concern my work; or, if the book is not my own, write out a separate abstract and of such abstracts I have a large drawer full."

Shortly after his return from his voyage round the world, Darwin wrote to Lyell: "My father scarcely seems to expect that I shall become strong for some years; it has been a bitter mortification for me to digest the conclusion that the race is for the strong and that I shall probably do little more, but be content to admire the strides others make in science."

Again, writing to Lyell from London, he says: "I am coming into your way of only working about two hours at a spell; I then go out and do my business in the streets, return and set to work again, and thus make two separate days out of one."

I shall quote one more passage giving a characteristic description of Darwin, although the *Life* written by his son is well known.

"Two peculiarities of his indoor dress were that he almost always wore a shawl over his shoulders, and that he had great loose cloth boots lined with fur which he could slip on over his indoor shoes. Like most delicate people, he suffered from heat as well as from chilliness. Often a mental cause would make him too hot, so that he would take off his coat if anything went wrong in the course of his work.

" He rose early, and took a short turn before breakfast. . . . He considered the 1½ hours between 8 and 9.30 one of his best working times. At 9.30 he came into the drawing-room for his letters. . . . He would then hear any family letters read aloud as he lay on the sofa. The reading aloud, which also included part of a novel, lasted till about half-past ten, when he went back to work till twelve or a quarter past. By this time he considered his day's work over, and would often say, in a satisfied voice, ' I've done a good day's work.' He then went out of doors whether it was wet or fine."

His son records a favourite saying of Darwin's, that saving the minutes was the way to get work done. He showed this love of saving the minutes in the difference he felt between a quarter of an hour and ten minutes' work. " So much of his experimenting," says Francis Darwin, " was of a simple kind that he had no need for any elaboration, and I think his habit in this respect was in great measure due to his desire to husband his strength, and not waste it on many things. . . . I was often struck by his way of working up to the very limit of his strength, so that he suddenly stopped in dictating with the words, ' I believe I mustn't do any more.' "

For nearly forty years Darwin never knew one day of the health of ordinary men. His secret lay in the patience with which he devoted whole years to reflection on an unsolved problem, and in his being born with a spirit which forbade him to follow blindly in the footprints of others. Thanks to these qualities, although every day he succumbed to the exhaustion brought on by the slightest effort, Darwin astonished the world by the important laws he discovered, by the more rational explanation he has given of the origin of living creatures, and by the light he has thrown on many of the phenomena of nature. His immortality is assured both by the originality and elevation of his thought, and by the hypothesis which he originated as to the origin of life, and which no philosopher before him had ever been able to conceive.

II

"The dawn is the friend of the Muses, and then poets seek out groves where they may find quiet and solitude." So says Haller in his work on Physiology, when he is studying the conditions which predispose the imagination to activity. Morning and solitude then favour the poet's task. But the physiologist is no longer satisfied with such vague indications. In the analysis of nervous phenomena, we must also study the conditions which predispose to thought, in the hope of there discovering laws. If one were to ask a physiologist what hours of the day are most favourable to intellectual work, I am much afraid that he would not know what to answer, or that his response would be full of uncertainty, so contradictory are the facts which would crowd into his mind.

A gentleman once showed me that in the morning his caligraphy was like that of an old man, whilst in the evening it was bold and firm. In all his manuscripts it was easy to tell what had been written in the morning and what in the evening. This fact, which will appear strange to many people, is for all that only an exaggeration of a common physiological phenomenon. Persons whose spinal cord is affected and who are often unable to walk on rising in the morning, frequently show considerable improvement after a few hours.

The reasons that the spinal cord functions better some time after one has risen are manifold. One may be mentioned. When we are standing, the blood accumulates in the blood vessels of the spinal cord, which is excited by the increase of pressure and the state of congestion thus produced ; hence the patient acquires better co-ordination of movement and more command of his limbs. The person of whom I was speaking above is editor of a paper. He tells me that in spite of his bad writing, he prefers to work in the morning, because then his mind is more tranquil ; in the evening his imagination is more active, and yet it often happens that in the morning he has to destroy what he had written the night before, because it seems to him too cold and dry. As a rule neurasthenics are worse in the morning than in the evening.

I have questioned several of my colleagues who do microscopic work, and are very skilful in cutting extremely fine sections, and several of them assure me that they work best in the morning ; in the afternoon they feel that they are a little nervous, and cannot so well perform the delicate manipulations required.

Physiology here finds herself in an almost unexplored region. A beginning has been made, but much remains to be done before we can find our bearings. We ought to study the acuteness of the senses at different times of the day, to examine similarly the perception, the judgment, the extent and duration of the memory, and the reaction time ; and all the measurements, all the investigations, which are being made at present in psychology ought to centre upon this question of the diurnal variations of nervous activity. We know already that the internal temperature of the body, the pressure of the blood, the number of heart beats, the respiratory movements, differ markedly at different times of the day. The point is to determine whether the activity of the brain also increases and diminishes with the flow and ebb of life, with the diurnal physiological variations which are a constant phenomenon.

In my laboratory Dr. Patrizi made a series of experiments with the ergograph, from which he came to the conclusion that muscular capacity for work, whether originated by the will or by an electric current, increases and diminishes with the diurnal variations of the internal temperature of the body. We become cold during the night ; when we rise in the morning our temperature increases steadily till about three or four o'clock in the afternoon, when it attains its maximum ; after which it again diminishes. The power of the muscles to resist fatigue varies in accordance with the daily modifications of our temperature. Yet neither these, nor food, nor sleep can be regarded as the cause of the oscillations. We are here in presence of the daily variations of the activity of the whole nervous system, produced perhaps by the light or by some other influence which escapes us, and which is profoundly bound up in the very nature of our being. To these variations correspond variations of the mechanism of nutrition upon which depend the chemical changes from which muscular contraction results. [1]

III

Seneca has said that one must force one's mind before it will begin to work :

Cogenda mens, ut incipiat,

and Alfieri used to make his servant tie him to his study table. Without going to such extremes, we all know that in any intellectual work whatever we do not get on so well at first as later. In works of the imagination, which demand creative and associative power, this difference is more perceptible than in works of the reasoning faculty or in science, where what is necessary is only the comparison of facts presented to us by nature.

[1] M. L. Patrizi, *Oscillazioni quotidiane del lavoro muscolare in relazione alla temperatura del corpo. Giornale della R. Accademia di Medicina di Torino*, January, 1892. *Archiv. italiennes de Biologie.* T. xviii, Fasc. ii.

Poets, artists, and composers especially feel the need of "winding themselves up," if I may make use of a popular phrase ; but the fact is one of common observance. One of my friends, a pure blooded idealist, with whom I am always glad to discuss the phenomena of the soul, once said to me : "Here we have a fact which physiologists cannot explain ; the body is evil and rebels against work ; the soul must punish it in order to obtain what it desires."

To me it seems that the explanation must be quite different, and nature is the gainer thereby, for the hypothesis of the physiologist is more marvellous than that of the idealist. The same thing occurs in the brain as we have all experienced in walking. After an hour's exercise we are more lively ; our limbs become loosened, our steps freer ; we feel a pleasant exhilaration which presses us onward, as if we had become lighter and slimmer.

One of the most marvellous perfections of our mechanism consists in this, that action does not depress and exhaust its energy, but renders it more fit for work. The cinders and dross which fall into the fire of life, if I may make use of a material metaphor, do not stifle the activity of the nervous system, but stimulate it.

Many of the phenomena which take place in the nervous system, and especially those which are non-voluntary in character, are now usually explained by physiologists as if they were purely mechanical. In the nervous centres there are some paths which offer more resistance than others, and the act of repeating the same nervous action in identical conditions diminishes this resistance. There is no doubt that this mechanical theory renders many obscure facts more intelligible.[1] The hypothesis which I would here suggest to explain the augmentation of the initial energy of the brain by exercise is that the fresh force brought into play is of chemical nature. It will be better understood when I have referred to the similar phenomena observed in muscular movement. A muscle separated from the body at first responds feebly to the stimuli which cause it to contract. The electric current at first causes five or six contractions of equal height; then the contractions will begin to increase in strength and the next fifty or a hundred will continue to increase steadily until they reach a height of about four times that attained at the beginning of the experiment. Once the maximum is attained the contractions diminish gradually both in force and speed—the strength of the electric current, of course, remaining constant—until the moment when total exhaustion of the muscle is reached. Something analogous to this takes place in the brain, the chemical products stimulate its activity and render its functioning easier.

IV

In the biographies of great poets and composers I find that their methods of working themselves up closely resemble one another. Buffon used to say that in order to do good work, one must "consider

[1] M. Foster, *A Text Book of Physiology*, 1890. Part iii, p. 910.

one's subject until it scintillates." Some people, by concentrating their attention for a few minutes, quickly attain the state of excitement desired; others require more time, and there are some writers who live for weeks in a species of exaltation, during which their toil is more productive; then exhaustion supervenes, and they are compelled to rest. This is a species of work fever. All who have had any experience of consumptive patients are agreed that in the evening, when the temperature of the body rises, they become more animated and some have a sensation of well being. There is an old adage in medicine to the effect that a slight fever renders the tongue more ready and the imagination more fertile. [1]

Albert Haller, the most learned writer on physiology of the eighteenth century, was at the same time a distinguished poet. His lyrics, odes, and descriptive poems on the Alps make up a volume, whch may still be read with pleasure. In his Physiology Haller tells us that he has several times observed that his verses flowed more freely when he was feverish.[2] Rousseau likewise says something similar.

It is a physiological law admitting of no exceptions that all substances and all causes which depress and tend to destroy the functions of the nervous system begin by acting as excitants. It is known that a dose of opium, chloral, or morphia, instead of procuring sleep, sometimes excites the patient, and this

[1] *Febris modica idearum fecunditatem et eloquium dat.*
[2] Haller, *Elementa Physiologiae.* tomus v, lib. xvii, par. xiii.

symptom warns the physician that he must immediately repeat the dose seeing that it was insufficient to produce the desired effect. When ether or chloroform is used to bring about insensibility, there occurs first a period of excitement which may be very violent, and even though consciousness be already lost, sometimes several people are required to hold the patient until the drug takes effect.

Anaemia also produces excitement, and we know that weakly people are more nervous. Death itself is preceded by a period in which cerebral activity sends out, as it were, one final flash of light.

The Abbé of Caluso tells how Victor Alfieri before death had a revival of memory and imagination which surprised those present. "His studies and labours for thirty years recurred to his mind, and, what was most astonishing of all, he began to recite a number of Greek verses from Hesiod, which he had read only once. Rising from his seat he went to lie down again in bed, and shortly afterwards, when night fell, he expired." [1]

I might quote instances of several other famous men who rallied before death, as if their mind were awakening once more. These are phenomena which the physiologist can easily reproduce in the nerves of any animal, as their death is always preceded by a period of abnormal excitability.[2]

[1] *Vita di Vittorio Alfieri.* Milano, Silvestri, 1841, p. 371.

[2] Reveille-Parise has written a very remarkable book, *Hygiène de l'Esprit.* It was published in 1834, and the physiological part leaves something to be desired; but at that time the study of psychology was, we may say, not yet born. Nevertheless this work and that upon old age are both

V

Some people believe that it is the changed conditions of modern society which causes many writers to work during the night. But one has only to read the biographies of famous men to see that many of them did the same thing in the past.

Rousseau says in his *Confessions* :[1] " I was working at this discourse in a very singular fashion which I have almost always followed in my other writings. I devoted to it the watches of my nights. I meditated in bed with my eyes shut, and turned and returned my periods with incredible pains ; then, when I was satisfied, I imprinted them on my memory, until I could set them down on paper ; but the time spent on rising and dressing made me lose all, and when I sat down to write, almost nothing came back to me of what I had composed."

To avoid this misfortune he made Madame Le Vasseur write to his dictation before he rose, and he continued this custom for many years. " And this

worthy of the greatest respect. In a chapter on the different actions of stimulating agents the writer records a curious fact. I respect the delicate feeling which led him to put the observation in a note.

Byron says in his *Memoirs* : " I can drink, and I stand wine well enough, but it does not enliven me ; it makes me fierce, suspicious, and even quarrelsome. Laudanum acts in a similar way, and I cannot take much without feeling the effects of it. What raises my spirits most—it sounds absurd, but it is true —is a dose of purgative salts—in the afternoon, be it understood, after the medicine has taken effect. Unfortunately one cannot take *that* in the same way as champagne." *Hygiène de l'Esprit*, p. 320.

[1] J. J. Rousseau, *Les Confessions*, livre viii, 1749.

practice, which I have long followed, has saved much from being forgotten."

Nevertheless to work during the day is more physiological, and some writers declare that they work better in proportion as the heat and light are more intense.

Johann Müller could not think well in the dark. "When we wish to see a question clearly, with our minds in full activity and our thought power at its best, we must choose a day full of light. He who is in a state of exaltation closes his eyes to give himself up to the play of his ideas; but profound meditation has need of the light of day. The optic nerve under the action of the light acts as a stimulus to the organs of the imagination and fancy." [1]

One of the most beautiful discoveries of Moleschott is that light increases the production of carbonic acid, the chemical processes, and the phenomena of life.

It is only those who are not free to work during the day who do it at night. In their aphorisms the ancient physicians have very truly said that vigils generate vigils. Intense brain work produces an excitement resembling fever, and we fall into a nervous state which prevents sleep. Some who are very strong succeed in forming a habit, and invert the rôles of night and day; but it is certainly more profitable and more healthy to follow the natural order of things, and for this I will give further reasons presently.

The only excuse for the custom is the greater

[1] J. Müller, *Ueber die phantastischen Gesichtserscheinungen*, p. 17.

intensity and efficacy of the work. "Continuity of thought upon one single thing," says Alfieri in his autobiography, "and the suppression of every source of distraction multiply in an extraordinary way the value of time." Accordingly he rose very early.

Goethe writes in his Life: "The first hours of the morning I have consecrated to poetry; the day belongs to the affairs of the world." [1]

There is a popular saying that the morning hours have gold in their mouth. [2] Towards evening the great writers gradually relax the intensity of their labours and, as it were, extinguish the fire with the setting of the sun. I have questioned some very able authors regarding their method of composition; they have all told me that they reserve the evening for occupations of less importance; they do not compose, but confine themselves to taking notes and revising what they have written. The majority of hard workers, after having spent the whole day at their desk, rest in the evening.

Stricker, in his new studies on Consciousness, in a chapter on the theory of temperament, says: "As a rule men are more cheerful in the morning (after having slept well and sufficiently) than in the evening, and this is very apparent in infants. Men who are overwhelmed with work, see their future in brighter colours in the morning, after they have passed a good night, than during the rest of the day. In the evening annoyances become more burdensome,

[1] Goethe, *Aus meinem Leben,* Siebzehntes Buch, p. 384.
[2] *Le ore del mattino hanno l'oro in bocca.*

especially in the case of men who have to do intellectual work during the day, and who thus fatigue the brain, or, to make use of physiological terms, diminish its excitability. For such people a problem which would be easily solved in the morning becomes impossible in the evening." [1]

VI

Socrates is, I believe, the author of this saying: "Let your thought wander like an insect which is allowed to fly in the air, but is at the same time confined by a thread." And he was right. Montaigne has expressed the same idea, but in more profound fashion.

"My conceits and my judgement march but uncertaine, and as it were groping, staggering, and stumbling at every rush. And when I have gone as far as I can, I have no whit pleased myself: for the further I saile the more land I descrie, and that so dimmed with fogges, and overcast with clouds, that my sight is so weakened, I cannot distinguish the same." [2]

These words of Montaigne's remind us that all that we know is never present to consciousness at the same time, but only a very small part is revealed at a time to our attention. The child in doing his school task feels in miniature the fatigue which a great writer experiences in composing a chapter of one of his works.

There are two methods of composition. Some

[1] S. Stricker, *Studien über das Bewusstsein*, Vienna, 1890, p. 61.

[2] *Essays of Montaigne*, Florio's Translation, chap. xxv.

think and re-think, purify and revise their work first, so that when they do take pen in hand they have a clear and correct conception both of their matter and of the form they wish to give it, and write as if from dictation. Possibly this was the method of Guerrazzi, whose beautiful clean manuscripts contain no erasures; and in this way Mantegazza wrote. But the biographies of great men furnish plenty of similar examples.

Cicero declared that all that he thought or composed was done when he was walking.[1] This is indeed one of the most common methods of composition.

Beethoven very frequently thought out his works when walking, and many of his compositions were written in the open air. But as a rule writers and artists are content with sketching out their subjects on their walks. Few men have the power of perfecting their composition and finishing it in its more minute details. The greater part of the work after the first outline is done at the desk.

In his autobiography Foscolo, speaking of Didimo Chierico,[2] says: "He had the bliss of being able to write easily thirty pages at a sitting; and the misery of wishing to reduce the whole to three pages, which he did with infinite labour." In literature there are some immortal pages which have passed through a series of alterations, and transforma-

[1] Quidquid conficio aut cogito, in ambulationis fere tempus confero.

[[2] Foscolo attributed his version of Sterne's *Sentimental Journey* to Didimo Chierico, and in the memoir of the writer which he prefixes to the work he gives many autobiographical details.—*Tr.*]

tions, such as the authors would never have revealed to their readers. Some famous writers work as if they were laying a mosaic. They gather together their words and ideas as the mosaic worker his stones, and with these they design and colour their forms. On their desks lie lists of words and phrases culled with patience from books and dictionaries, which with equal industry they fit into their own periods.

No one, I believe, can improvise or invent in the proper sense of the words ; not even genius has the gift of immediate creation.

Giorgio Vasari tells us that Michelangelo " burned a great number of his drawings, sketches, and cartoons before his death, so that no one might learn from his unfinished work the labour he had undergone and his methods of trying his powers, wherefore I have not found any of them in Florence. Thus we learn that even this great master, when he wished to bring forth Minerva from the head of Jupiter, had need of the hammer of Vulcan."

VII

If time sufficed me I would write a book entitled Genius and Fatigue.

I do not say that genius is patience. It would indeed become a physiologist less than any one else to admit that will and perseverance are sufficient to give genius. I say only that fatigue is the basis of all creation in science as well as in the fine arts. There are, it is true, some favoured individuals. As there are prodigies of memory, so there are minds of marvellous fertility; but if we study these apparent exceptions more closely, we may convince ourselves that even they are not exempt from the stern law of fatigue. Their mental activity, the mechanism of their imagination, is at bottom always the same as in others. But it operates with a marvellous rapidity, security, and novelty of result; wherefore these men stand out above all their fellows, who gaze up at them as if their pinnacle were unattainable, and a miracle had placed them there.

Raphael had, if I may so express myself, the supernatural gift of genius, which in the imagination finds the sublime image of the beautiful, nevertheless toils in pursuit of that which is revealed to it by an inward voice. The treasure of absolute inspiration I do not believe that nature has vouchsafed to any one. Even for Raphael fatigue was the basis of his undying fame; and this was first said by Michelangelo, who was certainly a competent judge. "Raphael," said he, "did not attain to his perfection by nature but by long study."

The current superstitions regarding genius are numerous, and rest in great part on our love of the marvellous, and on the desire which the majority of famous men have to conceal their labours so as to appear greater than they are.

Some of the errors of biographies are in truth singular, as, for instance, the famous story that it was the sight of a falling apple which inspired Newton with the idea of universal gravitation. Now Newton, like Galileo and Darwin, was an indefatigable worker. "I never lose sight of my subject," said he, "while waiting till the first faint dawn becomes by degrees the full light of day."

Goethe alone by the measureless extent of his genius and the profundity of his mind at one time appeared to me to be an exception to the general rule. I had read his Autobiography, his Letters, and the very interesting Life by Lewes, in regarding which as the best I am not influenced by the fact that he was a physiologist, for I am only agreeing with all the rest of the world. But in all the biographical studies I had read, Goethe always appeared to me as a man whom labour did not fatigue. I was greatly confirmed in this impression by the following words of Schiller's: "Whilst the rest of us must toilsomely collect and sift in order to bring forth at the end something passable, he needs but gently shake the tree to bring down ripe, weighty, magnificent fruit."

Later, however, I had to change my mind, when in the last volume of Goethe's work on the *Theory of Colour* I read this confession: "From the first appearance of my poetic attempts, my contemporaries showed themselves sufficiently benevolent towards me, recognising at least that I had poetic talent and inclination. Yet I myself had towards the poetic art a quite peculiar relation which was only practical when I for a long time cherished in my mind a subject which possessed me, a model which inspired, a predecessor who attracted me, until at length, after I had moulded it in silence for years, something resulted which might be regarded as a creation of my own; and finally all at once, and almost instinctively, as if it had become ripe, I set it down upon paper."[1]

Flaubert worked fourteen hours a day, and every one knows that in him the endeavour after perfection of style had become a disease. Of this many anecdotes are told; among others that he rose during the night to correct a word; that he remained motionless for some hours, his hands in his hair, bent down over an adjective. Style was a tyrant to him; it became his passion to wear himself out in the insatiable search for the mysterious law of a beautiful phrase, and this ceaseless striving ended by becoming an insuperable obstacle to work.

In Flaubert's life there are some original traits of interest to physiologists. Flaubert says *penser c'est parler*, and perhaps no writer has excelled him in the study of the connexion between thought and speech. He tested the rhythm of his periods on the register of his own voice. A bad phrase, he was wont to say, is a weight on the chest and is found outside of the conditions of life if it is not in accord with the physiology of language, if one cannot read it aloud harmoniously.[2]

Stricker has investigated this subject from the physiological point of view, and points out that when we are thinking of a word we pronounce it silently, and can feel the movements of the larynx as if we were speaking without sounding the words.

We have all hundreds of times seen people in the

[1] Op. cit., p. 277.
[2] *Journal des Goncourt*, p. 277.

street talking aloud, who become silent when we are passing, but begin to talk again as soon as we have gone on a few steps. Our presence distracted their thoughts, but as soon as we were past they returned to them involuntarily and began again to talk.

Excellent examples of the indissoluble bond which unites thought to speech are afforded by the biographies of great writers, especially of those who have left in their works the imprint of the strong passions which agitated their minds. On Alfieri's return from Holland at twenty years of age, his heart full to overflowing with melancholy and love, he felt the need of applying his mind to some severe study, and set himself to read Plutarch. "The lives of these great men," he says, "even at the fourth or fifth reading, aroused in me such outbursts of cries, tears, and even rage, that any one who had heard me from the next room would certainly have set me down as mad." He used to leap to his feet beside himself with agitation, while tears of grief and rage gushed from his eyes.

Honoré de Balzac, the celebrated novelist, whose fertility of invention was such as to be comparable only to the marvellous vivacity of his imagination, produced so many books that one would not have believed it possible for him to find time to correct them all. And when we know the extremely laborious nature of his method of work we are even more astonished at his facility. Hear how he composed his books: he meditated for a long time on his subject, then threw off a rough sketch of it in a few pages. This sketch he sent to the printers, who returned him a first proof printed on large pages. These he filled with additions and corrections in every line, so that these corrections looked like fireworks thrown out by the first sketch. A revised proof was sent in which all the first text had disappeared; this Balzac went over again, modifying it and changing it indefatigably and profoundly. Some of his novels were printed from the twelfth proof, others from the twentieth. The compositors were in a state of despair when they had anything to do with one of his manuscripts; the editors used to refuse to bear the expense of his additions and corrections.

CHAPTER XII

OVERPRESSURE

I

"I INSANELY destroyed my health by seven years' study at the very time when I should have been laying the foundation of a good constitution."

These words of Giacomo Leopardi sum up all that is to be said on the subject of mental overpressure. In the goodness of his heart he desires others to escape an evil from which he had suffered so sadly in his youth, and adds—

"I have most unhappily ruined myself for my whole life and rendered my appearance wretched and contemptible—all that great part of man which is the only thing of which most people take any account."

Thus did he lament at the age of twenty, when, exhausted by meditation, bowed by study and sleepless nights, he left the solitude of his ancestral estate of Recanati, where he had spent his joyless youth.

Of a certainty no other genius ever paid so high a compliment to nature. At eighteen years of age he was so familiar with Latin and Greek that neither of these languages had any secrets for him; at the age of twenty he rivalled as a poet the greatest bards of Greece. But the poetic talent and the erudition, which made Giordani hail him as the miracle of our age, sapped his constitution, rendering him an invalid for life and bringing on a melancholy which overclouded the springtime of his years.

Alexander von Humboldt says of himself: "I was eighteen years of age and I knew nothing; my masters presaged little or no good of me, but had I adopted their methods and bent to their requirements, both my body and mind would have been ruined for ever."

I have cited these two examples because they show that from the beginning of the nineteenth century the disastrous influence of overpressure has been thoroughly appreciated. Only of late years, however, has the attention of physicians and hygienists been specially directed to the evil which overpressure may produce in the youthful organism. To the best of my belief it was in 1877, at the Congress of Hygiene at Nuremberg, that Professor Finkelnburg spoke of it for the first time.

The conclusion of this Congress was that the German school system interferes with physical development, more particularly with sight; that the brain work in the schools is excessive; and that physical culture is neglected.

The Germans, with their facility in creating and adopting new words, call this excess of mental work *Ueberbürdung*, or as we might say, an overburdening of the mind. The English call it *overstrain* or *over-*

work ; and the French borrow a veterinary term and call it *surmenage intellectuel.*

Hitherto we have no generally accepted expression in Italian to designate excess of intellectual work ; perhaps because the attention of the public has been directed to the study of this problem less in Italy than in other countries, and perhaps because among us the evil resulting from excessive brain work is less felt.

It seems to me that the expression *strapazzo del cervello* would correspond to the idea we wish to express. It is unnecessary to discuss here the question of over-study. Leaving the cause aside, we desire to study the effect of the maltreatment to which the brain is subjected by requiring from it intellectual work beyond its strength.

II

When children are taken from their peaceful home life and sent to school, they do not at first feel any great discomfort, nor are they fatigued by the new mental work, because the novelty of the thing diverts them ; but the long fixation of attention begins to tire and ends by exhausting them so much that their health is affected ; and we can all see this for ourselves in the pallor which takes the place of the beautiful rosy complexion of childhood. The children become less merry and lively, lose their appetite, become dull or more excitable, and complain of headache.

Professor Finkelnburg summarises the consequences of mental overpressure in children as follows : Disturbances of vision and especially shortsightedness. Cerebral congestion resulting in headache. Bleeding from the nose, and vertigo. Tendency to round shoulders. Loss of appetite, and indigestion. Predisposition to pulmonary affections. Spinal curvature. Cerebral disorders. Nervousness. In girls, disturbances which manifest themselves in irregularity of menstruation.

Scarcely was this question of mental overpressure raised when congresses, societies, parliaments, commissions innumerable, began to busy themselves with it. There is already quite a literature upon the subject ; there are journals, such as that of Kotelmann published by Voss at Hamburg, which deal exclusively with school hygiene ; and at the University of Berne special instruction is given upon it.

Axel Key,[1] Professor of Physiology at Stockholm, has published a very important work upon this subject, and the investigations which he made in Sweden have proved irrefutably that instruction was becoming too fatiguing, and that the health of the children was suffering.

In this question of the overpressure of school children people as usual began to affirm and deny, to accuse and defend, without having first collected sufficient material to justify a definite opinion. Some of the statistics published of recent years are certainly exaggerated. Just for the sake of giving an example I shall quote the figures published by Professor Nesteroff[2] in one of his writings entitled *The Modern School and Health.*

His observations, which were commenced in 1882

[1] Axel Key's *Schulhygienische Untersuchunge,* 1889.
[2] *Zeitschrift fur Schulgesundheitspflege,* N. 6, 1890, p. 318.

and extended over a period of four years, were made on the pupils of a Moscow gymnasium, the children examined being 216 in number.

With respect to diseases of the nervous system, he had the following results in the eight classes—

In the Preparatory Class	8	per cent.
I	15	,,
II	22	,,
III	28	,,
IV	44	,,
V	27	,,
VI	58	,,
VII	64	,,
VIII	69	,,

Fortunately these are not true diseases, but simply nervous disturbances, neurasthenic conditions, hypersensibility, headache, neuralgia, palpitation of the heart, and disturbances in the sexual organs.

Axel Key shows that too prolonged sitting is particularly harmful to children, and that in school more time should be allowed for running about freely, and also a longer period for rest after lunch.

From the investigations he made in the secondary schools of Sweden, he found that only one-half of the pupils were perfectly healthy.

In such an inquiry one insurmountable difficulty presents itself, namely, that we do not know what the proportion of healthy to unhealthy children would be if no one went to school. In this comparison what is wanting is the normal mean, and the type of healthy child that has been engaged solely with the business of nutrition and growth. It would hardly be reasonable, however, to suppress the school entirely to permit of such studies being made. Even if there are such children as we want, it is difficult to assemble enough of them to give the normal average.

In Sweden the children in the higher classes work eleven or twelve or even fourteen hours a day. Of the girls 36 per cent. are anaemic, and about 10 per cent. have spinal curvature. After subtracting cases of myopia, Axel Key found that 40 per cent. of the school children in Sweden and Denmark suffered from chronic affections, and this exhaustion and deterioration of the children he attributes to mental overpressure and the too great difficulty of the tasks with which they are tormented.

Even in England, although from the hygienic point of view that country is superior to all others, the children suffer from mental overstrain. Recently Dr. Ballantyne, lecturer on the Diseases of Children in the University of Edinburgh, published in the *Lancet* a study of overpressure in England. According to him the ideal school should divide the time of the children equally between work and play, between physical and mental education. He proposes that children should be sent off to the country when their parents notice that they talk of their lessons in their sleep. The following are the conclusions of Dr. Ballantyne's important paper—

That the hygienic arrangements of the school be perfected, and greater attention be given to the promotion of the children's physical development. That the instruction be *extremely varied* so that the children are now sitting, now standing, that they read and write, work and play alternately. That arrangements be made in all schools to prevent the children coming to lessons with wet feet. That there be a frequent change of class room, constant use of the blackboard, pictures, and models. That tasks which injure the pupils by occupying their holidays be abolished.[1]

An experiment which well deserves to be recorded is one made by Charles Paget in England.[2] Being dissatisfied with the progress of a class, he divided it into two sections. One of these he continued on the old lines, the other divided its time between work and play in a field where there were trees. At the end of the session the latter surpassed the former both in diligence and in knowledge.

It is especially in the gymnasia and the high schools that overpressure finds its victims. At the University, except at examination time, one may say that there is rest for the majority of the students. Even with regard to the schools there are those who fear that there has been exaggeration in regarding the work which children have to perform as productive of overstrain. For example, Dr. Luys [3] thinks that the little interest children take in their lessons, and the short duration of each class, prevent their being over-fatigued. In this inquiry the same thing has taken place as in that regarding the work of women and children in workshops ; since in spite of the rooms

[1] *Lancet*, 1890, vol. ii.

[2] *Journal for Education*, Oct. 1884.

[3] A. Riant, *Le surmenage intellectuel*, Paris, 1889, p. 197.

full of inquiry forms, reports, and various publications, doubt arises as to the value of the statistics and comparisons, because to one single cause—cerebral labour—is attributed what is actually the effect of many causes acting conjointly.

III

Diogenes Laertius relates that Theophrastus, on his death-bed, being asked by his disciples if he had any last words of advice to give them, replied: "Live happy, and avoid studies which demand great effort; or pursue them with zeal, for they lead to glory."[1]

This is advice which parents and teachers should never forget. The best thing for children who cannot stand overpressure is to seek out a trade or profession in which their brain will not be too much over-taxed.

A stiff entrance examination for the high schools is as necessary as the searching medical inspection which prevents the enrolment of conscripts who are unfit to bear arms.

Physiology cannot say with certainty how much fatigue the brain can stand without overstrain, nor at what precise age it can sustain fatigue without danger. Before the sixth year it is certainly never well to fatigue a child at school. On the other hand, moderate mental exercise conduces to the development of the brain, for, as physiologists say, function makes the organ. There is an intricate network of causes and effects, acting reciprocally one upon the

[1] Leopardi. *Di Bruto Minore e di Teofrasto.*

other, and on this subject alone a whole book might be written. It has been shown that school is one of the most effective means of ameliorating the condition of cretins in places where cretinism exists endemically. A brain must be made to work, just as a field must be cultivated in order to prevent it running wild. But the moment study becomes exhausting it ceases to be useful. We ought to exercise the brain constantly, but never to exhaust it.

To regulate our intellectual fatigue we must not look to what others can do, but to what we can do ourselves. Within physiological limits intellectual work is certainly useful to the brain, as is proved by the statistics published by Beard, who has written an important chapter on the longevity of brain workers.

"The history of the world's progress," says Beard, "from savagery to barbarism, from barbarism to civilization, from the lowest degrees towards the higher, is the history of increase in average longevity, corresponding to and accompanied by increase of nervousness. Mankind has grown to be at once more delicate and more enduring, more sensitive to weariness, and yet more patient of toil, impressible, but capable of bearing powerful irritation: we are woven of finer fibre which, though apparently more frail, yet outlasts the coarser, as rich and costly garments oftentimes wear better than those made of rougher workmanship."[1]

Rousseau has said: "*l'homme qui pense est un animal dêpravé.*" This is one of the sophisms with

[1] G. M. Beard, *American Nervousness*, p. 287.

which the works of Rousseau abound. I do not pause to refute it, because Rousseau adduces no proofs which are worth examination, and moreover in his other writings there are statements which affirm the exact opposite. Rousseau was born with an abnormal nervous system, and the excessive activity of his brain certainly contributed to the deterioration of his psychological state. In my youth I read Rousseau's *Nouvelle Héloïse*, his *Emile*, and his *Confessions*; and I was delighted with them. Recently I read them again, and experienced a disillusionment so profound as to resemble the chill that would come over one in making an autopsy on a loved friend. Possibly my coldness arose from the disposition of my own mind, so different from that of twenty years. Now I read the works of Rousseau to see whether he was a neurasthenic, and I convinced myself that his brain was actually diseased. His vice of playing the vagabond, his want of moral sense, his exaggerated sensibility, his diffidence, his loves, the strange adventures of his life and the very nature of his death, prove that he was a man deserving compassion rather than admiration.

IV

When Cervantes wished to make Don Quixote mad, he made him read much and sleep little; thus his brain became enfeebled, and then it was good-bye to sound judgment. From this moment begin the sublime extravagances with which we all are acquainted.

Overstrain is less frequent among literary men than is generally believed, because the student can rest when he is fatigued. The most favourable conditions are those of experimenters and artists, who alternate manual with mental work, reading with writing; but even among artists I have met characteristic examples of overstrain. I shall only mention one, that of Dupré, which is the more important because it was produced almost exclusively by meditation on one subject.

Fatigue of the eyes very frequently complicates the question, and when this can be eliminated, as in the following case, the study of cerebral fatigue is much simplified. One of my friends was treating himself with arsenic for very severe headache, which had been tormenting him for almost a year. He consulted a colleague, and the doubt arising whether his sight was not affected, it was suggested that he should treat himself for a precocious presbyopia. He ceased taking arsenic, bought a pair of spectacles to use when reading, and was cured directly.

Among artists, overstrain is produced by the continued contemplation of their mental images, before they attempt with brush or chisel to produce them on the canvas or in marble. I could not better describe this phenomenon than in the words of Dupré, who was a healthy strong man, save for a slight touch of melancholia which sometimes made him doubt his own power to conquer the difficulty of his art. Here are his words—

" I therefore turned to the group of the *Pietà*, and even if the novelty of the conception and the harmony of line gave me reason to have good hopes of the success of my labour, yet the passion with which I began to work, the difficulty in obtaining the Virgin's expression in contrast with that of the divine peace on the face of the dead Jesus, the impossibility of finding such peace among the models, most of whose faces express the very opposite : all this had such an effect upon my poor head that I began to hear noises which, gradually increasing in intensity, disturbed me so much that I had to cease work ; the thought of my impotence affected me so forcibly as to cause melancholia, loss of sleep and aversion to food. My good friend Dr. Alberti, who was treating me, advised rest and distraction. But what kind of distraction, when everything bored me ? Day and night without intermission I was worn out by a persistent rumbling in my head ; and what was worse, the slightest noise, even the gentlest voice, became unbearable to me. A coachman cracking his whip terrified me, and I fled whenever I saw one. At home my poor wife and children were forced to talk in whispers, and sometimes by signs.

"As I have said, both sleep and appetite deserted me, and I grew visibly thinner. I could not read two consecutive pages, and as for writing, not even in a dream was that to be thought of. I would go out to escape my melancholy, and walk a long way without knowing where I was going. The rumbling in my head and the street noises tortured me. If I saw any one who knew me, I avoided him, that I might not be troubled by the usual question of how I did. I used to go to my studio, and my melancholy would change to acute pain at the sight of my works, to which I could not put a finger, and my grief was such as nearly to rend my heart.

"Such a condition I could not long endure, so on the advice of my doctor I resolved to go to Naples with my family." [1]

In politicians and men of business, on the other hand, overstrain is very common. In proof of this one need only think of the most terrible result of cerebral exhaustion, namely, madness. In one of his writings, entitled *Il bilancio della pazzia in Italia*, Professor Andrea Verga gives the census of persons affected with madness from 1874 to 1888, and finds that the Jews furnish the largest contribution, the proportion among them exceeding three per thousand. The same result is obtained in every country in Europe, and "must," says Verga, "be attributed to the feverish anxiety with which this strong and intelligent Semitic race pursue their interests."

But American politicians in this respect far surpass the Jews of Europe. In the district of Columbia, which is the seat of Government, there are 5·20 cases of insanity per thousand. This figure I have taken from Scribner's statistical tables, and I am ignorant of the cause of such an enormous proportion. In the State of Vermont, which stands next in the record, the proportion is only three per thousand, whilst in Texas and other States the proportion decreases to ·9 or ·5 per thousand. [2]

Pinel, the founder of modern psychiatry, who towards the end of the eighteenth century was

[1] *Ricordi autobiografici* di Giovanni Duprè, p. 358.
[2] *Scribner's statistical Atlas of United States*, 1880.

Professor of Mental Diseases in Paris, showed that political revolutions profoundly affect the nervous system of a nation, and bring about an increase in the number of the insane. The last civil war in America was a sad confirmation on a large scale of this statement, and important papers were published bearing upon the point. Among others that of Professor Stokes deserves mention as containing very curious psychological documents.[1]

Sclerosis of the brain often results from prolonged emotion and cerebral overstrain. Just as a paralysis of the spinal cord may be produced by forced marches, so likewise may a paralysis of the nervous system be produced by cerebral exhaustion. I shall return to this later when I bring together for closer comparison the phenomena of muscular and those of nervous fatigue.

V

Political men, with few exceptions, wear themselves out by overwork and age very rapidly. The correspondence of Cavour is full of allusions to the sleepless nights and the profound exhaustion both of body and of mind which his political campaigns cost him. Scarcely had the law abolishing religious corporations been passed (to quote a single example) when we find him writing to M. De la Rive—

[1] Hitherto English and American medical literature has contributed most largely to the study of cerbral overstrain. I may select for special mention the book written by Professor H. Wood, *Brain-work and Over-work*, Philadelphia, 1880; that of Richardson, *Diseases of Modern Life*, London, 1876; and the papers published in journals by Farquharson, Fothergill, Johnson, MacCabe, Routh, Wilks, and Winslow.

"After a keen struggle, a struggle carried on in Parliament, in the salons, at Court and in the street, and rendered the more painful by a crowd of distressing circumstances, I find my intellectual powers exhausted, and have been forced to seek recuperation by several days' rest. Thanks to my natural elasticity, I shall soon be able to take up the burden of office once more, and before the end of the week I expect to have returned to my post."

In Cavour's letters a happy expression has struck me, which he uses several times to indicate a physiological conception, the necessity, namely, of rest after excessive mental work. He says one must let the brain *lie fallow*, like a field which is allowed to rest, so that it may be sown again the next year.

Another of our greatest politicians, whose life was worn out by excessive work, was Quintino Sella. I was one of his friends, being bound to him no less by gratitude than by the great admiration which I had for him. In the last year of his life I was often with him, and was among the first summoned to his deathbed. I informed myself of the details of his last illness, and was convinced that he died from the effects of cerebral overstrain. He suffered from a prolonged and excessive fatigue which slowly destroyed his forces.

Originally robust and endowed with great energy, he would fight to the very last, and in the effort overstepped the limit of possible recovery.

I recollect that he made an appointment with me for seven o'clock in the morning, and for me who sleep well this was an unwonted hour in winter.

But in the evening after dinner even he was fatigued, and being overcome with sleep could not maintain the conversation. How different he was in those last years from the time I first knew him on the Alps or in the discussions at the *Lincei*. His will, his energy, his political skill, were exhausted, and we regarded him anxiously, feeling great uneasiness about him.

I have questioned several of my friends who have held office in the Government upon the subject of overstrain. One of them writes to me that he experienced the greatest fatigue when he had to give audience. When he had to receive numerous visitors in the evening, tired as he was with the day's work, and to cudgel his memory for forgotten details, the effort became insupportable. For the sake of exactitude I quote a portion of his own letter: "In a few months my hair turned from black to white. I have often experienced a regular pain in my brain, quite different from the neuralgia from which I sometimes suffer. This was a dull, aching pain, an uncomfortable sense of weight, which I attributed to actual cerebral exhaustion. The culminating symptom was insomnia, or a restless sleep in which I uttered such groans that my wife frequently awakened me believing that I was ill. My stomach was atonic, all trace of appetite gone, and sexual desire suppressed."

I begged another of my friends, who was a Minister for several years, to give me some notes on the state of his health during a protracted and very lively contest which he had to carry on in Parliament in the defence of one of his bills. Here is his reply: "My character was much altered. I suffered from an extraordinary degree of nervous excitability. Usually good-natured and affectionate in my family life, I became taciturn and extremely irritable; and perhaps things would have gone from bad to worse had not my friends, urged thereto by my family, constrained me to leave my work and go off to the country.

"I was getting no good from my food, though my muscular energy had not decreased, save that in the evening I felt as if I could not move from my seat. My sight was much affected, and I suffered from sudden nervous twitches."

These notes are of the more importance in our study of the effects of great and continuous work, in that their writer is a man of great capacity and energy who attained to power in the prime of life, when he was already inured to Parliamentary contests.

For other evidence regarding overpressure among politicians, I have been indebted to the kindness of some of my colleagues, who have had to attend patients of this class.

Affections of the heart and neurasthenia become very common among those members who take part fn the Parliamentary debates. I shall record some facts regarding them which have been made known to me by their physicians.

There is one very energetic member who succumbs from time to time to cerebral fatigue, and is forced to call in medical aid. In his case the first symptoms are insomnia and headache, but these are not sufficient to arrest him in the rush of his political engagements. He perceives that he is exhausted only when at the end of a sitting of the House he cannot recall what has been said at the beginning. He is then terrified and dejected, because he finds himself out of the fight. Sleep is of little use to him, for he dreams continually of the debates and of political affairs. This is one of the most serious symptoms of cerebral overstrain. When our day's occupations pursue us in our dreams and we feel insufficiently rested in the morning, there is no need to consult a doctor ; we must take a holiday or greater evils will follow.

Another member, after having undergone great fatigue at the House, was attacked by palpitation at an official banquet where he had to propose a toast, and was forced to limit his speech to a few words. From that day he had frequent attacks of palpitation, and suffered from nausea when he was obliged to work at his desk. He was troubled with insomnia, and had remarkable fits of trembling in his legs and hands, more especially when he appeared in public. Sometimes when he was making a speech this trembling became so troublesome that he had to sit down. The smallest indiscretion in diet was followed by diarrhoea lasting for two or three days.

All these phenomena are the more characteristic of overpressure in that the man in question possessed a good constitution with no unfavourable hereditary predispositions, and always enjoyed good health before entering political life. He complained to his medical adviser that he had become irritable ; and being naturally of a good-natured and pacific disposition, he felt every outburst of anger as a profound humiliation.

When at the House he was unable to write, if any one was near who caused him to feel the slightest constraint.

As he had not the courage to intermit his laborious occupations and attend to his health, his condition became worse and worse, till at length the effects were evident even in his speeches. His delivery became more rapid, and he omitted syllables and even words without ever suspecting it. His memory appeared to him to be less reliable, because thoughts crowded into his head and immediately vanished. He was tortured by feeling that, while words and images abounded in his excited imagination, he could only express himself badly and confusedly. At times he hurried his speech so much that, while it could not be said that there was any actual defect in him, it was nevertheless evident from his pronunciation and the uncertainty of his words, that he was not in a normal state. In a short time he lost nearly two and a half stones in weight, and during the night he suffered from insomnia and profuse perspiration. A month's rest and treatment sufficed to make all these symptoms disappear, and to improve the general conditions of nutrition.

One of my non-medical friends, who knew that I was collecting material for a work on intellectual fatigue, told me about a Member of Parliament in whose company he happened to travel back from Rome. He was so struck by the mental exhaustion of this Deputy, that he asked me whether he might not be suffering from some serious disease of the nervous system, or rather from mental debility brought on by excessive work. In talking he constantly lost the thread of his discourse. The smallest digression, a parenthesis of even a few words, was enough to leave him open-mouthed and unable to recall his ideas. He kept forgetting that they had been students together, and treated my friend with formality. My friend called his attention to this several times in a jesting manner, then out of pity he let it pass; and also ceased to take any notice of his unfinished remarks. I know that this Deputy was recently re-elected; hence I conclude that there was no serious affection of the nervous system, but that the symptoms simply resulted from overstrain.

One of my colleagues called my attention to the fact that many politicians are prone to take infectious diseases and die young; and that this must be attributed to the depression of their nervous system.

I have by no means exhausted the subject either of cerebral or of muscular fatigue; but for this volume the reader has doubtless had sufficient.

Butler & Tanner, The Selwood Printing Works, Frome, and London.