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Functional Inertia—A Property of Protoplasm

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note by the Rev. Dr. Stevenson, of Glamis, on this fungus. It is there mentioned that this remarkably rare fungus was only twice found on the Continent, and not in England since February 1790. I may say that I found this fungus in two stations in Kells Parish, and twice in the neighbouring parishes. It grows on dead willows. I have seen no record of any other one finding it.

FUNCTIONAL INERTIA—A PROPERTY OF PROTOPLASM. By DAVID FRASER HARRIS, B.Sc. (Lond.), M.D., Lecturer on Physiology and Histology in the University of St. Andrews.

(Read 13th February 1902.)

I. Just as "dead" matter has two forms of inertia—that of rest (mass) and that of motion (momentum), so too, I think, has living matter (protoplasm, whether animal or vegetable). It is owing to the inertia of matter at rest that the heavy gate, swung on even almost frictionless hinges, cannot be instantaneously set in motion, and, when it has been set swinging, it is owing to its inertia of motion (momentum) that it continues to swing for some time after we have ceased to push it. Now, I think, protoplasm has a functional inertia—that property of remaining in the *status quo ante* for a longer or shorter time according to the function considered, that property of continuing to act as it has been acting, in spite of the application of a stimulus tending to effect a change of action, and that power of continuing to exhibit the phenomena it has been exhibiting after even the death of the organism of which it is a constituent. The inertia of protoplasm is, then, the capacity for remaining in the functional *status quo ante*. This inertia of "livingness" expresses itself under several different modes or categories—bio-chemically, as "latent period," as "refractory period" (physiological insusceptibility), rhythmically, or as accompanied by a conscious correlate, according as we study the manifestations of the livingness from the standpoints respectively of chemical change, time-relation to stimulus, affectability, alternation of metabolic phase, or finally consciousness. Livingness is, from the bio-chemical stand-

point, bound up with the two-phased process of metabolism in which, while anabolism and katabolism are coexistent and mutually adjusted, it is generally possible, at any given instant, to say, with regard to most tissues, whether anabolism or katabolism is the predominating or characteristic phase. There would, then, be a functional inertia of katabolism (or katabolic inertia), a tendency for that phase pre-eminently to be continued after the reception of a stimulus tending to induce any other metabolic distribution (anabolism either equal to or greater than katabolism), and conversely, there would be a functional inertia of anabolism (or anabolic inertia), the tendency for that phase pre-eminently to be continued in spite of a stimulus of opposite nature. This power of maintaining the *status quo ante* of a particular phase of metabolism, I call the functional inertia of the protoplasm. As examples of katabolic inertia, there is that large class embracing all cases of local life, of organs, tissues or cells, after somatic death, the *post-mortem* expression of the functional inertia of katabolism, *e.g.* the muscle of the familiar "nerve muscle preparation," which still "acts" though removed from its nutrient lymph, the excised and isolated bloodless frog-heart beating on a glass plate for hours after the death of the animal, the isolated medullated nerves still giving evidence of conductivity for many hours after excision, the vivisected, non-nucleated portion of *Lacrymaria olor*,¹ and other *Protista*, the ciliated epithelium from frog's gullet living for days as an isolated patch, and even the isolated cilium itself exhibiting movements "till it perishes." In this class I do *not* include the cases of organs surviving by reason of perfused defibrinated blood, for here their metabolism is being constantly supported by nourishment applied under artificial conditions; but I would include all cases of organs isolated from all nervous and vascular connections, and surviving by reason of the perfusion of salt solution. No food is thereby introduced, the NaCl is powerless to prolong life indefinitely—no longer than the time when the katabolic inertia of the protoplasm shall have been spent. Of course organs and tissues still *in situ* in the dead body can exhibit their

¹ Verworn. "General Physiology." London, 1899, p. 570.

katabolic inertia; examples are numerous, *e.g.* the respiratory centres emitting impulses even after evisceration in Marmot (Marckwald), the *post-mortem* continuation of intestinal peristalsis, the medullated nerves remaining excitable three to four days after severance from the central nervous system, the growth of hairs, and all cases of local cell-life after death—spermatozoa in the vesiculæ seminales, cilia in trachea, etc., and amœboid leucocytes generally. All cases of *post-mortem* bio-chemical change are illustrations of katabolic inertia, *e.g.* the excised liver continuing to convert glycogen to dextrose, the isolated and bloodless muscle producing CO_2 in atmosphere of N or H, the tissues continuing to produce heat, to reduce deoxidisable material brought into contact with them, and the *post-mortem* formation of enzymes generally; also all cases of tissues living without food, whether it be total deprivation (starvation) or partial, as in the withdrawal of O_2 , or H_2O , are examples of katabolic inertia. Of course, it is not only in normal conditions that protoplasm exhibits its functional inertia—the very expression of its inertia, when not in harmony with the general well-being of the body, constitutes the “disease.”

Thus the Adipose Diathesis is the almost ineradicable and often inherited tendency of certain tissues to deposit fat; but this can be stated as accurately, thus—that fat-deposition is the result of a particular chemical expression of the functional inertia of certain forms of protoplasm, this particular expression of the inertia being “morbid,” in that it is abnormally long-continued and altogether excessive. Or, again, we have a pathological chemical manifestation of functional inertia of certain tissues in *Diabetes mellitus*. Their inertia expresses itself chemically in the excessive production of sugar—a tendency in many cases (as also in fat-deposition) not amenable to drugs (chemical stimuli), and morbid, in that it is a disregarding of the metabolic needs of other tissues, for such a quantity of circulating sugar is to them a poison. According to Professor Adami, the property of inertia of protoplasm is one of the essential conditions underlying the perverted “habit of growth” of certain cells which is responsible for many kinds of cancerous tumours. Professor Adami, both

in his paper on "The Causation of Cancerous Growths,"¹ and in a private communication, acknowledges that what he had, since 1896, called "habit of growth" in certain cells, which ought *not* to be proliferating then or there, is "based upon that principle of inertia" concerning which he quotes at some length from my original paper.²

I had early seen that it must be in virtue of the inertia of protoplasm that certain cells hold on their disastrous course of local growth, utterly oblivious to the vital needs of adjacent tissues, but I did not feel myself entitled to speak on matters pathological with that authority which belongs to a specialist in pathology. I felt sure the principle was capable of wide application, not only to problems in pathology but in embryology (and teratology), and in the study of inheritance in its widest aspects. Functional inertia seems as universal a property of living matter as is the inertia of non-living matter. In my original paper I used the term functional "momentum" as equivalent to katabolic inertia; I have not persisted in the use of the term, because of the very precise mathematical meaning ($\frac{1}{2}MV^2$) assignable to "momentum"; if, however, momentum be used without this exact signification, and merely as a synonym for "inertia of matter in motion," then there *is* a functional or protoplasmic momentum.

All those cases insisted upon by Heidenhain of organs performing their functions, especially glands secreting, either in the absence of blood or after extreme vasoconstriction, are clearly cases of katabolic inertia; the secretion cannot be indefinitely kept up after the blood-supply (= food-supply) has been cut off, the apparent independence is only temporary, the bloodless protoplasm indeed maintains its secretional *status quo ante*, but only so long as its katabolic inertia persists. Functional inertia expresses itself very markedly in the phenomenon known as "latent period" or "physiological lost time." In the case of stimulation of the cardiac Vagus, it is katabolic inertia that is responsible for the "latency." It is very well known that this stimulus does not take effect at once, but that the time of about a beat and a half (frog's heart) may

¹ "Brit. Med. Journal," 16th March 1901, pp. 624 and 626.

² "Brit. Med. Journal," 15th Sept. 1900 (paper read August 1900).

elapse between the instant of the application of the stimulus and the consequent cardiac inhibition. The heart, in other words, gives no "outward and visible sign" of the impending change of condition during, it may be, two beats—the time-expression of the katabolic inertia of cardiac protoplasm. It is shorter but demonstrable in the mammalian heart. Again, it is in virtue of the katabolic inertia of nonstriated muscle that there elapses the relatively very long time (latent period) of 18" before stimulation of the splanchnic nerve is followed by inhibition of the intestinal movements, *i.e.* induces the anabolic phase. Similarly, the phase of predominating katabolism having been induced, *e.g.* in cardiac acceleration, it will be maintained for 30" (frog-heart) after the withdrawal of the accelerating stimulus, in virtue of the cardiac katabolic inertia. Thus, as exhibited under the time category, functional inertia is that property of protoplasm in virtue of which it does *not* respond to a stimulus (the time of non-response or latency being longer or shorter according to the tissue and function, in the case of vegetable protoplasm relatively very long—an hour or more), and is thus the opposite property to affectability or irritability. Viewed under the category of non-response itself, functional inertia is the property underlying physiological insusceptibility, "refractory period" and allied states; it is thus the functional counterpart of irritability. It is by reason of the property of irritability that living matter responds to stimuli, but it is in virtue of its other property of functional inertia that it does not do so instantaneously. It is by reason of its affectability that the quiescent heart performs a systole on stimulation; it is by reason of its functional inertia that it performs a maximal systole—the "all or nothing" action, as it has been called, and in virtue of which the heart cannot be tetanised. Just as dead matter cannot be instantaneously caused to change its state, neither can bioplasm; by the inertia of its mass, or of its motion, "dead" matter tends to remain in the *status quo ante*; by the inertia of its livingness (in relative rest or in relative activity) protoplasm tends to remain in its (functional) *status quo ante*.

Passing to cases where there is a conscious correlate, we have, in the positive after-sensation, a good example of

katabolic inertia. An active state has been set up in an end-organ, and has thence been propagated into the central nervous system; a particular sensation is the conscious counterpart. The stimulus is now suddenly withdrawn, but, as is well known, the sensation does not equally suddenly cease—it persists as the + after-sensation due to the katabolic inertia of the tissues involved. This is well-marked in the case of sight, where the + after-image is the correlative in consciousness of the continued activity (post-stimulant) of the retino-cerebral protoplasm, *i.e.* its katabolic inertia. It is to this inertia that the beautiful modern illusions of seeing movement are due, in the instruments known as kinematograph (kinetoscope, mutoscope, etc.).

II. The functional inertia of resting protoplasm, *i.e.* of the characteristically anabolic phase (*anabolic inertia*) is quite as well marked, though there may not be so many familiar examples. We have just spoken of the + after-image; we have a good example of anabolic inertia in the negative after-image. After retinal activity—the katabolic phase—has existed for some time, the phase of relative rest, reconstruction must supervene, and this gives in consciousness the – after-image (reversal of black and white, complementary colours, etc.). Now very often this fades away and is succeeded by the + after-image, that again by the –, there being a series of alternating metabolic phases—the rhythmical or oscillatory expression of the retinal functional inertia, the analogue in living matter of the to and fro swing of the pendulum or the vibrations of the jelly.

Anabolic inertia is well expressed in terms of time-delay, by the familiar “true latent period” of the stimulation of muscle. The muscle is at rest or in its anabolic phase, and the functional inertia of this is exhibited in the no doubt short, but demonstrable, interval between the reception of the stimulus and the commencement of response. In striated muscle it is very short (less than $\frac{1}{100}$ ”), in nonstriated it is much longer, .5”; in other words, nonstriated muscle has greater anabolic inertia than striated, and this agrees precisely with the conception of functional inertia being the counterpart of irritability, for nonstriated muscle has less irritability than striated.

Regarding the inhibition of intestinal muscle through splanchnic stimulation as the establishment of the phase of anabolism, we have anabolic inertia expressed in the persistence of the state of relaxation after the inhibitory stimulus has been withdrawn. This post-stimulant relaxation may last for 25". Similarly, after the withdrawal of stimuli in cardiac inhibition, there is a (post-stimulant) "latent period" before the heart resumes beating, due to the anabolic inertia of cardiac protoplasm. The latent period that exists before secreto-motor effects in glands appear, is the expression of anabolic inertia in glandular protoplasm: in stimulation of vagal pancreatic secreto-motor fibres, it is as long as 15" to 3'. Verworn¹ tells us that "the motion of cilia does not begin at the exact moment at which the light strikes them," but only after a "latent period" of one to two seconds—this is anabolic inertia.

More especially expressed under the category of rhythm, we have all those cases of intermittent discharges or series of effects from an (apparently) single stimulus, *e.g.* Ritter's tetanus, Wundt's tetanus, and the strychnine tetanus. These are rhythmic expressions of inertia, comparable to the oscillations of the jelly consequent on a single tap given to it. Functional inertia may express itself in the *maintenance* of a certain rhythm of discharge of impulses, as has been brought out by Professors Horsley and Schäfer in their experiments upon the normal rate of discharge of cells of the spinal cord. They showed that whatever was the rhythm of stimulation, provided it was ten per second or more, artificially imposed upon the nerve-tracts proximal to the cells, the rhythm of discharge was always ten per second, *not more*. The protoplasm of these spinal cord cells has *its* own phase of physiological insusceptibility, its "refractory period," and no artificial rate of stimulation will accelerate the rhythm (provided the stimulation be below a certain intensity)—this is functional inertia. The anabolic inertia of the cells of the reflex "centres" of the spinal cord must be the principle underlying the insusceptibility to single stimuli, and the necessity for "summation" of stimuli before the

¹"General Physiology," p. 401. Macmillan: London, 1899.

action takes place. The nervous system, in common with other tissues, shows us many cases of insusceptibility, *e.g.* to drugs and poisons. The idiosyncrasy of one man to a given drug in that he is peculiarly insusceptible to it, is as well expressed by saying that, owing to the magnitude of the functional inertia of some tissue of his, the drug has no influence, while owing to the smallness of the inertia of the tissues of another man, the drug has considerable influence. The man whose cerebral protoplasm has much anabolic functional inertia, *e.g.* with respect to chloroform, will take a longer time to become anæsthetised by that drug than some other man whose protoplasm has less.

III. In the more characteristically psychic sphere, examples of functional inertia, psychic inertia, are numerous. A person appears taller than he otherwise does, if his clothing shows longitudinal striping—the idea of extension up and down occupies the mind, and we carry more of it over into the estimate of the person's height than we would have done had he been differently dressed—by its inertia (active phase) a given idea imparts to the subsequent one some of the characters of itself.

So in connection with the illusion as to the relative lengths of the lines *A* and *B*—the lines are of equal length, but *B* appears greater than *A*. Mental functional inertia seems to be responsible for the erroneous estimate. Owing to the manner in which the short converging lines turn back, as it were, upon the line *A*, they suggest the ideas of “backwards,” “the end reached,” “limited,” and

so on, so that in estimating the length of *A* there is a pre-existent disposition to see it short, limited, etc., evidently the effect on the notion (length of *A*) due to the (mental) functional inertia of the preceding idea—"end reached," "bounded," "limited," etc. Similarly, the short diverging lines on the ends of *B* suggest "extension," "outwards," "boundaries not fixed," and so on, hence we carry over into the next idea—length of *B*—by mental functional inertia some disposition to see *B* "long," "going outwards," or "upwards," "not bounded," and so on. Since in the notion, length of *A* by itself, there is a latent tendency to under-estimation, and in the notion, length of *B*, a tendency to over-estimation, we at once judge *A* shorter than *B* when the two ideas are present to the mind simultaneously.

The well-marked tendency to think, say, or do what has been thought, said, or done before—to yield to habit, to the familiar—is nothing other than the expression of the functional inertia of psychic activity. Quite a number of people, for instance, will say "thirty or forty" for "thirty or fewer" when in reading aloud they meet the latter phrase. The mental condition in hypnotism, where the suggestion has started a train of thought adhered to with astonishing tenacity, and worked out to its uttermost consequences in spite of all possible distractions, is surely well expressed as the inertia of psychic activity: the inertia—the obliviousness—has been by artificial means morbidly increased for the time being: it is an insusceptibility to all but a few stimuli, and may amount to actual sensory paralysis. So, too, it is mental inertia that causes certain persons to be refractory to hypnotic influence. But examples could be indefinitely multiplied. Are not bigotry and fanaticism respectively the inertia of psychic rest and the inertia of psychic movement? Superstition and an unenlightened dislike to change are surely due to the inertia of psychic rest. The lingering of superstition from generation to generation is an example of psychic inertia in the race—all failure to respond to intellectual environment, must arise from mental inertia. In the child-mind it is owing to the feeble degree of inertia of psychic rest and of psychic activity that it

exhibits so high a degree of suggestibility. The child-mind maintains for so short a time, and in so slight a fashion, any one course of action or set purpose, that almost any fresh idea (suggestion) from parent or play-mate can divert it into a fresh channel, and the new idea, in turn, can be easily supplanted by some other notion newer still. There is so little inertia of position belonging to the idea in possession of the mind that the idea can be very easily supplanted, and the new idea has so little momentum that it can be at once turned out of its course by some new thing. Thus a volatile nature is one with but slight mental inertia of movement; a "dogged" temperament is one with much. The great obstinacy of the uncultured, and the "fixed delusion" of the lunatic are cases of excessively developed inertia of psychic rest. Surely psychic anabolic inertia is responsible for the lack of correspondence between sensation and stimulus as formulated in the Weber-Fechner law; certain increments of stimulus *not* giving rise to any increase of sensation until certain intensity-limits are passed. The insusceptibility that exists through a whole series of increments of stimulus, from the last sensation-producing increment to the next one, seems one more instance of psychic inertia. Lastly, the differences in duration of reaction-time ("personal equation") between various kinds of people are directly due to the differences in degree of the psychic anabolic inertia of their cerebral cells.

The graphic record of reaction-time gives us a measure in fractions of a second of the degree of their cerebral anabolic inertia, but their whole characters are a daily and familiar exposition of psychic inertia of rest or of activity respectively.

THE LATENT LIFE OF PLANTS.

By R. A. ROBERTSON, M.A., B.Sc., F.R.S.E.

(Read 13th February 1902.)

The manifestation of plant life depends on certain external conditions, and in reference to these it is usual to make a distinction between the tonic and the stimulant effects. That particular combination of influences necessary