Experiments made with a view to ascertain the principle on which the action of the heart depends, and the relation which subsists between that organ and the nervous system / by A.P. Wilson Philip.

EXPERIMENTS

MADE WITH

A VIEW TO ASCERTAIN THE PRINCIPLE ON WHICH THE ACTION OF THE HEART DEPENDS,

AND THE

RELATION WHICH SUBSISTS BETWEEN THAT ORGAN AND THE NERVOUS SYSTEM.

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EXPERIMENTS, *&c.*

Read before the ROYAL SOCIETY, *February* 9, 1815.

THE following experiments were begun with a view to ascertain the manner in which certain poisons act in destroying life. I soon found that, in order to make any considerable progress in such an inquiry, it is necessary to ascertain how far the powers of the nervous and sanguiferous systems directly depend on each other. There seems never to have been any difference of opinion respecting the direct dependence of the nervous on the sanguiferous system. When the powers of circulation are increased or diminished, the nervous system always suffers a corresponding change, nor can the latter, under any circumstances, continue to perform its functions after the former are destroyed. I speak of the warm blooded animals. In cold blooded animals the process of dying is so slow, that the functions of the nervous system abate very gradually, after the circulation has wholly ceased. The converse of the above proposition is by no means so generally admitted. It is evident that certain changes of the nervous, produce corresponding changes in the sanguiferous, system; yet, while some assert, that the action of the heart

depends as immediately on the brain, as that of the latter does on the heart, others maintain, that the nervous power may be wholly destroyed without impairing the vigour of this organ. This point it is necessary to determine, before we can trace with precision the *modus operandi* of poisons. The following inquiry therefore may be divided into two parts. In the first, I shall endeavour to ascertain how far the power of the heart is influenced by the state of the nervous system; in the other, by what steps certain poisons destroy the powers of both. This I shall reserve for another paper, and here confine myself to the first part of the subject.

Till the time of HALLER, it seems to have been the general opinion, that the muscles derive their power from the nervous system. He taught, that the power of the muscles depends on their mechanism, that the nervous influence is merely a stimulus which calls it into action, and consequently that those muscles, the heart for example, which act only by the application of one peculiar stimulus, unconnected with the nervous system, are wholly independent of it. This opinion seemed confirmed by its being generally admitted, that the action of the heart continues after it is removed from the body, and that it cannot be influenced by stimulating the brain, or spinal marrow, or the nerves which terminate in it. HALLER and his followers maintain, that there are two distinct vital powers, one of the nervous and another of the sanguiferous system.

The supporters of HALLER's doctrine however, found many difficulties to contend with. The evident objections to it are, that the heart is influenced by affections of the mind, and that it is supplied with nerves. Various hypotheses have been

framed to get rid of these objections, some of which imply a considerable modification of the original opinion. Several writers have maintained, that although the heart is independent of the brain and spinal marrow, it may be subject to some peculiar action of its own nerves; others, that the ganglia through which its nerves pass have a power independent of the sensorium commune. FONTANA and others have maintained, that the nerves of the heart are absolutely useless; others, that these nerves are distributed on its vessels, and do not enter the substance of the heart. SCARPA, however, has proved, that nerves are distributed to the heart in the same way as to other similar parts. Nothing can show more strikingly the imperfection of our knowledge of this important branch of physiology, than that opinions so different, and so destitute of proof, should be maintained by the best writers upon it.

An author has lately appeared, who, among other ingenious and important experiments, has made many relating to this subject, and arrived at conclusions which have surprised physiologists, yet apparently so well supported as to have obtained their general assent. M. LE GALLOIS* maintains, that by the destruction of the whole or cervical part of the spinal marrow, the action of the heart is immediately so debilitated, that it is no longer capable of supporting the circulation; while by the destruction of the brain, on the contrary, its action is unimpaired: from which he infers, that it is from the

* Expériences sur la principe de la Vie, notamment sur celui des mouvemens du cœur, et sur le siège de ce principe, suivies du Rapport fait à la premiere Classe de l'Institut, sur celles rélatives aux mouvemens du cœur, par M. LE GALLOIS, Doct. en Méd. &c. Paris, 1812.

spinal marrow that the heart derives the principle of its life and of its motions. Those motions of the heart, says M. LE GALLOIS, which remain after the destruction of the spinal marrow, or the interruption of the nervous influence upon the heart in any other way, and which misled HALLER and his followers, are motions without force, incapable of supporting the circulation, and analogous to the motions of other irritable parts on the application of a stimulus, which in this case is the arterial blood contained in it.

The experiments, on which these opinions are founded, he repeated in the presence of a Committee of the National Institute at Paris, which has expressed its conviction of their accuracy. Notwithstanding this high authority, I was led, from some experiments which I made many years ago, in which both the brain and spinal marrow were destroyed by the action of opium and tobacco, to doubt M. LE GALLOIS' conclusions. The reader will judge how far the following experiments tend to invalidate these conclusions, and influence our opinions of the subject to which they relate.

I cannot here omit to express my thanks to Mr. HASTINGS, House-surgeon to the Worcester Infirmary, who assisted me in the following experiments. His expertness in dissection was often of great use, where it was necessary to be expeditious, and to lose as little blood as possible.

Exp. 1. A rabbit was deprived of sensation and voluntary power by a stroke on the occiput. When the rabbit is killed in this way, the respiration immediately ceases; but the action of the heart and the circulation continue, and may be supported for a considerable length of time by artificial respiration, as practised first, I believe, by FONTANA, and since by

CHIRAC, Mr. BRODIE, M. LE GALLOIS, and others. This mode of destroying the sensibility does not influence the result of the experiment, and has the double advantage of preventing the animal's sufferings, and his motions. Its greatest inconvenience is, that if the blow is very severe, considerable vessels are sometimes ruptured, and there is always some rupture of vessels, which of course tends to impair the vigour of the circulation.

In the present experiment, the circulation was supported by artificial respiration. The spinal marrow was laid bare from the occiput to the beginning of the dorsal vertebræ. The chest was then opened, and the heart found beating regularly, and with considerable force. The spinal marrow, as far as it had been laid bare, was now wholly removed, but without in the least affecting the action of the heart. After this, the artificial respiration being frequently discontinued, we repeatedly saw the action of the heart become languid, and increase on renewing it. The skull was then opened, and the whole of the brain removed, so that no part of the nervous system remained above the dorsal vertebræ, but without any abatement of the action of the heart, which still continued to be more or less powerful, according as we discontinued or renewed artificial respiration. This being for a considerable time discontinued, the ventricles ceased to beat about half an hour after the removal of the brain. On renewing the respiration, however, the action of the ventricles was restored. The respiration was again discontinued and renewed, with the same effects.

Exp. 2. A rabbit was made insensible by removing part of the skull, and applying opium to the brain. The spine was

then opened between the cervical and dorsal vertebræ. We then laid open the thorax, and supported the action of the heart by artificial respiration. The force with which it beat was carefully observed, and the spinal marrow destroyed by running a hot wire up and down the spine, through the opening made in it, by which the action of the heart was not at all affected.

Exp. 3. In the foregoing experiments, it may be said, there was no direct proof of the continuance of the circulation after the spinal marrow was destroyed or removed. On this account several of the following experiments were made. A rabbit, previously exhausted by dividing the eighth pair of nerves, was deprived of sensation by a blow on the occiput, and the circulation supported by artificial breathing. The carotids were seen beating near to the place where the nerves had been divided. The cervical part of the spinal marrow was then destroyed by a hot wire, after which the carotids were still found beating.

Exp. 4. In a rabbit rendered insensible by a blow on the occiput, the whole spinal marrow was destroyed by a hot wire, and the breathing artificially supported. One of the carotid arteries was then laid bare. Its beating was evident, and on dividing it, florid blood flowed from it freely.

Exp. 5. The only difference between this and the last experiment was, that artificial breathing was not performed. In both, the spinal marrow was destroyed, by introducing a wire hot enough to make a hissing noise through an opening between the cervical and dorsal vertebræ, first through the upper portion into the brain, then through the under portion to the end of the spine. On laying open one side of the neck, the

carotid artery was found beating. On dividing it, blood of a much darker colour than in the former experiment was thrown out copiously *per saltum*.

Exp. 6. A rabbit was rendered insensible by a blow on the occiput, and artificial respiration maintained. The spinal marrow from the base of the skull to the beginning of the dorsal vertebræ was removed, and a hot wire forced through the remaining part of the spine. The carotid artery was then found beating, and on dividing it florid blood rushed out with great force *per saltum*.

Exp. 7. This experiment resembled the last, except that the spinal marrow, instead of being partly removed, was wholly destroyed by a hot wire, and artificial breathing was not performed previous to opening the carotid, from which dark coloured blood flowed *per saltum*. We then inflated the lungs, and arterial blood soon began to flow copiously from the vessel, and appeared like a florid stream mixing with the dark coloured blood which had previously come from it. This experiment was repeated in the same manner, and with the same result.

Exp. 8. In this experiment the rabbit was rendered insensible, but not motionless, by the blow on the occiput, so that the breathing still continued. The spine was opened, and the spinal marrow destroyed, as in the preceding experiment. The wire was used very hot. On introducing it through the spine into the brain, the breathing immediately ceased. The femoral artery was laid bare about two or three minutes after respiration had ceased. The beating of the artery was evident. On opening it, a dark coloured blood flowed from it freely. We now had recourse to artificial respiration. When

it had been continued for about half a minute, the blood, which continued to flow copiously from the artery, became of a highly florid colour. The other femoral artery was then opened, from which florid blood also flowed freely. When about an ounce of blood had flowed from the two vessels, the inflation of the lungs was discontinued, and the blood again flowed of a dark colour. On renewing the inflation of the lungs, the blood, in less than half a minute, again became of a florid colour. It continued to flow from the femoral arteries altogether for seven minutes. Three minutes after the blood had ceased to flow from them, the artificial respiration being continued, one of the carotid arteries was opened, from which a florid blood flowed in a free stream, to the amount of a dram and a half. The flow from the carotid artery ceased in eleven minutes after the femoral artery had been opened. Most of the blood was now of course evacuated. A good deal had been lost in opening the spine, which always happens. The left auricle and ventricle were found nearly empty. The blood which remained in them was florid. The right auricle and ventricle were full of dark blood.

Exp. 9. From various trials, we found that in such experiments the circulation ceases quite as soon without, as with the destruction of the spinal marrow. Loss of blood seems to be the chief cause which destroys it. When the animal was operated upon, without being rendered insensible, pain also contributed to this effect. We frequently, after laying open the skull and spine, found the circulation lost before either the brain or spinal marrow had been disturbed. In the younger rabbit, it was lost sooner than in the older. The former seemed to die sooner from any injury, except the inter-

ruption of respiration. The circulation is particularly apt to fail, if artificial respiration is not carefully performed after the animal ceases to breathe. In making such experiments, after opening the bone, it is always necessary to ascertain whether the circulation continues, before we destroy or remove the brain or spinal marrow. As little blood is lost in this part of the operation, when the carotid arteries were beating before, we always found them beating after it. The result of this experiment is still more striking in the cold blooded animals, in which death takes place so slowly, that the circulation continues long after the total destruction of the nervous system.

Exp. 10. The brain of a frog and the spinal marrow as low as the dorsal vertebræ were laid bare. The thorax was then opened, and the heart found acting vigorously; and from the transparency of its sides, the passage of the blood through it distinctly seen. The part of the spinal marrow, which had been laid bare, was then removed, but without at all affecting either the motion of the heart, or the passage of the blood through it. The brain was then removed, with the same result.

Exp. 11. The brain and spinal marrow of a frog were wholly removed. On opening the thorax, the heart was found performing the circulation freely.

I have already had occasion to observe, that it is generally admitted that the action of the heart cannot be influenced by stimuli applied to the nervous system: and it seems almost a contradiction to suppose that it should, when we see that it cannot be influenced by the total destruction of this system. There were many reasons, however,which induced me to try

the effect on the heart of stimuli so applied to the brain and spinal marrow, as not to excite any of the muscles of voluntary motion, whose action, either by throwing more blood towards the heart, or in some other way influencing its action, prevents our judging of the effect of the stimulus.

Exp. 12. A rabbit was deprived of sensation and voluntary motion by a blow on the occiput, the action of the heart supported by artificial respiration, and the brain and cervical part of the spinal marrow laid bare. The thorax was now opened, and the action of the heart, which beat with strength and regularity, observed. Spirit of wine was then applied to the spinal marrow, and a greatly increased action of the heart was the consequence. It was afterwards applied to the brain with the same effect. The increase of motion was immediate and decided in both cases. We could not perceive that it was more in the one case than the other.

Exp. 13. The foregoing experiment was repeated, with the difference, that the whole of the spinal marrow was laid bare. The motion of the heart was nearly, if not quite, as much influenced by the application of the stimulus to the dorsal, as to the cervical portion of the spinal marrow; but it was very little influenced by its application to the lumbar portion.

Exp. 14. In this experiment, only that part of the brain which occupies the anterior part of the head was laid bare. The rabbit in other respects was prepared in the same way as in the preceding experiments. The spirit of wine applied to this part of the brain, produced as decided an effect on the motion of the heart as in those experiments. The spirit of wine was washed off, and a watery solution, first of opium, then of tobacco, applied, with the effect of an increase, but a

much less increase of the heart's action than arose from the spirit of wine. The increased action was greater from the opium, than from the tobacco. The first effect of both was soon succeeded by a more languid action of the heart than that which preceded their application to the brain. This effect was greatest, and came on soonest when the tobacco was used, and we always, for we frequently repeated the experiment, saw an evident increase in the action of the heart, when we washed off the tobacco. We could also perceive this, though in a less degree, when the opium was washed off. Little or none of this debilitating effect was observed when the spirit of wine was used. After its stimulating effect had subsided, the action of the heart only returned to about the same degree as before the application of the stimulus.

Exp. 15. The foregoing experiment was repeated on an animal of cold blood. Mr. HASTINGS had found, that immersing the hind legs of a frog in tincture of opium, in less than a minute, deprives it of sensibility. This does not arise from any action of the opium; a watery solution of opium, we found, however strong, does not produce the effect. It is immediately produced by simple spirit of wine, and arises from the action of the spirit on the nerves of the part to which it is applied, for it takes place quite as readily as in the healthy frog, after a ligature has been thrown round all the vessels attached to the heart. It is remarkable, that if simple spirit of wine is used, the animal expresses severe pain, if tincture of opium, very little. I have already mentioned the reason why it is necessary, in order to judge of the result of this experiment, that the animal should be rendered insensible. (*Exp.* 11.)

Having thus deprived a frog of sensibility, we laid bare the

brain and spinal marrow, and opened the chest. The heart was found contracting with vigour. Spirit of wine was then applied to the spinal marrow, with an immediate and evident increase of the action of the heart. It was then applied to the brain with the same effect. Watery solutions of opium and tobacco were also applied to both, with precisely the same effect as in the rabbit. The increase of action from the opium and tobacco was much less than from the spirit of wine, and was soon followed by a great diminution of action. The increase of action was least, and the diminution greatest from tobacco. On washing off the opium and tobacco with a wet sponge, the heart immediately beat more strongly. The different parts of this experiment were frequently repeated with the same result. It is remarkable that we could affect the motion of the heart by stimuli applied to the brain and spinal marrow, after they had ceased to produce any effect on the muscles of voluntary motion through the medium of the nervous system.

Exp. 16. This experiment only differed from the last in the cervical part of the spinal marrow and lower part of the brain being removed, and the stimuli applied only to that part of the brain which lies between the eyes of the frog. Spirit of wine, opium, and tobacco, thus applied, affected the motion of the heart quite as much, and precisely in the same way, as when they were applied to the entire brain and spinal marrow. When opium and tobacco were applied to the lower part of the spinal marrow, the motion of the heart appeared to be hardly at all affected by them. It was evidently increased when spirit of wine was applied to the same part.

We found in the foregoing experiments, that considerable

pressure, either on the brain or spinal marrow, produced little or no effect on the action of the heart. Its action could be influenced by stimuli applied to the brain and spinal marrow long after the circulation had ceased.

The peristaltic motion of the intestines, as far as we could judge from the following experiments, obeys the same laws as the action of the heart.

Exp. 17. A rabbit was deprived of sensibility by a blow on the occiput. The whole of the spinal marrow was then destroyed by a hot wire. On opening the abdomen, we found the peristaltic motion of the stomach and small and great intestines quite as strong as when the nervous system is entire, as we ascertained by exposing the abdominal viscera of other rabbits. In another experiment, the spinal marrow was wholly removed, without at all affecting this motion. The removal of the brain, we found, produces as little effect upon it, as that of the spinal marrow. When both were removed at the same time, it remained unaffected. It continues till the intestines become cold, so that when the portions exposed to the air have lost their power, the motion of the parts beneath still remains.

We endeavoured to ascertain how far this motion is influenced by stimuli applied to the brain and spinal marrow, but from its nature it is in every way so irregular, that no certain result can be obtained. It often appeared to us, that spirit of wine applied to the brain and spinal marrow increased it.

The admission of air into the cavity of the abdomen throws the bowels into strong spasmodic action, which alone would obscure any effect that can be supposed to arise from stimulating the brain. To remove this cause of failure, the abdomen

was opened under tepid water; but this was found to excite even stronger spasms than the air had done.

What are the simple results of the foregoing experiments? The first set prove, that the power of the heart is independent of the brain and spinal marrow, for we find that it continues to perform its function after they are destroyed or removed, and that their removal is not attended with any immediate effect on its motions. The second set prove, that the action of the heart may be influenced by agents applied to any considerable portion either of the brain or spinal marrow. It is as readily influenced by agents applied to the anterior part of the brain, as by those applied to the cervical part of the spinal marrow. This is what we should expect when we trace the various origins of its nerves.

If it be said that the results of these experiments imply a contradiction, that we cannot suppose the power of the heart to be wholly independent of the brain and spinal marrow, and yet influenced by stimuli applied to them, the reply is, that such are the facts, of the truth of which any one may easily satisfy himself. Daily occurrences correspond with these facts. We rarely see the action of the heart destroyed by injuries of the brain and spinal marrow, unless they are such as interrupt respiration; yet its action is constantly influenced by affections of the mind.

On a closer examination of the phenomena of the nervous system, we shall find other similar difficulties. The experiments of M. LE GALLOIS prove, in the most satisfactory manner, that a principal function of the spinal marrow is to excite the muscles of voluntary motion, and that it can perform this office independently of the brain. It performs it

after the brain is wholly removed, and its powers seem not at all immediately impaired by the removal of the brain; yet we constantly see injuries of the brain impairing the functions of the spinal marrow. We may wholly remove the brain, and the animal performs the various motions of its limbs as well as before its removal. Yet an injury of the brain often produces complete hæmiplegia, nay often instantly destroys every function of the system. Of this apparent inconsistency, M. LE GALLOIS justly remarks, that two facts well ascertained, however inconsistent they may seem, do not overturn each other, but only prove the imperfection of our knowledge.

Whichever of the disputed opinions respecting the functions of the nervous system we adopt, the foregoing phenomena seem to imply a contradiction; for an explanation of them, therefore, we must recur to principles different from those hitherto assumed. The following experiments point out still another instance of this apparent contradiction, and seem to suggest the principle on which the whole depends.

Exp. 18. By applying strong stimuli to the spinal marrow of a frog, strong and repeated contractions were excited in the muscles of the hind limbs, as long as the stimuli would produce the effect. On examining the state of the muscles of these limbs, I found them wholly deprived of their excitability. Now it is well known, that although all the nerves supplying the limbs of a frog be divided, and cut out close to the place where they enter the muscles, the latter still retain their excitability, which appears to be not at all less than while the nerves are entire. Lest it may be supposed that the nervous influence, which was exhausted in this experiment by stimulating the spinal marrow, still remains in

the muscles after the nerves are divided, and thus preserves their excitability, the following experiment was made.

Exp. 19. All the nerves supplying one of the hind limbs of a frog were divided, so that it became completely paralytic. The skin was removed from the muscles of the leg, and salt sprinkled upon them, which, being renewed from time to time, excited contractions in them for twelve minutes; at the end of this time they were found no farther capable of being excited. The corresponding muscles of the other limb, in which the nerves were entire, and of which consequently the animal had a perfect command, were then laid bare, and the salt applied to them in the same way. In ten minutes they ceased to produce any contractions, and the animal had lost the command of them. The nerves of this limb were now divided, as those of the other had been, but the excitability of the muscles to which the salt had been applied was gone. Its application excited no contraction in them. It sometimes happens, while the nerves of the limb are entire, that the voluntary efforts of the animal prevent the contractions usually excited by the application of salt. This experiment was repeated in the same manner, and with a similar result. After the experiment, the muscles of the thighs in both limbs were found to contract forcibly on the application of salt. It excited equally strong contractions on both sides.

It is remarkable, that in this experiment, the excitability of the muscles whose nerves were entire, was soonest exhausted. In the repetition of the experiment, this was the case to a still greater degree, the muscles, whose nerves were entire, losing their excitability in about one half of the time required for exhausting the other.

From this experiment it is evident, that the nervous influence, so far from having a power of preserving the excitability of the muscles, exhausts it like other stimuli. The excitability therefore is a property of the muscle itself. Yet we have just seen, that it may be wholly destroyed by changes induced on the nervous system. On the same principle we explain the seeming contradiction respecting the action of the heart. We have seen that its power exists as independently of the brain and spinal marrow, as the action of the first muscles to which the salt was applied, whose nerves had been divided; but, while the brain and spinal marrow retain their functions, and the connection of nerves is entire, the heart, as well as the muscles of voluntary motion, may be influenced by agents acting through the nervous system. It is not difficult to account for the latter being more copiously supplied with nerves than the heart, because all the stimuli which affect them, act through their nerves, while the heart is only now and then influenced through its nerves, its usual stimulus being as immediately applied to it, as the salt was to the muscles of the limb in the above experiment, and acting as independently of the nervous system. We do not surely in all this see any difference in the nature of the muscular power of the heart, and that of the muscles of voluntary motion, except their being fitted to obey different stimuli, a difference which we find in the two sides of the heart itself.

It may here be objected, that in apoplexy the power of the muscles of voluntary motion is lost, while that of the heart is little or not at all impaired. Were such the fact, this objection would be unanswerable; but I have repeatedly examined the state of the muscles of voluntary motion in apoplexy,

both in the warm and cold blooded animals, and found their excitability unimpaired. It is not their power, but the stimulus which excites them, that is lost in apoplexy. In this disease, the heart continues to contract, because its stimulus is still supplied; the muscles of voluntary motion cease to contract, because their stimulus is withdrawn.

By the foregoing experiments we arrive at the conclusion of HALLER, that the heart and other muscles possess an excitability independent of the nervous system; but we are carried a step farther, and taught that they are all equally capable of being stimulated through this system, by which the great objections to HALLER'S doctrine are removed. We may, I think, trace the subject still farther. It has been shown by direct experiment by M. LE GALLOIS, that the spinal marrow is capable of performing its functions independently of the brain, yet, as has just been observed, the spinal marrow may be influenced through the brain. Thus the excitability of the spinal marrow bears the same relation to the brain, which that of the muscles bears to the spinal marrow and its nerves, and I would add all nerves distributed to muscles, some of which arise from the brain, but seem to bear precisely the same relation to the sensorium with those which arise from the spinal marrow. Even M. LE GALLOIS, although his experiments lead to an opposite conclusion, observes, that the brain seems to act on the spinal marrow as the latter does on the parts it animates. We know the peculiar office of the brain, by observing what functions are lost by its removal, the sensorial functions. The nervous, then, obeys the sensorial system, in the same way in which the muscular obeys the nervous system, but as the muscular system has an existence independent of the

nervous, so has the nervous, independent of the sensorial system.

What is here said is finely illustrated by reviewing the various classes of animals. In the lowest class we find only the muscular system, which exists without either nervous system or sensorium. In the next class we find the muscular and nervous systems, which exist without sensorium. In the most perfect animals, we find the three vital powers combined, each having an existence not immediately depending on the others, but all so connected, that none can exist long without the others. The nature of this connection is obvious, when we consider that all are supported by the circulation, which depends for its immediate support on the muscular system, and cannot long exist without respiration, and that this depends not on the sensorium, but, as M. LE GALLOIS has satisfactorily proved, on the nervous system, which system is under the immediate influence of the sensorium, directing, but not producing, its various movements; and such is the power of the sensorium over the nervous system, that its affections may, through this system, at once destroy every function of life. Thus joy and other strong passions have killed more speedily than suffocation can, and therefore otherwise than through the destruction of respiration.

Exp. 20. All that has been said of the vital power of the heart is strikingly confirmed by the following experiments. If the head and spine of a frog be removed, the heart continues to perform its function perfectly for many hours, nor does it seem at all immediately affected by their removal. But we find the effect very different when the most sudden and powerful agent is applied to them. If they are destroyed by being cut

to pieces, or even by a hot wire, the heart after their destruction beats just as before it. But if either the brain or spinal marrow be instantly crushed, the heart immediately feels the shock.

The thorax of a large frog was laid open, and the motion of the heart observed, which performed the circulation perfectly, and with great force. The brain was then crushed by the blow of a hammer. The heart immediately performed a few quick and weak contractions. It then lay quite still for about half a minute. After this, its beating returned, but it supported the circulation very imperfectly. In ten minutes its vigour was so far restored that it again performed the circulation with freedom, but with less force than before the destruction of the brain. An instrument was then introduced under the heart, and after ascertaining that this had produced no change on its action, the spinal marrow was crushed by one blow, as the brain had been. The heart again beat quickly and feebly for a few seconds, and then seemed wholly to have lost its power. In about half a minute it again began to beat, and in a few minutes acquired considerable power, and again supported the circulation. It beat more feebly, however, than before the spinal marrow was destroyed. It ceased to beat in about an hour and a half after the brain had been destroyed. In another frog, after the brain and spinal marrow had been wholly removed, the heart beat nine hours, gradually becoming more languid.

In this experiment we see that the heart not only retains its power long after the brain and spinal marrow are removed, but that if they are destroyed in such a way as to impair and almost destroy the action of the heart, it can recover the power of performing its function, after they no longer exist; pre-

cisely as a muscle of voluntary motion will by rest recover its excitability, although all its nerves are divided, if its circulation continues.

M. BICHAT (*Recherches Phys. sur la vie et la mort.*) has shown that in a frog the circulation continues in the capillaries after the heart no longer propels the blood.

Exp. 21. The foregoing experiment cannot be performed in the same way on warm-blooded animals, but it may be performed in a way equally satisfactory. In two rabbits the brain was crushed by a blow. In both the heart immediately beat with an extremely feeble and fluttering motion. The anterior part of the brain only was crushed in another rabbit, with the same result. A strong ligature was thrown round the neck of a fourth rabbit, and at the moment it was tightened, the head was cut off. The bleeding was restrained by the ligature, except from the vessels defended by the bone. General spasms made the body hard for the space of between one and two minutes, so that the beating of the heart could not be felt. At the end of this time, the heart was felt through the side, both by Mr. Hastings and myself, beating regularly, and not more quickly than in health. All the rabbits used in this experiment were of the same age.

Exp. 22. The following experiment is still more conclusive. The anterior part of the brain of a rabbit was crushed by a blow. The side was rendered hard by spasm for about half a minute. Neither during this, nor after it, could I perceive any motion of the heart by applying the hand to the side. The head was then cut off, about three quarters of a minute after the brain had been crushed. No blood spouted out, and very little ran from the vessels. A strong ligature

was passed round the neck of another rabbit of the same age. It was suddenly tightened, and the head cut off. In this instance little spasm took place, and the heart was found beating regularly under the finger for about three quarters of a minute. At the end of this time, the ligature was slackened, and the blood spouted out to the distance of three feet, and continued to spout out with great force, till nearly the whole blood was evacuated.

Exp. 23. From the strength of the spine of a rabbit, and the situation of the neighbouring parts, it is impossible to crush it, without directly influencing the state of the heart by the blow. We opened it between the cervical and dorsal vertebræ, and suddenly forced a steel rod through the cervical part. As in the experiments of M. LE GALLOIS, the action of the heart was immediately debilitated. In the preceding experiments, the reader has seen, we repeatedly, slowly destroyed, or removed entirely, both the cervical and other portions of the spinal marrow, without at all influencing the action of the heart.

These experiments point out an easy solution of the difficulties mentioned by M. LE GALLOIS in the 119th and following pages of his Treatise. When the whole spinal marrow was destroyed by small portions at a time, comparatively little effect was produced on the heart; but when a considerable part of it was crushed at once, the power of the heart was so impaired, that circulation ceased. So in other cases, where the injury was inflicted slowly, and where it was inflicted suddenly, the result was found to be different.

Thus he observes, that if the spinal marrow be divided near the occiput, and a certain part of it immediately destroyed,

circulation ceases. If some time intervene between the division and the destruction of precisely the same part, the circulation is not interrupted.

M. LE GALLOIS' explanation of these facts cannot surely be admitted, and indeed is inconsistent with his own positions. He found, that confining the circulation to a less extent, by throwing ligatures round the large vessels at some distance from the heart, enables this organ to support the circulation under circumstances where it would otherwise have failed. Writers on midwifery have, on the same principle, recommended compressing the arteries of the limbs when the powers of the heart are much weakened by hemorrhagy. From this experiment, compared with others, M. LE GALLOIS infers, that when the spinal marrow is destroyed by small portions, the circulation, in the parts corresponding to these portions, being impeded, the effect is similar to that produced by the ligatures. Now, although it were ascertained that the circulation is impeded in any part by destroying the portion of the spinal marrow from which it is supplied with nerves, which I think may easily be shown not to be the case, this explanation would still be in opposition to M. LE GALLOIS' fundamental position: "Que la quantité, que le contingent de forces, que chaque "portion de moëlle fournit à cet organe, égale pour le moins "celles dont il auroit strictement besoin pour entretenir la "circulation dans les seules parties correspondantes à cette "portion." When the ligatures were thrown around the vessels, the heart was deprived of none of its supposed nervous influence. When, on the contrary, portions of the spinal marrow were successively destroyed, as far as this is supposed to confine the circulation, it must also, according to M. LE

GALLOIS, occasion a loss of power in the heart. He remarks that till the above explanation occurred to him, he had resolved to abandon this part of the inquiry. " Après bien " des efforts inutiles pour porter la lumière dans cette téné- " breuse question, je pris le parti de l'abandonner, non sans " regret d'y avoir sacrifié un grand nombre d'animaux, et " perdu beaucoup de temps." Just before, he observes, " En " un mot, j'eus presque autant de résultats différens que d'ex- " périences." This may be easily accounted for, as he was not aware that the rapidity with which any portion of the spinal marrow is destroyed, influences the result. We also see why the sudden destruction of one half of the spinal marrow, after it had been divided, not only brought death to that part of the animal to which it belonged, but to the other also; a fact which seems in direct opposition to M. LE GALLOIS' explanation of that we have just been considering.

In M. LE GALLOIS' experiments, the spinal marrow was always crushed by a stilet, of precisely the same dimensions with the cavity of the spine. In the foregoing experiments, the spinal marrow was either removed or destroyed by a comparatively small wire moved about in it till all its functions ceased. The reader will easily understand, from what has been said, why this apparently slight circumstance occasions so essential a difference in the result of the experiments. We have just seen the difference of the result when any portion of the spinal marrow is successively destroyed by parts, or crushed at once, and when the brain is crushed at once or wholly removed.

We have every reason to believe, from the experiments which have been related, that the peristaltic motion of the

bowels obeys the same laws as the action of the heart. It appears from those experiments, that this motion is wholly independent of the nervous system. It continues till the parts become cold after the brain and spinal marrow are removed. I have already mentioned the circumstances which prevented our positively ascertaining, whether it is influenced by stimuli applied to the brain and spinal marrow, (Exp. 17.) but we know that the action of the bowels is frequently influenced by affections of the mind.

From the whole of the foregoing experiments and observations, it appears,

1. That the muscles of involuntary motion obey the same laws with those of voluntary motion. Exp. 1, 2, 3, 4, 5, 6, 7, 8, 10, 11, 12, 13, 14, 15, 16, and 17, compared with Exp. 18, and 19; see also observations under Exp. 19.

2. That the apparent difference in the nature of these muscles, arises from their being under the influence of different stimuli; see observations under Exp. 19.

3. That they are both capable of being stimulated through the nervous system. Exp. 12, 13, 14, 15, 16.

4. That the power of both is independent of the nervous system. Exp. 1, 2, 3, 4, 5, 6, 7, 8, 10, 11, 17, 18, and 19.

5. That what is called the nervous system consists of two parts, whose existence is not immediately dependent on each other; the one performing the sensorial functions, the other conveying impressions to and from the sensorium, and, without bestowing any power on the muscular system, acting as a stimulus to it. See the observations under Exp. 19. See also Exp. 1, 2, 3, 4, 5, 6, 7, 8, 10, 11, 18, 19.

6. That there is therefore in the most perfect animals a combination of three distinct vital powers, not immediately depending on each other; one of the muscular system, one of the nervous system properly so called, and one of the sensorial system. See observations under Exp. 19.

7. That the muscular system, though independent of the nervous system, is so influenced by it, that the power of the former may even be destroyed through the nervous system. Exp. 1, 2, 3, 4, 5, 6, 7, 8, 10, 11, compared with Exp. 18, 20, and 23

8. That both the muscular and nervous systems, though independent of the sensorial system, are so influenced by it, that they may even be destroyed through it. Exp. 8, 10, 11, 17, and two last paragraphs under Exp. 19, compared with Exp. 20, 21, 22.

9. That although in the less perfect animals we find the muscular life existing alone, and the muscular and nervous existing without the sensorial life; in the more perfect animals they are so connected, that none can exist long without the others. See the last paragraph under Exp. 19.

10. That nutrition, circulation, and respiration, are the means by which they are so connected.

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