THE PSYCHOGALVANIC REFLEX: A REVIEW.

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(From work carried out at Cambridge for the Medical Research Committee.)

WALLER [45], during his investigations on the electrotonic changes of excitability of the motor and sensory nerves of man in 1880, noticed irregular galvanometric deflections, which at that time he could only explain as being due to slight alterations of contact between the skin and the electrodes caused by muscular movement. Féré [7] was the first to point out in 1888 that an emotional reaction was accompanied by electrical changes in the human body, demonstrable by galvanometric deflections, when the resistance of the body to a weak electric current was being investigated; he noted that these changes were correlated with the alterations in volume of the limbs as shown by the plethysmograph, but reported that the galvanometric deflections had been insignificant in the normal persons he had experimented upon, and were only established for hysterical patients. In Féré's opinion the changes were due to a lowering of the resistance of the body under the influence of emotional states.

In the same year, independently of Féré, Tarchanoff [42], working on the electromotive changes in the body, and using no external current, showed that the phenomenon was a normal one, and occurred in all healthy individuals, when two non-polarizable electrodes attached to asymmetrical parts of the body were connected up with a galvanometer. Tarchanoff concluded that "the galvanic phenomena observed in the skin, which are concomitant with different kinds of nervous activity, should be considered as due to an active state of the sweat glands, which at this time produce a secretory current."

The work of Féré and Tarchanoff remained for several years unnoticed, and it was not until E. K. Müller [24], an electrical engineer without any knowledge of the previous work, rediscovered Féré's phenomenon in 1904, and communicated his results to Veraguth [43], who gave the name "psycho-physical galvanic reflex" to the phenomenon, that any methodical research was carried out. Although Veraguth's term, now shortened to "psychogalvanic reflex," has come to be used indiscriminately for all electrical changes shown by the

galvanometer due to psychophysiological processes, it is necessary, in order to avoid the confusion in which some investigators of this subject have entangled themselves, to deal separately with the phenomena as reported by the original observers: (1) Galvanometric deflections due to production of some electromotive force when no external current is used (phenomenon of Tarchanoff); and (2) Galvanometric deflections due to apparent change of resistance when a weak electric current is passing through the body (phenomenon of Féré).

APPARATUS EMPLOYED TO DEMONSTRATE THE REFLEX.

(1) *When no external current is used.*—Tarchanoff [42] employed non-polarizable clay electrodes attached to the skin by means of hygroscopic pads saturated with saline solution. These were connected with a Meissner and Meyerstein galvanometer. The electrodes were applied at different times to asymmetrical parts of the body such as the hands and fingers, feet and toes, face and back, whilst the subject was kept at complete rest. Experimenting in this way he found that psychic stimuli, real and imaginary, provoked galvanometric deflections. Later, investigators have followed this method with but slight modifications. Sticker [41] repeated Tarchanoff's experiments in 1897, and Sommer [39] in 1902. Fürstenau [8] experimented on the physical nature of the phenomena and the effects of different electrodes. Sidis and Nelson [38] relied chiefly on platinum hypodermic electrodes, used a d'Arsonval galvanometer ("sensibility 225 megohms"), and took photographic records of the deflections; they showed that even from symmetrical parts of the body, in the case of the two hands, a galvanic reflex was produced. Gregor and Loewe [15] and Philippson and Menzerath [30] employed an Einthoven's galvanometer with photographic recording apparatus, the former relying chiefly on Ostwald's electrodes, and the latter on Einthoven's zinc sulphate electrodes.

Radecki [33], using zinc electrodes, got similar results with Lippmann's capillary electrometer, and found that the electromotive force produced was about 0.005 volt.

(2) *When an external current is used.*—Féré did not give any particulars of his method. The usual technique of most of the investigators is a modification of that employed by Veraguth. He introduced a d'Arsonval mirror galvanometer with a shunt into a circuit, through which a feeble electric current from one or two Leclanché cells was being conducted through the body, the places of entrance and exit of

the current being the palms of the hands, and the electrodes being nickel-plated brass cylinders. He measured the deflections of the galvanometer on a horizontal celluloid scale, on which the light from the mirror registered its movements. A similar technique, with the addition of a device for recording the deflections by hand on a kymograph, was adopted by Peterson and Jung [27, 28], using copper plates as electrodes, Ricksher [34] with brass plates, and Radecki [33] with zinc electrodes. Sidis and Kalmus [37], and also H. Müller [25], used liquid electrodes—glass vessels filled with concentrated saline solution, in which large copper electrodes of about 500 cm. area were permanently placed, and in which the hands or the feet could conveniently rest. Gregor and Loewe [15] were the first to take systematic measurements of the deflections in terms of apparent resistance, and compare it with the resistance of the body by means of a Wheatstone bridge. Waller [47, 49] independently has adopted this method as the most convenient for accurately determining the magnitude of the deflections in terms of ohmic resistance, or, reciprocally, of conductance, introducing also into the circuit a potentiometer delivering one-tenth of the E.M.F. of a Leclanché cell for purposes of calibration, by means of which the deflection can also be directly measured and expressed in terms of voltage; he passes his main current from two Leclanché cells through one hand, and applies the electrodes, usually zinc discs covered by chamois leather moistened with 0.6 per cent. saline solution—one on the dorsum and the other on the palm of the hand. By this method he has shown that the reaction expressed in terms of voltage may be 0.5 volt.

PHENOMENA OF THE REFLEX.

The only fact about which there is general agreement amongst the investigators on this subject is that the phenomena of the reflex have been definitely established, both with and without the use of an external current.

(1) *Galvanometric deflections due to psychical causes.*—Any stimulus giving rise to an emotion, such as the unexpected ringing of a bell, flashing a light, a pin-prick or a burn, after a certain latent period will cause a deflection which is proportional to the subjective state aroused. An actual stimulus is not necessary, the expectation of the stimulus is sufficient, and it is only necessary for the experimenter to walk behind the chair of the subject for a deflection to be produced. The threat of

a stimulus often provokes a greater reaction than the stimulus itself. Also calling up memories of painful experiences, or referring to questions concerning which the subject may have pin-pricks of conscience, will give a deflection.

(2) *Galvanometric deflections due to physical causes.*—Alterations in contact between the skin and the electrodes will cause deflections, but these are easily recognized. When using liquid electrodes, this deflection is always in an opposite direction, due to withdrawal of the hands or feet from the solution: when using metal electrodes, firm pressure on them can produce a very slight deflection in the direction of the emotional reaction, but muscular movement causing diminution of contact will produce a deflection in an opposite direction. These deflections can be distinguished by the fact that they take place immediately, and are not characterized by a long latent period.

(3) *Galvanometric deflections due to physiological causes.*—A deep inspiration, cough, yawn or sigh will produce a large deflection, whilst ordinary respiratory movements will not visibly affect the galvanometer. These deflections have a latent period of the same order as the emotive deflections.

(4) *Latent period.*—The latent period varies in different people, and in the same people at different times. It is of an average duration of two to three seconds. The periods recorded by different observers vary slightly, as some—Veraguth [43], Knauer [19]—make it longer, having measured the time from the commencement of the stimulus to the summit of the reaction, instead of to the commencement of the reaction, as is now generally done.

(5) *After-discharge effect.*—The reaction provoked by the excitation persists for some time. This time varies considerably in different persons; it may last only ten to twenty seconds, or it may persist for a few minutes.

(6) *Fatigue of reflex.*—After a stimulus has been repeated a few times it begins to lose its emotive effect, and very little reaction then occurs. It cannot be regarded as a true reflex fatigue. After a subject has been experimented upon for some time and has become familiar with the procedure, he may give no reactions until some new and unexpected stimulus catches him unawares.

(7) *Diminution of reflex as result of fatigue.*—The same subject will react differently to the same stimuli at different times of the day, and at the same times on different days, according as he feels in good or bad health. Physical or psychical fatigue diminishes the reflex.

Other important phenomena are that, when an external current is used, only the palms of the hands and the soles of the feet give a visible reaction, and that when no current is used the best reaction is given by a combination of left hand and right elbow. (Philippon and Menzerath [30].) When an external current is used there is a slow, constant deflection, indicating an apparent gradual increase in resistance when the electrodes are attached to the skin of the palms of the hands or soles of the feet, and an apparent decrease when they are attached to the skin of the forearms or legs. The apparent gradual increase in resistance was called by Veraguth "the curve of rest," and is now known to be due to a polarization effect.

NATURE OF THE REFLEX AS A PHYSICAL PROBLEM.

All investigators of the psychogalvanic reflex, having satisfied themselves of its reality, have admitted that the nature and causation of the phenomenon is an extremely complex one, and for the most part have only been able to put forward hypotheses to account for it.

In the case of deflections produced by emotional reaction when there is no battery in the circuit, the problem resolves itself into a physiological one to explain the causes for change of potential between the two electrodes.

But the physical problem is more complex when an external current is used, and great discussion has centred round the question as to whether the galvanic deflections are due to change of resistance or to the production of an electromotive force.

Féré's [7] view that the phenomenon was due to a lowering of the resistance of the body was tacitly assumed to be correct, and was upheld by Veraguth [43], who states: "The psychogalvanic phenomenon is an expression of the change of resistance of the skin under the influence of psychic phenomena." This explanation was accepted by Peterson and Jung [28], Ricksher and Jung [34], and Peterson and Scripture [29], without any definite experiments from this point of view. It was not contested until Sidis and Kalmus [37] reported that the phenomenon was definitely not of the nature of a resistance, but was essentially of the nature of an electromotive force.

Thus Sidis [36] states: "All our experiments prove incontestibly that the galvanic phenomenon is due to an electromotive force which is muscular in origin." Sidis's technique must therefore be examined in some detail. Sidis only employed [37] "a single cell giving a con-

stant E.M.F. of about one volt, which was sometimes replaced by a thermo-element giving only a few millivolts, and sometimes entirely removed from the circuit." But unfortunately he does not indicate what strength of current he used in the different experiments, beyond the fact that in most of the experiments on which he relies for his evidence he used no cell at all, and was therefore only dealing with an electromotive force. The strength of the current used in eliciting the reflex is however an important factor, and seems to have been ignored by previous investigators. I have shown in experiments, not yet published, that it is possible to diminish the reaction *pari passu* with the diminution of the current, and practically to abolish the reflex altogether, except for the slight one due to electromotive force, by reducing the current sufficiently. Therefore, if Sidis used a current of only a few millivolts, he would probably get a reaction due to electromotive force only, and not to change of resistance.

Secondly, Sidis, referring only once in all his experiments [37] to the latent period, which he found to be variable, but of the order of magnitude of a few seconds, confesses that "no attempt was made to study accurately such latent periods," and he omits to indicate what the latent periods were in his crucial experiments, nor had he any photographic records for this part of his work. As investigators have come to regard the latent period of an average of two to three seconds following the stimulus as the direct proof of a genuine galvanic reflex, and we know that muscular movement can produce a galvanic deflection, there is no *prima facie* evidence that Sidis in some of his experiments was investigating the psychogalvanic reflex at all. Thirdly, to complete our criticism of this part of Sidis's work, it is well recognized that the galvanic reaction following muscular movement occurs immediately after the stimulus, and is, when using liquid electrodes, in an opposite direction to that caused by the emotional reaction. Moreover, it has been clearly shown by Waller [48] that large reactions are obtained without any muscular movement visible on a myograph of sufficient delicacy to indicate the movements of the pulse. Sidis's theory that the phenomenon is due to an electromotive force of muscular origin can therefore be disregarded. Albrecht [3] also held the view that there were two factors in the causation of the phenomenon, and that of these the electromotive force was the more important.

That the phenomenon is due to an apparent diminution of the resistance of the body or skin, and not to the production of an increased electromotive force within the body, is evident from the following experiments:—

(1) As was pointed out by Radecki [33] and others, the deflection remains the same, and is in the same direction when the electrodes themselves are changed from one hand to the other. If the deflection was due to an electromotive force, then under these conditions the direction of the deflection would be reversed.

(2) Waller [48], using a current from two Leclanché cells (2·8 volt), has shown that the deflections may be of high apparent voltage (0·5 volt and above), whereas Radecki [33], using Lippmann's capillary electrometer, showed that the reactions due to electromotive force only averaged 0·005 volt.

(3) Waller [48] has shown that "during a persistent emotive deflection of high voltage, a superadded deflection, caused by throwing in an additional calibrating deflection, is augmented in proportion with the augmented conductivity."

(4) The experiment I have recorded above, namely, reducing the current sufficiently to abolish the reflex. If the reaction was due to electromotive force, then this procedure should increase the reaction instead of decreasing it.

Having decided that the phenomenon in the presence of an external current is due to an apparent diminution of resistance, the next question is whether the apparent resistance is one of the body or of the skin.

The determination of the resistance of the body to an electric current is a complex problem, for it depends on the degree of polarization and the number and nature of the ions which enter the tissues. We know, from the results of electrotherapy by ionization, that the glandular orifices are the probable channels by which the ions and the electric current penetrate the body. Leduc [20] has shown that with the same electrodes we get varying resistances with different active ions, and Girard [13] has shown that the permeability of the skin is not the same even to the same ions, as the skin and all the membranes are susceptible of giving rise to polarization. Any experiments on the resistance of the body must therefore take into consideration these polarization effects. Weiss [53] has devised an arrangement for measuring this polarization, and found a potential of 0·2 to 0·25 volt due to polarization of the tissues of the body. It is probable that this polarization effect varies considerably in different persons and in different parts of the body, and our psychogalvanic reflex experiments must make us suspect that it is at any rate often much higher in the palms of the hands and the soles of the feet. Gildemeister [10] claims that it is

possible to produce a contrary electromotive force due to polarization effects of two volts in the frog and of six volts in man.

With an alternating current the phenomena due to the polarization effects are reduced to a minimum. It has recently been shown by Gildemeister [12] that the resistance of the body varies according to the method of measurement. With the constant current the resistance depends on the duration and intensity of the current; with alternating currents the resistance is smaller the greater the frequency. After the removal of the skin the variations are smaller, whilst observations on the skin alone show the fluctuations just as the intact body does. It was pointed out by Aebly [2], working under Zangger, that the resistance of the body by Kohlrausch's method remains the same whether or not a current was passing through it, and that the resistance of the body to the alternating current does not alter under the influence of emotional reaction. By analogous experiments Gildemeister [9, 11] demonstrated the presence of the psychogalvanic reflex without any alteration in ohmic resistance, and Schwartz [35] got identical results in the frog.

It is now obvious why a diminution in the strength of the current reduces, and may if sufficient practically abolish the large reaction usually obtained when using a current of about 2 volts, for alterations of the current will affect the polarization of the skin.

We can, therefore, definitely exclude bodily resistance as a cause, and point to the polarization of the skin as the chief factor in the production of the reflex.

Knauer [19], in his criticism of Veraguth's book, "*Das psychogalvanische Reflex-phänomen*," got very near to this view, but it was H. Müller [25], and Aebly [2], who first drew attention to the phenomena of polarization and recognized that the reflex was a polarization effect; they held that the increase in conductivity of the body was due to a diminution of the electromotive force of polarization, and this view was upheld by Piéron [31], and in part by Gregor and Loewe [15]. The polarization effect then might be due to a diminution of the electromotive forces of polarization, as held by Müller, Aebly, and Piéron, or to a diminution of the resistance set up by the membrane where polarization occurs. Waller [48] has settled this point by the experiment here quoted. "If a potentiometer is put in series with the subject in the fourth arm of the bridge, we shall obtain indications that will enable us to decide between the two alternatives—electromotive force increased or resistance decreased. If the former, a known E.M.F. from the potentiometer should give the same deflection before and during an

emotive change. If the latter, the potentiometer deflection should be increased during the emotive change. And in point of fact this second alternative is what actually occurs; whenever I have measured the resistance in ohms before and during emotive excitement, I have found that the potentiometer deflection was inversely proportional with the resistance." We must conclude, therefore, that the psychogalvanic reflex in the presence of an external current is brought about by a diminution of the resistance of the skin due to the effect of polarization, and that this polarization is influenced by an emotional reaction.

PHYSIOLOGICAL PROCESSES CONCERNED IN THE CAUSATION OF THE REFLEX.

The physiological processes that will have to be considered as being possibly concerned in the causation of the reflex, both as causes for the change of potential between the electrodes when using no current, and as causes for the changes in the polarization of the skin in the presence of a current, are: (1) Unconscious muscular movement; (2) changes in the capillary circulation; (3) respiratory changes; (4) secretory activity of the skin; (5) nervous excitation through the intermediary of the cerebrospinal or automatic nervous system; (6) biochemical changes in the skin, or to a combination of these. But slight changes sufficient to cause a difference of potential, such as currents of action due to unconscious muscular movement or secretory activity, which may be the concomitants of emotion, are not sufficient to account for the large changes obtained when a current is being used.

(a) *Reflex due to production of an electromotive force.*—Investigators who have given theories to account for the changes of potential are Tarchanoff [42], Sticker [41], Sommer [39], Sidis and Nelson [38], Radecki [33], and Philippon and Menzerath [30].

Tarchanoff relied entirely on the activity of the sweat glands to account for the phenomenon, and explained the galvanometric deflection as being due to a secretory current. He showed that by placing non-polarizable electrodes on different parts of the body the area most rich in sweat glands became negative to the less glandular area. This question of the activity of the sweat glands must be taken up later when dealing with the processes concerned in the presence of a current.

Sticker repeated Tarchanoff's experiments, and, whilst not opposing his secretion theory, held that the changes in capillary circulation also played an important part; he based his view on the work done by

Hallion and Comte [16] on the influence of emotion on capillary circulation. Radecki's experiments support Sticker's theory; his conclusions are that the reactions are due to changes in the circulatory and secretory systems; that the changes of potential result from discharge of electricity which takes place during glandular activity, and that these changes depend directly on secretory and excretory processes, and indirectly on the capillary circulation. Though it cannot be denied that the above processes do cause changes of potential, there are serious objections to considering any of them as the specific cause of the psychogalvanic phenomenon. As Sidis [37] has shown, when using no current, exclusion of the skin by the use of hypodermic needle electrodes, or covering the skin with shellac and paraffin, leaving only the nails exposed, does not prevent the occurrence of a galvanometric deflection. Also exclusion of the circulation, in man by means of an Esmarch's bandage and in the frog by ligation of the arteries supplying the limb, does not materially affect the reaction. Sidis and Nelson [38], on the other hand, having excluded the skin and circulation, claim that the phenomenon is exclusively muscular in origin. They have recorded some very careful experiments from this point of view, and showed the presence of galvanometric deflections due to muscular contraction when the other causes were excluded. But the difficulty in accepting Sidis's conclusion is that these experiments were done on animals; that they do not mention anything at all about the latent periods, nor is it possible to deduce them from their records, and that they did not try any experiments in man from the point of view of excluding muscular contraction and leaving the skin as a possible factor. They relied on the fact that the deflection was abolished in the curarized frog. It is possible that they were in reality investigating the currents of action due to muscular contraction, and were only repeating the classical experiments of Du Bois Reymond [6]. The most recent work has been done by Philippson and Menzerath [30], who conclude as the result of their experiments that the origin of the difference of potential causing the galvanometric deflections during emotional excitement cannot be attributed to any one specific cause. They hold that it is due to the following combination of causes: (1) Exclusively cutaneous by changes in the activity of the sweat glands or in the chemical products secreted; (2) musculocutaneous when the right hand becomes positive to the left, which phenomenon they explain after Du Bois Reymond [6] as being due to the distension of the skin following involuntary contraction of the right hand; (3) exclusively

muscular. They also confirmed Tarchanoff's [42] statement that there is no correlation between the reflex and respiration, for the pneumogramme and the electrogramme do not show any parallel. It would seem *a priori* that the same changes in the skin which will account for the reflex in the presence of a current would also set up a difference of potential and produce the electromotive force reflex. The evidence to be put forward as the result of experiments with an external current tend to prove that none of these causes can be regarded as the exclusive cause of the reflex, and at present the problem is still unsolved.

(b) *Reflex due to change of resistance.*—Muscular movement can be definitely excluded by the experiments already cited.

The effects of circulation as a specific cause may also be excluded, for the reaction is not appreciably affected by the application of an Esmarch's bandage, as originally shown by Veraguth [43]. In spite of these experiments, Radecki [33] still maintains this view. He holds that the reflex is due to a vasodilatation provoked by a psychic excitation, and that the changes in the circulation cause an increase in gaseous exchange in the organism and thereby increase the conductivity. It is true that vaso-dilatation may cause a reaction in the same way that a forced inspiration will, but it is not the cause of the galvanic reflex.

The influence of the respiration deserves more attention than has yet been given to it. A deep inspiration, a cough or a yawn produce a most marked effect, often greater than that produced by emotion, whilst ordinary respiratory movements do not affect it. At first sight it would seem that here we might have an explanation of the phenomenon; but in an extensive study on this question, Peterson and Jung [28] have shown that there is no constant relation between galvanometric and pneumographic curves. They conclude: "When the emotions are very labile and show the most marked excursions in the galvanometer curve, the respiratory curve is often regular and even. On the other hand, where the galvanometer curve is marked by little fluctuation, or even by none, there will often be most decided variations in the pneumographic curve." These authors, referring to the rise in the galvanometric wave due to inspiration and coughing, state: "We are inclined to think that this rise may also be psychic, that is emotional. Certainly, in the curve we observe exhaustion by repetition of the command to cough or breathe deeply, as in the case of other analogous stimuli." It would seem more likely that the exhaustion in these experiments, which is, however, slight after fifteen deep inspirations and fourteen coughs, is

due to physical fatigue, and that the change in polarization of the skin produced by a deep inspiration is a purely physiological effect. If this is the case, then the changes in the skin due to a deep inspiration or coughing are analogous with the changes produced by emotion, but they are independent of each other. However, a study of the biochemical changes in the skin due to forced respiration might possibly give us the key to the psychogalvanic phenomena.

The theory which has been most strongly supported is that the phenomenon is due to alterations in secretory activity. Veraguth [43] supposed that the seat of the change of conductivity was the skin, and thought that this conductivity changed, for the following reasons: "The cells of the body, like colloids surrounded with a membrane, ought to show, each in its own particular way, a specific obstacle to migration of the ions. This way varies in the same cells, both according to general tone and according to the alterations in their state brought about by excitation." He excludes participation of the perspiration itself, for the results were similar in hands made dry with formalin, but he does not exclude secretory activity. He quotes one case in which he placed a belladonna plaster on his subject for three hours, then took it off and rubbed the hand with liquid extract of belladonna, and found that the psychogalvanic reflex was diminished.

Peterson and Jung [28] attribute the phenomenon to a secretory activity. "It would seem that the sweat glandular system is the chief factor in the production of this electric phenomenon, inducing on the one hand under the influence of nervous irritation a measurable current and on the other hand altering the conductivity of the current. Change in resistance is brought about either by saturation of the epidermis with sweat or by simple filling of the sweat gland canals, or perhaps also by intracellular stimulation; all of the factors may be associated." This view has been very generally accepted. Gildemeister [9], and more recently Philippon and Menzerath [30], have accepted this explanation, relying apparently on the experiments of Leva [21].

Leva found that in ten subjects a subcutaneous injection of 1 mgrm. of atropine sulphate entirely abolished the reflex; that directly after the injection, and for the next ten to fifteen minutes, the galvanometer deflection was of the usual order, but that after fifteen to twenty-five minutes it diminished rapidly, and after about thirty minutes even the strongest stimulus gave no reflex. The results of Waller's experiments from this point of view [50] are directly opposed to those of Leva. Waller states: "I have taken great pains to satisfy myself about the

action of atropine upon the emotive response, and have failed to find any evidence that it possesses any action at all upon the response." This view is supported by the experiments of Markbreiter, working in collaboration with Waller [22]. In one of these experiments, even after an injection of 2 mgrm. of atropine sulphate into the palm of one hand, when the usual pharmacological action was marked, no effect was produced on the galvanic reflex, and equal responses of the usual order were obtained from both hands. The inconsistency in the results of Veraguth, Leva and Waller seems difficult to explain. Neither Veraguth nor Leva give any photographic records of their experiments, nor any detailed accounts of their technique. Certainly in Veraguth's experiments the electrophysiological conditions did not remain constant during the test. It is possible that Leva, who used non-polarizable electrodes, was only dealing with a deflection due to a small electromotive force, caused by a current of action due to secretion, the nature of which was determined by Hermann [17] in his experiments on the forearm. In this case Leva was only repeating experiments analogous with that of Hermann [18], who showed that atropine suppressed the ascending current due to secretory activity, which was normally produced by excitation of the sciatic nerve in the curarized cat.

Further confirmation of Waller's atropine experiments is afforded by his results with pilocarpine and the calcium chloride capsule experiments, devised by him [46] for the measurement of insensible perspiration. He has demonstrated [50] that an increased emotion, as shown by the galvanometer, is not necessarily accompanied by an increased secretion, and in fact in the four experiments on the same subject which he quotes the contrary was the case, and an increased emotive deflection was accompanied by a decrease of secretion. Waller concludes: "While it is no doubt true that the deflection is due to diminished resistance, and that perspiration causes diminished resistance, it does not follow logically that the deflection is due to perspiration, since there are many occasions on which the emotive fall of resistance occurs without augmentation of either sensible or insensible perspiration." Waller's evidence is so strong that we must conclude that the change in polarization, and consequently the psychogalvanic reflex, does not depend on the secretory activity of the skin.

There remain therefore only the influence of nervous excitation, through either the cerebrospinal or autonomic nervous system, and changes in the biochemical processes in the skin dependent on them, to account for our reflex. Very little work has been done from these points of view.

V. J. Müller [26], in researches on the *Macacus cynomolgus*, found that the reflex was suppressed by perineural injection of an anæsthetic round the nerves supplying the palmar surfaces of the upper limbs, but that in man the reflex was not suppressed, but only diminished. Section of the nervous trunk gave an immediate suppression, and this suppression lasted while the electrodes were in contact with the palmar surfaces, but at the end of some time the dorsal regions, which did not previously give reactions, then gave them. This is not explainable, and has not been followed up by further work to verify this result. Sticker [41], working only on Tarchanoff's phenomenon, noted that the reaction occurred in both anæsthetic and analgesic skin areas, organic and functional, but there is not sufficient information on this point in regard to Féré's phenomenon. Any further consideration of the physiological nature of the reflex must at the present time be hypothetical. Waller's view is that the emotive phenomena belong to nutritional or trophic changes in the course of metabolism, that "it is a sudden brief intensification of a slowly fluctuating state in nutrition," and imagines "the changes as brought about through what we are accustomed to designate as 'trophic' nerve fibres." He is now investigating the subject from this point of view.

Meanwhile we must conclude (1) that the ultimate nature of the reflex is still an unsolved problem; (2) that muscular, vasomotor, respiratory and secretory changes may be concomitant with emotional reactions, but that none of them is exclusively responsible for the psychogalvanic reflex; (3) that the probable cause is to be found in the biochemical changes in the skin, which are brought about by nervous excitation, but that there is no evidence to show what is the nature of these changes, or through what nervous channel this excitation takes place.

CLINICAL AND PSYCHOLOGICAL STUDY OF THE REFLEX.

The psychological problems involved in a study of the psychogalvanic reflex would seem to open up wide fields for inquiry, and yet on this side little systematic work has been done. Whatever may be the actual nature and causation of the phenomenon, it still remains for the psychologist to determine its significance, and also the conditions under which it varies, and to investigate the mental processes concerned in its excitation. The difficulty in interpreting the results of different observers is, firstly, that they are obtained under varying electrophysiological conditions, and are not directly comparable; and, secondly, that

the usual variations obtained between different individuals are not much greater than those obtained in the same individual at different times under different conditions of health; and, thirdly, that no standard measurement under constant electrophysiological conditions has yet been determined by any observer for this amount of variation in the same individual.

Waller [49] has worked out the periodic variations of conductance of the palm of the hand for one subject, and has found that they have a diurnal periodicity, the resistance being greater during the night than during the day. The question as to whether there is any constant relation between the strength of the psychogalvanic reflex and the apparent resistance of the skin as determined at the beginning of the experiment must remain open. Waller [49] thinks there is, but is not yet able to state it with complete numerical evidence. On the other hand, Ricksher and Jung [34] state that there is no relation between the two. If this question were settled in favour of Waller's assumption, then equally valuable evidence from a clinical point of view might be afforded by recording the apparent resistance of the skin, without any observation of the reflex itself. This would be a continuation of the original work of R. Vigoroux [44], who pointed out in 1879 that the resistance of the skin was considerably diminished in cases of exophthalmic goitre, and increased on the anæsthetic side in patients suffering from hysterical hemianæsthesia.

The observations which have been made from the clinical standpoint are mainly on the value of the reflex in the diagnoses of hysterical conditions, particularly hysterical anæsthesia, and also in the differentiation of the psychoses. Veraguth [43] has recorded cases of tabes, syringomyelia, &c., to show that, after painful stimuli in anæsthetic and analgesic skin areas of organic origin, there is no psychogalvanic reaction, when the stimuli are not appreciated subjectively by the patient as such. He has shown the importance of bandaging the patient's eyes and of giving no verbal indication of the stimulus during such experiments. If the patient could see or hear the approach of the stimulus, a normal psychogalvanic reaction was then given after stimuli in the anæsthetic and analgesic areas, due to the psychical effect of expectation. He also records one experiment with a cat, in which the reaction was abolished during ether narcosis, and in which, after dividing the spinal cord in the lumbar region, and allowing the cat to regain consciousness, a painful stimulus to the tail gave no reaction, whilst one to the front paw gave the usual reflex. He showed, on the

other hand, that stimuli in anæsthetic skin areas of functional origin always gave the usual reaction, and this has been the experience of all observers. I have also made use of the reflex for the purpose of diagnosing a functional amnesia from an organic one, and in one case in which the patient had a complete loss of memory for all his war experiences, I was able, by means of his galvanic reactions, to trace out roughly the history of the patient's movements during the war, and to determine the place where he was "blown up." In addition, I have used it as the only trustworthy test to decide whether a deafness is a true organic one or not; the amount of functional deafness in organic cases can be determined in this way. If the patient states that he does not hear the stimulus, but at the same time gives a reaction, then that amount of deafness is functional. It is impossible to state at present whether in these cases a negative reaction always indicates an organic deafness, but, by analogy with the cases of organic anæsthesia, it seems probable that this is the case.

Before studying the variation of the reflex in the psychoses, it is necessary to investigate the mental processes concerned in its excitation. So far it has been tacitly assumed that the reflex is simply an indication of an emotional reaction. Though it is easy to show that all emotional stimuli provoke galvanometric deflections, it is not so easy to say whether the deflections provoked by the psychical stimuli may not also be due to the effects of intellectual processes. Radecki [33] concludes that "the phenomena take place in the human organism exclusively as an expression of our emotions and affective states." Binswanger [4] has also expressed a definite opinion on this question to the effect that "among mental activities only the affective processes, in Bleuler's sense, have any influence. Intellectual work or simple sensory impression have no effect." On the other hand, it is the experience of most observers (Peterson and Jung) [28], Veraguth [43], Starch [40], Gregor and Gorn [14], that mental effort does produce a small reaction. Starch [40] concludes that "all the different types of mental processes produced by the various stimuli were accompanied without exception by galvanometric changes. Emotional processes and muscular activity produced the widest deflections, while habitual mental activity and the process of visual attention produced the least deflections. Quiet mental activity, even when involving considerable effort, produced small galvanometric changes. The degree of intensity of emotional experiences corresponds very closely with the amount of deflection." It is impossible to say how much affect accompanies an intellectual process

such as an arithmetical calculation, due to the effort of attention. Very often a strong affect is produced by the surprise at the question, or by the embarrassment and possible annoyance that the solution of the problem may be incorrect, and this can only be decided by introspection on the part of the subject. Even if a pure intellectual process does produce a reaction, it is very small, and is in no way comparable with the deflections produced by an affective process, so that for all practical purposes it may be considered that among mental activities only the affective processes have any influence in exciting the reflex. This is also confirmed by the fact that after repetition of the stimulus, thereby reducing its emotive effect, the reflex becomes correspondingly diminished.

The next question, which does not seem to have occupied the attention of any of the observers, is whether the deflections are not equally due to the attempt to suppress the emotion aroused, and to prevent it from operating. As Waller [49] puts it, "the more perfectly an examinee can control the visible signs of the emotion, the more violently is the galvanometer deflected through the palm of the hand by reason of his suppressed emotion." Waller only makes this statement in support of the fact that the palmar electrical sign is not under voluntary control, but it would seem to have a greater significance than he attaches to it. Waller [51] is of the opinion that the phenomenon is not a psychogalvanic reflex, and prefers not to use the prefix "psycho," because in his view the phenomenon has nothing to do with the conscious mind. He states "it is not a cortical phenomenon, it is a subcortical phenomenon." I have been led to think that there is a constant correlation between the visible signs of emotion as shown by muscular movement, which is under voluntary control, and the psychogalvanic reflex, which is not directly under voluntary control. The greater the visible signs of emotion, and the greater the muscular movement, the less is the response on the galvanometer. From this point of view a high psychogalvanic reflex would indicate not merely an emotive response in Waller's sense, but in addition an increased sensitiveness on the part of the subject which may be partly due to experimental conditions and also an increased power of control. Whereas a low reflex would indicate that the subject was of diminished sensibility or had little control over his emotions, it might also mean that the subject was of low emotivity, as Waller says, but it would not necessarily be so. In my view then the phenomenon is as much cortical as subcortical, and is not a true indication of the emotivity of the subject.

Not only has the psychogalvanic reflex been evoked by emotional reactions concomitant with mental causes known to consciousness, but also it has been shown by Morton Prince and Peterson [32], Peterson and Jung [28], Binswanger [4] and others, that stimulation of ideas in a state of repression in the unconscious ("complexes") will also produce a reaction. Morton Prince and Peterson carried out experiments on Sally Beauchamp in her different states of personality, and showed that a memory of an experience which could not be recalled to consciousness provoked the usual reactions; they also showed that the reaction was the same in hysterical anæsthesia as in the normal, and that objects in the peripheral field of vision not consciously perceived were recognized sub-consciously (with Prince "co-consciously"). Radecki [33], working with Abramowski, showed that reactions could still be obtained through the sub-conscious by giving stimuli whilst the attention of the subject was concentrated on some mental problem, when the subject was not able to recall the fact that such stimuli had been given. Peterson and Jung [28] and particularly Binswanger [4] have done elaborate experiments on "association" tests to show that the galvanic phenomenon, like reaction time and alteration of reproductions, may give evidence of the existence of an unconscious "complex." These reactions have been so marked that they have given it as their opinion that reactions are evoked particularly by "complexes," and they have used it extensively as a "complex" indicator. Binswanger points out that an existing affect or lasting concentration of the attention on matters irrelevant to the experiment inhibits the psychical elaboration of the stimulus, and that, therefore, under these conditions the stimulus does not provoke much emotive reaction or give a psychogalvanic reflex. Prolongation of reaction time without a corresponding increase of the galvanic reaction may occur when there are purely intellectual difficulties, such as indistinct perception of the stimulus word, but more frequently under the influence of perseveration. Increase of the psychogalvanic reflex without corresponding prolongation of the reaction time may occur for purely linguistic reasons, when a genuine emotional reaction takes place, but is masked if an easy reaction word is at hand, favouring a habit reaction or sound association. In the latter case the galvanic reaction is the only way of discovering the real significance of the stimulus word. This significance is often not known by the conscious mind and can then only be established with certainty by psycho-analysis. The psychogalvanic reaction is therefore a much more delicate and correct "complex" indicator than the "reaction time" test.

The influence of hypnosis on the reflex has been recorded by Moravcsik [23]. He quotes only one case, but this is a particularly interesting one, from the fact that the reflex was almost completely abolished as the result of suggestion. The reaction to a pinprick, after the suggestion that the hand was hypersensitive, corresponded to 35 mm. on his scale, and after the suggestion that his hand had become anæsthetic the reaction was only 5 mm. After the suggestion that the subject was deaf and blind, auditory and visual stimuli provoked no reactions at all. This result is difficult to explain, and is not in accord with our usual experience of functional anæsthesia and deafness in hysterical cases. Also it is not in accord with the experience of Morton Prince and Peterson [32], already quoted. I got different results in some experiments I did with Waller two years ago, which were not reported, but of which photographic records were taken. These subjects, three men and one girl, had been hypnotized by me previously to the experiments two or three times, and were able to go into the somnambulic state quite easily; one of the men had had three teeth extracted and an operation for whitlow, and the girl had had two teeth stopped, with the extraction of a live nerve from one of them, under hypnosis, without any visible signs of the perception of pain or conscious memory of the operation. Records were taken both in the normal and hypnotic states, and there were no appreciable modifications in the galvanic reactions, either to painful or auditory stimuli. Moravcsik does not record the normal reactions of his subject, and does not state whether the subject was previously acquainted with the experimental conditions of the reflex. It would, for instance, be easy for a subject who had become acquainted with the physiological processes causing a deflection, and who gave normally a small deflection, due to familiarity with the stimuli, to produce a big deflection by taking a deep inspiration. On the other hand, there are undoubtedly some persons who can influence the rate of their pulse, and possibly even the surface temperature of their body by suggestion. Moravcsik [23] has recorded one such case in which the pulse-rate was altered from 84 to 104 and the temperature from 37.3° C. to 38° C. Presumably such subjects would be able to influence indirectly the psychogalvanic reflex. That voluntary effort can in certain cases affect the reflex in the direction of diminution is claimed by Radecki [33], who thinks that this effect is due to the influence on respiration, and also to the fact that voluntary effort produces attention which interferes with the emotional reaction evoked. The most probable explanation would seem to be that the

attention necessitated by voluntary effort prevents the full psychical elaboration of the stimulus, and consequent production of emotion, and therefore the galvanic reaction is diminished.

The effects of different stimuli vary in different individuals. In some there is a greater reaction to actual sensory stimuli, such as pin-pricks and burns, than to stimuli involving the ideational processes, such as the expectation of a burn or the recalling of unpleasant memories. These differences appear to have some diagnostic value. It is difficult at present to compare quantitatively the reactions of different individuals, as the electrophysiological conditions are rarely comparable, but general conclusions can be drawn from the work of different observers. In respect to data concerning the latent period the conditions are more comparable. They can be recorded with accuracy in the case of sensory stimuli, but in the case of stimuli where associative elaboration takes place it is impossible to say exactly when the emotive effect begins. All observers are agreed that the latent period in healthy persons may vary from one to five seconds. Peterson and Jung [28] have recorded that the latent period is lengthened in cases of dementia præcox, with katatonia. Abbott and Wells [1], in an investigation on maniacal-depressive stupor, have reported that "the latent times to sensory stimuli observed under stupor are within normal limits," and that the "perceptive processes in conditions of maniacal-depressive stupor are but slightly lengthened from the normal. The retardation may lie in a lessened complexity of the associations formed, or in the slower and feebler conversion of these associations into their motor expressions.

An important question is as to whether there is any correspondence between intellectual development and the quality and quantity of the psychogalvanic reflex. There certainly appears to be some correlation between intellectual development and the reactions to the two different classes of stimuli. The greater the intellectual development the more pronounced are the reactions to ideational stimuli. The same condition exists in cases of anxiety neurosis; whereas in cases of conversion hysteria the reactions to sensory stimuli appear to prevail over those due to ideational stimuli, but there is not sufficient data forthcoming to decide this with any certainty. M. D. Waller [52], as a result of her investigations on seventy-three medical students, concludes that intellectual efficiency as judged by examination results is associated with higher nervous sensitiveness in the psycho-galvanic reflex. It is certainly my experience that the reactions in subjects of poor intellect, as evidenced by their low standard at school, are rarely so marked as in

my intellectual subjects, and I have attributed this to the fact that the intellectual subject has usually a much greater control over his emotions and has a wider range in the association of ideas. Claparède [5] has reported experiments on four idiots of the lowest grade, in whom no psycho-galvanic reflex of any kind was obtained even after painful stimuli, in spite of the fact that the stimuli were perceived and were responded to by marked muscular reactions.

Gregor and Gorn (14) disagree with Claparède, and quote one case in whom they obtained normal reactions to sensory stimuli.

The chief work on the psychoses has been done by Peterson and Jung [28], Ricksher and Jung [34], and Gregor and Gorn [14]. Peterson and Jung have reported experiments on eleven cases of dementia præcox. They observed nothing especially noteworthy in the hebephrenic type, but in the katatonic forms, especially the acute forms, they observed variations from the normal, both in the quality and quantity of the reflex, the chief observation being that there was almost no reaction at all in acute katatonic stupor. They consider that this result is due to the fact that "the entire psychic activity is bound up with the morbid complex." This explanation might be plausible if it were not for the fact that a similar result can be obtained in other forms of insanity, arteriopathic dementia for example, and according to Claparède in idiots, so that this result would seem to be more in accord with the auto-intoxication theory and deterioration of the cerebral cortex. Gregor and Gorn have reported similar results in dementia præcox. They found that the reactions became less as the disease advanced, but that the reactions reappeared as the patients began to come out of the stupor, and became greater as the patients began to improve. On the other hand, in transitory psychogenic stupors the reactions were normal.

The reactions were also small in cases of hebephrenia, and the reactions to pain stimuli were greater than those to other stimuli, whilst in hebephrenic maniacal excitement the reactions were practically absent. A similar picture was obtained in cases of general paralysis. In manic-depressive cases the reaction was reduced at the height of the depressive phase, but in all cases of mania there was a very marked reaction. Gregor and Gorn concluded that "the observation of the psychogalvanic reflex has a definite clinical value: (1) in judging the effects of impressions in stuporose and inaccessible individuals; (2) in distinguishing benign psychasthenic 'regression' from similar conditions in the course of progressive maladies; (3) the objective characterization of affective conditions as a criterion of affective sensibility; (4)

the prognosis of melancholia and katatonia; (5) distinguishing maniacal states due to paralytic or hebephrenic excitement; (6) the diagnosis of malingering."

In conclusion, it can only be said that a very good case has been made out for further investigation into the psychological study of the psychogalvanic reflex. The observations so far recorded are small and the opinions of the observers are often conflicting. But it would seem that we have in the psychogalvanic reflex a valuable objective sign, which may be able to help us in the elucidation of the many unsolved problems in psychological medicine, and which we cannot afford to disregard.

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