ANALYSIS OF 'LOCALISATION,' ILLUSTRATED BY A BROWN-SÉQUARD CASE.

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§ 1. *Present obscurity concerning the 'localising' process. Elucidation hoped from a remarkable 'Brown-Séguard' case recently admitted into the Nerve-hospital at Leipzig.*

§ 2. *History of the patient. Surgical operation. Prolonged series of tests.*

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§ 1. *Introductory.* It would be superfluous to dwell upon the psychological and philosophical importance of the problem, as to how we manage to feel the position of our limbs; or, more precisely, as to how our tactile sensations come to be endowed with 'thereness.' The earliest systematic investigation into the matter seems to have been

that of E. H. Weber in 1834¹; of his results—which caused no little stir in the scientific world—the one most highly prized by himself² was the demonstration of a wide gulf parting all the more subjective sensibilities from this seemingly objective perception; for while the discrimination of pressure, heat and cold was found to be nearly equal all over the body, that of space proved to be no less than 50 times finer in some places than in others³. Thirty years later the distinction was corroborated and further evolved on the pathological side: Leyden discovered that disturbance of the localising power, though on the whole proportional to that of the other sensibilities, could sometimes be almost independent⁴.

Modern opinion has diverged from Leyden's, but in two contrary directions. On the one hand, a number of workers have drifted back into the old complete identification of the sense of space with that of simple contact; thus Laehr⁵, from a careful study of sixty cases of *tubes*, is able to declare that "the lightest injuries to the tactile sensibility are those in which touches can still be quite well felt, but are falsely localised"; he even states that dulness to contact and inaccuracy of localisation often appear merely alternating symptoms in the same area of skin. On the other hand, vigorous efforts have been made to sunder the two functions still further, deriving the sense of space more or less completely from another factor, movement. As an account of the ultimate origin of 'thereness' in ancestral or infantile experience this theory is ancient enough⁶; but there has arisen a tendency to apply it to adult persons in their present condition. Accordingly, in 1901, Förster⁷ formally declared that the localising power is not at all dependent upon contact sensibility, but wholly so upon 'movement sensations' (*Bewegungsempfindungen*). For proof he brings 19 varied and carefully examined pathological cases from his own experience; as regards previous medical records he says that they are all on his side, if only inspected critically enough. He admits that in the class of

¹ *Annotationes anatom. et physiol.*

² See *Berichte d. k. Gesellschaft d. Wiss. zu Leipzig*, M. P. Klasse, 1852, S. 86.

³ Elsewhere given by him as 60 times (*Die Lehre vom Tastsinne u. Gemeingefühle*, 1851, S. 78-9): *a priori*, the greater uniformity might have been expected from the spatial perception.

⁴ *Virchow's Archiv*, Bd. XLVII. S. 321.

⁵ *Archiv für Psychiatrie*, Bd. XXVII. S. 693 and 725.

⁶ See the works of Thomas Brown, the Mills, Steinbuch, Bain, Krause, Spencer and others; Wundt's position is less extreme.

⁷ *Monatsschrift f. Psychiatrie u. Neurologie*, Bd. IX. S. 31 and 131.

cases named after Brown-Séquard the injured localisation seems—according to the text-books—to be accompanied by insensibility to contact rather than to movement; but he points out that very few instances of this kind have been adequately investigated, and that never has the alleged loss of localising power been measured *quantitatively*, so that these very isolated exceptions may well be only errors of observation.

There is another fundamental question which has given rise to no less difference of opinion, namely, whether this so-called spatial sense be not really a confusion of two distinct elements. As regards the great bulk of Weber's work, the reagent was simultaneously touched by both compasses-points, which were gradually neared until the exact distance was found where they could only just be distinguished; occasionally, however, the variation was introduced of touching the reagent in one place only and letting him try to indicate the spot (without looking). But in 1858 a protest was raised, Aubert and Kammler¹ declaring that the compasses tested nothing but the pure 'sense of space' (*Raumsinn*) into which our outer sensations range themselves by transcendental necessity, whereas the spot-finding method dealt with the very different 'sense of locality' (*Ortsinn*) elaborated out of the spatial sense by long experience of movements. A step even further was taken by Brown-Séquard², who reduced the compasses to the rôle of a 'barometer of the state of the skin' and tested localisation exclusively by spot-finding. But next Leyden³ came forward as a trenchant champion of the older view; once more the spatial sense was regarded as one single function and all its various manifestations were held to be most completely and satisfactorily tested by the compasses alone. Nor to this day has any general reconciliation been achieved; the distinction between the sense of space and that of locality continues to be maintained and denied with unabated energy—and, perhaps, with increased acrimony.

The present paper is an acceptance of Förster's challenge; a particularly unequivocal Brown-Séquard case has been taken in hand, and the patient's power of localisation has been submitted to the careful quantitative measurement not unreasonably demanded: upon this occasion the same rigorous procedure has also been applied to the other two terms compared, the senses of contact and of movement (as far as I am aware these three faculties have never before been

¹ Moleschott's *Untersuchungen*, Bd. v. 1, S. 174. See also Aubert's *Physiologie der Netzhaut*, 1865, S. 6–10.

² *Journal de Physiologie de l'homme et des animaux*, 1858.

³ *Virchow's Archiv*, Bd. xxxi. S. 1 and 2.

quantitatively tested in any one person). Moreover, the localising faculty has been tried by both the methods of Weber, as well as by the principal other types of procedure, the results arrived at being often of instructive discrepancy. By the aid of the information thus attained an attempt is made, not only to clear up the two long vexed questions mentioned above, but also to attain a clearer and deeper analysis of the whole localising process.

To Professor Flechsig, Director of the Leipzig Nerve-hospital, I am indebted for his most kind permission to examine the patient freely, and further, for his invaluable personal assistance. I must also express my hearty thanks to Dr Kaulfers, who was in special charge of the case and was ever ready with his useful cooperation.

§ 2. *History of the patient.* To avoid the not uncommon confusion between observation and hypothesis I will narrate the facts of the case as simply as possible first, then proceeding to analysis and suggested interpretation.

On the 12th of September, 1903, S., a powerfully built miner, 45 years old, of healthy and well-nourished appearance, presented himself at the hospital, where the following symptoms were recorded. *Motor*: walk is spastic-paretic; there is a general restriction of movement and reduction of strength in both legs, but much more markedly in the left. *Kinaesthetic*: in the left leg all movements are atactic and the patient cannot tell what position has been given to it; in the right, the ataxia is slight and perception of position is normal. *Sensory*: almost all the lower part of the body has become insensible to touch, pain, temperature and vibration; the upper limits of the anaesthetic zone are sharply defined by a horizontal girdle about 10 cm. above the navel; on the left side there is considerable improvement lower down; but on the right only the toes and sole still have some slight sensibility. No sweat is excreted in the anaesthetic zone, although abundant in the upper portions of the body; the patient has lost all sexual power and suffers from difficulty of defecation and urination.

Thus S.'s left leg could hardly move, while his right could scarcely feel. The physician perceived that the symptoms were of the Brown-Séquard type and accordingly suspected one-sided lesion of the spinal cord; Röntgen rays were turned on and actually revealed a small triangular foreign body to the left of the 6th dorsal vertebra. Thereupon the patient was induced to relate that twenty-six years previously he had been stabbed in the back; for some months afterwards he had been unable to use his left arm, but since then had

not been further troubled; he had no idea that the point of the weapon had broken off inside. He said that the present symptoms had gradually commenced about two and a-half years ago; first, there had merely been a weakness in the left foot; this had spread up the leg; and all the other mischief had soon followed. An operation was performed upon him on the 5th October; pressing against, but not severing, the dura mater on the right side of the spine, was found the anticipated rusty old knife-point, which was easily extracted. The immediate effect of this operation was to aggravate the symptoms generally; but then commenced a steady though very slow improvement.

My own examinations of the patient extended from May to August, 1904; such a long period enabled me to give him an adequate methodological training and to apply sufficiently numerous tests (about 3800). Thus, aided by the patient's great willingness and intelligence, I was in a position to obtain data which are, I believe, of unusual reliability¹. The results will be given under the three principal heads: movement-sensations, sensations of contact and power of localisation.

§ 3. *Movement-sensations.* By this term will be understood that whole system of sensations which constitute or immediately engender our feeling that a limb moves². Strictly speaking, the present tests only dealt with movements of a passive nature³; but this qualification will hereinafter be omitted, chiefly for brevity's sake, but also because the perception of active movements only differs in introducing some additional factors. The precise anatomical seat of these sensations—variously attributed to the muscles, skin, joints, or tendons—need not here be discussed; their existence, at any rate, is indisputable.

To excite them alone is not a very easy matter. Leyden⁴ slung the tested leg from a high pulley on a gallows-like structure; Goldscheider⁵ worked it up and down by means of a pump in the room underneath, breaking through the floor for the purpose; the Americans seem usually

¹ Data, such as are ordinarily to be obtained in the sick-room, would in any good psychological laboratory be taken as mere preliminary exercise.

² Sometimes this expression is used to denote, not sensations revealing movement, but those caused by movement; more often, unfortunately, these two meanings are confounded. In the present case there is little fear of ambiguity, for the two phenomena practically coincide, in that the sensations caused by a limb's movement always bring with them a perception of this movement; the only exception is for those minimal changes of position which are just enough to produce sensation, but yet insufficient to excite idea of motion (Goldscheider, *Archiv für Physiologie*, 1889, S. 373).

³ That is, movements imparted to a limb by another person.

⁴ *Virchow's Archiv*, Bd. XLVII, S. 344.

⁵ *Loc. cit.* S. 396.

to put a hinged board under the limb. But all these devices, apart from other inconvenience, suffer from the disadvantage that the movement of the supporting apparatus does not at all accurately coincide with the direction of the rotation of the limb; hence, the reagent's skin is subjected to very disturbing tensions and frictions. To escape these a large wheel was fixed for me upon a stand and furnished with a laterally projecting well-padded board; the limb to be tested is placed upon this board in such a manner that the axis of the joint is in prolongation of the axis of the wheel; then the wheel—and with it the limb—can easily be rotated at any desired speed; 1 degree per second is employed mostly.

With this apparatus, S.'s right leg could just distinguish upward from downward movements¹ when these were of the following amplitude: about the hip, 0.7° ; about the knee, 0.8° ; about the ankle, 1.2° ; these amounts are quite normal. But with the left leg things were very different; the hip was again normal enough; but with the knee a rotation as large as 20° could not be noticed; while the ankle failed to yield any sensation whatever from 40° (the greatest amplitude I could produce). Now, it happened that two or three times a week S. was allowed a few minutes' walking exercise, which appeared to greatly fatigue him; on testing him in this state the right side showed itself still unaffected; but on the left even the hip had become nearly insensible, the knee totally so, while the ankle was too stiff to be tested at all.

It will be observed throughout that the transition from soundness to infirmity is demarcated with remarkable distinctness; a joint either escapes altogether, or else it is affected profoundly; and even a temporary fatigue can at once transform the one state into the other. This may be taken as indicating that the fibres transmitting these movement-sensations to the brain are, at any rate near the 6th dorsal vertebra, ordered into very compact groups corresponding to the respective joints²; a similarly compact grouping seems to exist in the cortex also, to judge from the recorded effects of lesions in the central and parietal

¹ Goldscheider conjectured that the faculty of discriminating a movement's direction might differ from that of noticing the mere fact of movement. No such discrepancy was noticed here; the stimulus necessary for the latter purpose was smaller than, but always proportional to, that required for the former. As discrimination of direction is far less disturbed by irrelevant factors it will be treated as the paramount criterion.

² The more peripheral parts of the leg are apparently represented by more lateral situations in the spinal cord.

convolutions¹. In spite of obscure origin, the movement-sensations of a joint appear to form a very well-defined physiological unit, and therefore can hardly originate from several substantially independent sources, as often supposed.

§ 4. *Contact sensibility.* For testing this recourse was had to von Frey's useful 'hair method².' A hair is pushed against the skin until the former begins to double up and lose force; the shorter the hair is made the stiffer it becomes and the deeper is the impression on the skin; the length at which the patient can just perceive that he is being touched furnishes the required measure of sensibility. I find it convenient to insert the hair in an ordinary pencil-case (by means of a minute cork sheath), so that the end can easily be projected to any length desired. My only essential modification of von Frey's procedure concerns the hair's tip, to which I attach a tiny globule of glue, in order to make it smooth and spherical; this is important, seeing that otherwise the bending hair has continually different amounts and shapes of surface in contact with the skin, and the sensory effect must be always changing³. Tested in this manner S. presented none of the contrasts just discovered for the movement-sensations. Some degree of abnormal insensibility was found all over both legs, especially the thighs and toes; when he was not tired, the right leg was only slightly worse than the left; but in fatigue, the former further deteriorated by about 50%, the latter by about 20%.

The senses of heat, cold, and pain were only tested in the usual rough unquantitative manner; all three seemed fairly normal in the left leg, but could hardly be elicited at all in the right (although the sensation of cold arose here *subjectively* so much as to annoy the patient, even when the rest of his body was unpleasantly warm).

§ 5. *Power of localisation.* Everything is now prepared for a crucial investigation of this faculty. On S.'s right side all the contact sensibilities are greatly degraded, while the movement-sensations

¹ Dana, *Journal of Nervous and Mental Diseases*, 1894; Wernicke, *Arbeiten a. d. psychiat. Klinik in Breslau*, Heft II.; Starr, *Psych. Review*, Vol. II.; Frenkel, *Neurolog. Centralblatt*, 1897, S. 688 and 734.

² *Berichte d. k. sächs. Gesell. d. Wiss.*, M. P. Klasse, Bde. XLVI. and XLVII.; also *Abhandl. d. k. sächs. Gesell. d. Wiss.*, M. P. Klasse, 1897. The sensibility of the tactile organs to this hair contact seems to correspond with that to electricity, but not with power to discriminate pressure or strain.

³ The sensory effect was found by von Frey himself to $= k/d$, where k is the maximum force of the hair and d is the diameter of the contact surface (*Berichte d. k. sächs. Gesell. d. Wiss.*, M. P. Klasse, Bd. XLVI.).

remain perfectly preserved; but on his left he can still feel contact tolerably, while to movement he is almost wholly insensible. If localisation depend upon perception of movement it must prove vitally injured in his left leg, but unimpaired in the right; if, on the contrary, the localisation closely correspond with the sense of contact, then we must expect to find it deteriorated in both limbs, but more so on the right, especially when S. is fatigued.

We have seen that there is a choice between two testing methods, that of distinguishing the compasses' points, and that of indicating the position of a spot touched. The latter must be further subdivided into at least three different procedures. First, there is the one used by Weber himself¹; the reagent is not allowed to open his eyes before pronouncing judgment, but may freely grope about for the place. Then there is Volkmann's procedure², by which looking is permitted, but not groping. Finally, both looking and groping may be forbidden³. For brevity, these three procedures of spot-finding localisation will be termed 'groping,' 'looking,' and 'simple' respectively.

Commencement was made with the simple procedure, for reasons which will appear later. It was conducted by me as follows. After closing the reagent's eyes, the limb to be tested is moved about irregularly until his last view of it can no longer help him; to prevent tactual recognition and correction, the limb is shielded at 1 cm. distance by a sheet of cardboard covered with white paper and perforated in the centre by a small hole; through the hole is introduced a bent wire 2 mm. thick and cased in cloth (to avoid cold). The reagent is given a stylographic pen and, on the wire pressing his skin, endeavours to indicate the corresponding spot on the cardboard⁴. Thus is immediately produced a graphic representation of the errors, showing both size and direction. As a rule it is important in this sort of test to distinguish the variable from the constant error; the former alone is the subject of the present work; but it may here be mentioned that S.'s constant errors happened to be so small as to be in any case almost

¹ *Berichte d. k. sächs. Gesell. d. Wiss.*, M. P. Klasse, 1852, S. 87.

² *Wagner's Handwörterbuch der Physiologie*, 1845, S. 571-2.

³ This was done in some experiments of Henri (*Über die Raumwahrnehmung des Tastsinnes*, 1898, S. 107), but his manner of procedure differed widely from that adopted by myself.

⁴ The reader will naturally suspect that a new factor may be introduced in the fact that the reagent has not got to indicate the touched spot itself but another spot just above. But some extensive experiments (not yet published) have shown this to make no appreciable difference.

negligible. The results by this procedure seemed as conclusive as could be desired. From the left knee downwards—where we had ascertained the contact sense to be injured moderately, but the movement-sensations to be almost wholly destroyed—there the patient now showed himself to have also lost all power of recognising the position of touches; the median error was no less than 10 to 17 cm., which comes to mere random guessing. But on the left thigh and whole right leg—where the injury to the contact sense had proved greater, but the movement-sensations were perfectly normal—there the error was about 4 cm., an amount no larger than often occurs with healthy persons (average, a little over 3 cm.). The only sign of localisation corresponding with sensibility to contact was that the left thigh did slightly better than the right (4.1, as against 4.8); to obtain more decisive evidence all the tests were several times repeated when S. was tired; in this state, though his contact was greatly reduced, his error of localisation never showed appreciable change anywhere. So far the evidence sufficiently agrees with Förster's view, that the power of localisation depends entirely on the movement-sensations and not at all upon the sensibility to contact.

We turn to Volkmann's visual procedure. The reagent, after noting the position of his limb (which is not subsequently shifted) shuts his eyes; some selected spot is touched for one second; a pause is given long enough for the mark on the skin to die away¹; then he is told to open his eyes and point out the place, but without touching it. The previous remarkable correspondence of localisation with movement proved now to have abruptly vanished. The formerly much inferior left leg had become even the better of the two, its thigh had an error of only 3.8, as against 6.2 on the right (normal, about 2.0); the calf showed 3.7, as against 4.1 (normal, about 1.8); the feet were perfectly equal on both sides, with an error of 1.8 (normal, about 1.5); only on the toes was the left leg still at a small but steady disadvantage, being 1.7, as against 1.4 (normal, 0.6). All these tests were repeated in S.'s fatigued state, and all the errors again remained unaltered. *Such performances do not seem possibly reconcilable with the extreme theory of movement-sensations*; for instance, these sensations have been found almost extinct in S.'s left knee, but perfectly intact in his right knee; yet the calf on the former side unquestionably localised the better of the two. As regards influence of skin sensibility, the evidence seems

¹ Reagents generally think that a delay of two or three seconds greatly affects their power of finding the spot, but objective measurements show no appreciable falling off.

contradictory; for though the localising error is generally greater on the parts duller to contact, sometimes it is even less on these parts.

We come now to Weber's own procedure, where the reagent's eyes must not be opened, but he is allowed to grope for the spot. S. was allowed to use his finger-tip for the purpose¹. The remainder of the procedure is just the same as in Volkmann's, except that now there is no need to wait for the mark to disappear. The results entirely corroborated the above visual ones; again, the left leg was superior in the thigh and calf, equal in the foot, and inferior in the toes; once more, no change took place during fatigue. For completeness, S. was occasionally allowed to both look and grope. One might expect such a combined performance to exhibit increased accuracy, but in practice I have always found it merely give values intermediate between those obtained by using either clue separately. This proved to be the case with S. also, so that the results do not appear interesting and will not be further mentioned.

Finally, we pass to the other general method of testing localisation, that with the compasses. It was first executed in the ordinary manner; that is to say, both points were placed upon the skin simultaneously². As result, the right leg continued to be slightly better than the other; when untired, both showed great dulness on the thighs, but elsewhere gave nearly normal values; *after exercise*, however, the whole lower part of the body became so insensible, that the two points could not be distinguished at any distance whatever (on the same segment, of course). Long ago it was pointed out that duality of sensation and spatial separateness are not identical; if, for instance, a hot and a cold point be applied to the skin within the same sensory area, the two sensations remain qualitatively distinct, but do not appear any more spatially separate than do two simultaneous musical tones³. I therefore modified the previous procedure as follows: I touched the patient with one point only, ceased doing so for one second, and then touched with the other point; he had to decide whether the second stimulus was higher up or lower down than the first one. But even then, although the task had become purely spatial—and at first sight might seem

¹ Most reagents prefer this, but their actual performances are no better than when using a wire or stick.

² In this sort of work I do not try to make the reagent examine subjectively whether he can detect a doubleness of sensation, but I test his practical power of deciding rightly as to whether he has really been touched in one or on two places.

³ Czermak, *Berichte d. k. Akad. d. Wiss. zu Wien*, M. N. Klasse, Bd. xv. 1855, S. 500.

almost identical with Weber's spot-finding—the objective facts remained quite unchanged; when untired, S. still gave fairly normal values everywhere except in the thighs; after his few minutes' exercise, he still appeared to have lost all measurable discrimination. *Thus the influence of the movement-sensations has now wholly disappeared, while that of skin sensibility would seem contradictory.*

So much for the measurements taken of the patient's sensibility. Now comes the very different task of interpreting them. In the above tests as to power of spot-finding, equal consideration has been allotted to three procedures, 'simple,' 'looking,' and 'groping' respectively. This, however, is by no means in accordance with traditional usage; for while dozens of laborious researches have been devoted to the two latter, the first sort has hitherto been almost wholly ignored¹. This appears to me as beginning at the wrong end; the 'groping' and 'looking' procedures can scarcely be treated otherwise than superficially, until a thorough investigation has first been made of the 'simple' one.

§ 6. *Analysis of 'simple' localisation.* Let us try to analyse the process; suppose an experimenter to touch a reagent on the foot; then the reagent, without looking, has to bring down his finger-tip until it seems to be just opposite the spot. But how can he know when this is the case? Seemingly, the mind flashes straight across from the sensation in the finger to that in the foot; but this could not really occur unless our limbs were able to perceive space objectively, a proposition that the most ardent realist would hardly dare to assert nowadays. Failing this short road to cognition, we are compelled to take one very roundabout; the brain cannot perceive that the finger is hovering near the touched spot, unless receiving sensory messages from all along the circuitous bodily connexion between the two; just as the pioneer cannot know that his tunnel is nearing its goal, unless maintaining a roundabout real connexion with the latter by a chain of back bearings.

The above requisite messages must necessarily be conceived as belonging to two different classes. First, there must be the excitations² which reveal the inclinatory angles of all the intervening joints; in our above example the reagent must at least be undergoing such excita-

¹ The only notice of it appears to be the previously quoted one of Henri, and even there it does not occupy a fiftieth part of his whole work.

² The term 'excitation' is chosen as most neutral. The reason for this caution will soon be evident.

tions at the finger joints, wrist, elbow, spine, hip, and ankle. And secondly, there must be the excitations at both ends of this open circuit, revealing the positions of the two intentionally compared parts with reference to their own anatomical segment¹; in the case we have just supposed the reagent needs to know the position of the tip² with reference to the finger and that of the touched spot with reference to the foot. These two classes of sensory messages are so important and must be so often cited as to urgently require brief names; the difficulty is to find any that do not prejudge some question under dispute; the excitations varying with the angle at the joint will be termed 'articular,' while those depending only upon the rigid segment between joints will be called 'segmental.'

Now, what relation do these two logically necessary messages bear to our actual sensations? For the segmental messages we evidently need to go no further than the ordinary sensory activities of the skin; the touched spot on the reagent's foot knows by long experience its relative position with regard to the foot; similarly, the tingling in his finger should be perfectly well able to tell that it comes from the tip.

Less easy is it to decide what furnishes the articular messages. How do the foot and finger discover in what direction they are pointing? In some way or other these articular messages or indications must be intimately connected with the movement-sensations, seeing that the former depend upon the joint's angle during rest³, while the latter depend upon the same angle during motion. Yet Goldscheider, embarrassed by certain difficulties (which we also shall have to encounter shortly), was driven to the hypothesis of two different sets of organs, one about the tendons and folds of the skin for the orientation during rest, and one in the joint for that during movement. But this hypothesis, already so improbable from a general point of view, becomes on closer empirical scrutiny quite untenable; medical records are unanimous in showing that loss of the movement-sensations is invariably accompanied by disorientation as to position, and *vice versa*; in our case of S. the movement-sensations and the

¹ 'Anatomical segment' is meant in a purely mechanical sense, indicating the extent of body which lies between two adjacent joints; it is nearly but not quite equivalent to Goodsir's and Huxley's word 'somatome.'

² If a stick be used the matter only becomes slightly more complicated.

³ Hereby is only meant that the 'articular messages' *so far discussed* occur during rest; later on reason will be seen for extending the same term to the messages during motion also.

positional indications always behave as a single physiological unit and, indeed, as a remarkably well-defined one; its faculties act as a whole—either escaping altogether, or being profoundly injured—quite independently of the normal or abnormal state of the other tactile processes. Whether we retain an old-fashioned faith in the muscles, or whether we are led by Goldscheider to put our confidence in the joint-surfaces, or whether we accept Pillsbury's¹ demonstration of the paramount importance of the tendons, at any rate *only one* of these sources must be held mainly responsible for orientation both in rest and in motion².

But this identification may be conceived in various ways. Some authors try to resolve the knowledge of a limb's position at rest entirely into a mere memory of its preceding movements. This view, however, has no real foundation beyond the general hypothesis that movement is the sole generator of spatial perception; even if the hypothesis were admissible, this would be no excuse for such a crude application of it. The factual evidence is entirely in favour of the articular excitations being at present able to orient without any movement; if we had to rely upon recollection of previous actions, in the dark the errors would so accumulate that we should quite forget where our limbs were. Far from this being the case I have usually found the error of localisation reach its maximum after very few unseen passive movements³.

With better reason is the contrary opinion advanced, that a movement sensation is no more than a continuous succession of resting or 'positional' sensations (*Lageempfindungen*). But even this view is liable to very serious objections, springing chiefly from close subjective observation. By most people, even psychologists, the movement-sensations are more or less confused with the other neighbouring tactile sensations (principally in the skin); not only are the latter much more conspicuous, but it is through them, not the real movement-sensations, that the movement is most vividly localised. With enough practice under suitable conditions, however, the real movement-sensations can be unerringly recognised and thoroughly studied⁴. The first fact elicited is that they are exclusively localised in or about the joints; but when one tries to

¹ *Amer. Journ. Psych.* Vol. XII. 1901.

² Although there may be many auxiliary and modifying influences, see 2nd footnote, p. 300.

³ Tabical incoordination often goes on increasing for some time after the patient has closed his eyes, but this case is different and more complicated. (Spaeth, *Beiträge zur Lehre von der Tabes*, 1864.)

⁴ They can be observed most clearly of all when the neighbouring skin has been rendered insensitive by anaesthetics or electricity.

feel the exact angle made by two segments, one appeals preferably to the sensations far away from the joint; if attention be directed on the joint itself, the impression as to the size of the angle becomes much vaguer; thus, the movement-sensations and the seemingly positional sensations are localised in different places. Next, the movement-sensations are found to be of an exceedingly uniform character, both in quality and intensity, so that it would be difficult to find twenty distinguishable grades (and this indistinguishability lies in the sensations themselves, not in any hindrance of the discriminative activity, as is the case with overtones, marginal vision, etc.). To afford all the required indications of position, some joints would require about 200,000 distinguishable grades¹, or three hundred times as many as there are between pitch darkness and dazzling light; thus, these sensations must be considered hopelessly inadequate for the purpose of indicating position. Indeed, no attempt is made to utilise such few grades as exist, for when the movement is very small the same sensation arises, but without evoking the least idea of movement. Further, on the movement diminishing, these sensations diminish also, and on the movement ceasing no trace of them is any longer perceptible; as they vanish whenever the limb takes up position, they cannot well be formed of positional sensations. Finally, apart from all these subjective observations, there is the convincing empirical fact, that if the skin be sufficiently numbed (with faradic electricity), the sense of position will be totally extinguished², while yet the movement-sensations and the perception of movement will remain unaffected; but there is no longer any perception of the movement's direction.

Thus, the 'positional' sensations do not exist³, and even the so-called movement-sensations are unable to reveal a movement's direction; there is absolutely nothing to be found in consciousness capable of furnishing the postulated articular indications. We appear forced to take refuge

¹ To get an approximate evaluation, we can conceive the whole cone comprising all possible inclinations of the limb as consisting of part-cones whose bases have diameters corresponding to just distinguishable differences of position; similarly, the average whole possible rotation of the limb is conceived as consisting of just distinguishable part-rotations; then, the number of part-cones multiplied by the number of part-rotations gives the required total.

² Goldscheider calls the sense of position under these circumstances "geradezu vernichtet." *Zeitschrift f. klin. Medicin*, Bd. xv. S. 98 and 111.

³ Or, what comes to the same thing, all tactile sensations are positional only in the limited sense that they possess 'thereness'; but this 'thereness' is itself, as has been shown, a product of many factors, including the sought articular indications.

in the hypothesis of articular indications *not in consciousness*. I would suggest that the process of tactile localisation is as follows. At every different angle assumed by a joint there occurs a correspondingly different excitation of certain tactile organs in or near it¹; during rest, these excitations do not reach consciousness; on movement they produce sensations, indeed, but not such as could enable us to recognise position; in both cases alike they produce a physiological but not a psychical articular indication. Then this indication has to combine with those from the other joints and with the segmental ones; the whole circuit of articular and segmental indications works out its own complicated summation as unconsciously as a calculating machine; into consciousness there only shoots up the total result, a simple perception of position². The reader may easily gain some conception of this view if he will ask himself (say, just after waking) the position in space of a touch on his hand or foot. He will not find himself successively reviewing and adding the angles upon which this position really depends; he need not have so much as *implicit* cognition of these angles; for all he knows at the moment, nearness of the foot may be due to flexion in the knee, hip, or spine; its sidewardness may have come from abduction of the thigh or from its rotation. In localising the exact position of the touch he simply perceives—without any geometrical premisses derived from the rest of the limb or body—that the touch is 'there.'

The chief objection to the above theory is the difficulty of admitting that mere unconscious physiological processes should be capable of entering into psychical associations; and this difficulty is enhanced by the fact that tactile localisation is very sensitive to the disturbing influence of further associations; the presence of unwonted circumstances, or even the absence of usual ones, will easily cause a touch to seem in an abnormal place. If the disturbance be prolonged the normal localisation can be modified to almost unlimited extent; for instance, Stratton³ made the experiment of wearing glasses that turned the visual field upside down; after a few days he found that the feeling in the head, arms, and legs was learning to agree with the sight and to assume the same upside-down 'thereness'; towards the end of the experi-

¹ If these are of any known specific anatomical form they would appear to be those discovered by Vater, and, a century later, rediscovered by Pacini.

² It is by no means intended to assert that the act of localisation is a bare fusion of all these articular and segmental indications, but that these indications are the *least* conceivable number of underlying factors; in reality there probably occur infinite further elaborative and associative complications.

³ *Psychological Review*, Vol. III. p. 611.

ment the tactile and visual sensations and memories grew so harmonious that the feeling of upside-downness began to wear off and everything to seem as natural in the new direction as in the old.

But still, such indirect reasoning appears insufficient to outweigh the above very positive evidence that *the articular excitations do not function psychically, namely, by means of differences for or in consciousness*¹; during rest, we have found that they produce no sensations appreciable at all; during movement, they furnished just enough sensation to show that this had not merely been hiding itself, but was really and essentially useless for localisation. Nor, perhaps, is the above objection quite as formidable as it sounds; psychical processes are in most intimate and varied interaction with purely physiological ones; there appears no cogent evidence, either empirical or *à priori*, that this interaction should not in the case of localisation take a form somewhat resembling that of the usual psychical association. Why the articular excitations should fail to become conscious is explicable easily enough; let us assume that originally they did reach the sensational layer of the cortex and that the ensuing sensations somehow evoked the 'thereness' in the simultaneous sensations from the skin; as the sequence, articular excitation—articular percept—skin percept, grew more habitual and mechanical, the middle link naturally became less attended to, less active cortically and, finally, unconscious; the uselessly indirect path is now replaced by one direct from the articular excitation to the skin percept.

In the above theory, neither has perception of movement been subordinated to that of position, nor *vice versa*, but both are placed upon the same footing; the unchanging excitations that occur during rest evoke perception of position, while the changing excitations that occur during movement evoke perception of that movement². Exceptionally, either sort of perception may lead to the other: an illusion of movement can falsify a percept of position, while conversely a very slow movement may be solely perceived through the cognitions of position before and after. As there is no importance in this distinction between

¹ Hereby I wish to oppose the theory that the required differences exist in consciousness and are merely too obscure to be noticed. Wundt's more subtle theory, that sensations may be hidden by essential transformation through 'chemical synthesis,' refers to the *ultimate* genesis of spatial perception, and therefore does not come within the scope of the present article, which only attempts to unravel the most recent chapter of genesis.

² With the merely practical superiority of being accompanied by a certain amount of sensation and forming, therefore, a useful test.

the unchanging and the changing excitation, we may extend the use of the expression 'articular,' so as to include the two, both rest and motion. The reason, then, why S. cannot point out any spot touched below his left knee, is not merely because here he cannot feel movement, but because here he has been deprived of the articular excitations in general.

§ 7. *Analysis of Volkmann's 'looking procedure.'* Here, the reagent opens his eyes and is able to identify directly the spot by means of a mental image aroused through the touch; *in this image we have a second manner of localisation* quite independent of the pure 'thereness' described above (p. 300); the circuit of articular excitations from the finger round to the leg is no longer necessary, the contact sense within the segment having become self-sufficient. Hence, the degradation of this sense grows more momentous; in the thighs, where the hair-test had had the greatest difficulty in eliciting sensation, now this sensation proves so perverted that the image aroused is useless; S. actually localises worse than with his eyes shut. In the same degree that the contact sense becomes more influential, damage to the articular sensibility is felt less; the left leg—despite its not knowing where it is—can now localise better than the other one.

A more remarkable fact is that this advantage of the left leg gradually diminishes towards its apex. On carefully examining the looking procedure subjectively, it will be found that the *first* spatial idea is again a 'simple' localisation (a pure 'thereness' with reference to the body and, especially, head), while the mental image only arises as an after-process, correcting and focussing the orientation already begun; so that even this kind of procedure must be to some extent dependent upon the accuracy of 'simple' localisation and, therefore, upon the efficiency of the articular excitations. The diminished degradation towards the upper part of the leg may possibly be owing to the slighter damage in the articular excitations, or to the smaller number of joints involved. It will be remembered that Mott and Sherrington¹, after severing an animal's sensory roots, always found the ensuing difficulty of movement to be greater towards the apices of the limbs; their results were subsequently corroborated by Hering².

However, before this or any hypothesis can be considered satisfactory, it must explain why in S.'s case the phenomenon should be so exceptionally pronounced in the *toes*; for there the left side actually localises

¹ *Proc. R. Soc.* 1895, Vol. LVII. p. 481.

² *Pflüger's Archiv*, Bd. LXX. S. 559.

worse again than the right. On closer examination it was discovered that lengthwise the error was very nearly equal on the toes of both feet, but *crosswise* was no less than double as large on the left; this side clearly suffered from a greater liability to confuse one toe with another. Now, it is well known that local signs, though differentiated all over any particular anatomical segment, are by no means very dissimilar to those on other analogous segments; they are much better adapted for distinguishing different parts of the same toe than the same parts of different toes. Hence, the function of discriminating one toe from another may well be expected to seek help from other sensory organs.

Solution on these lines might seem at once offered by the circumstance that the tests on the toes cause considerable flexion of their joints and, consequently, movement-sensations; the latter may form an important auxiliary, of which S.'s left leg has been deprived. We may recall Weir Mitchell's communication¹, that when a person's fingers are irregularly laced behind his back and one of them is touched, it will be less often mistaken for another if it be moved. But I have found that this improvement only takes place if the finger be moved by the person himself, when it has obvious enough reasons; a passive movement does not seem to reduce the number of mistakes in the least degree. Similar results have been obtained by me as regards the toes also; whether flexed or not in the test, they are confused with one another to just the same amount. Hence the clue afforded by the joint in our localising procedures (where the movement is always passive) must be of a subtler nature than that alluded to by Weir Mitchell. Further, it must be such as can be equally furnished while the joint is at rest; it must not consist of the movement-sensations in particular but of the articular excitations in general.

Let us again appeal to subjective observation; if the reader will try to localise a touch upon the third or fourth toe, he will notice how the sensation simultaneously takes part in the two processes above mentioned; it quickly acquires a thereness with reference to the foot and head; and also it materialises into the mental image of the limb. These are very different things², the thereness being an almost purely spatial percept, whereas the image is a vignetted mental picture (at first localised very indefinitely) of the particular region of the body. But the two processes will be found to be interacting sympathetically; when, say, the 'thereness'

¹ *Injuries of Nerves and their Consequences*, 1874, Chap. vii.

² Even if both be ultimately visual, and even if the former be derived from the latter originally.

lies towards the outer side of the foot, the image will seek the shape, and eventually situation, of the fourth or fifth toe. The same curious doubleness and interaction may be detected when localising touches on the fingers; sometimes the two sorts of perception even contend with one another, much as happens when each eye looks through a differently coloured glass.

Thus our explanation with regard to the toes is that, *when the articular excitations are damaged and cease to furnish touch sensations with proper 'thereness,' in default of such prompting an originally indecisive image will be apt to settle upon the wrong segment.*

The same analysis would seem to clear up at last a little mystery now over twenty years old, that of the so-called 'Allocheiria.' In 1882 attention was drawn by Obersteiner¹ to the unaccountable fact that some patients were inclined to localise tactile sensations in precisely the corresponding point on the other side of the body; some attention was roused at the time, but so small progress was made that Gay², summing up in 1893, was unable to suggest any even plausible explanation³. Upon critical review, cases of Allocheiria appear divisible into two classes, organic and hysteric respectively; we shall consider only the former (as being less equivocal) but the same explanation will be found perfectly applicable to the hysterical kind also⁴. The actually recorded perversions of sensibility seem to have been less fixed than generally supposed; if a given patient frequently takes the right leg for the left, he will sometimes take the latter for the former, and most often, probably, he will recognise both quite correctly; nor is the transference invariably from one side to the other, for it also occurs from one to another segment on the same side; the whole phenomenon is reducible to the fact that limbs are confused with other anatomically similar ones, while nevertheless the relative position as regards the limb itself continues to be perceived with almost normal accuracy. But this is what we have found in the case of S.'s toes, and have traced to a deprivation of articular excitations. Now, authentic cases of organic Allocheiria actually resemble that of S., in being caused by lesion of the spinal cord; further, the disturbance is always greater towards the apex of the limb and especially noticeable in

¹ *Brain*, Vol. iv. p. 153.

² *Brain*, Vol. xvi. p. 431.

³ He concludes his article as follows: "The common sensory stimuli, finding their usual channel closed against them, are conducted upwards by the non-decussating fibres and are consequently referred to the opposite side of the body. This will probably be regarded as very fanciful, and indeed the theory is only suggested *faute de mieux*."

⁴ Compare the description of it by Pierre Janet, *Neuroses et idées fixes*, 1898, Chap. vi.

the toes; finally, the only common accompanying symptom is just this deprivation of the articular excitations (shown by loss of sense of position and by incoordination of movement). Moreover, if the Allocheiria is thus regularly attended by deprivation of articular excitation, the converse is no less true; Brown-Séquard¹ does not fail to mention that his patients refer touches on the still sensible side over to the other; Weir Mitchell² finds an illusive transference in the opposite direction; S. makes the one mistake as much as the other, on the toes frequently, on the feet sometimes, on the calves rarely. In short, this organic Allocheiria appears to be nothing more than a constant and explicable symptom of injury to the spinal tracts conducting the articular excitations; the hysterical affection is a malady of these same excitations on their arrival at the cortex.

§ 8. *Analysis of the procedure by 'groping.'* Theoretically, this seems quite equivalent to that of the compasses, at any rate in the latter's successive and purely spatial form described on page 295, for in this the reagent is touched somewhere and then is touched in other places nearer and nearer to the original one, until their difference of position can no longer be detected; just the same occurs in 'groping,' for here too the reagent is touched somewhere and then applies his stick to successive places, until there remains no perceptible difference of position. Practically, also, the values gained by the two methods under normal conditions appear to correspond very closely³. But in the present pathological case the results by 'groping' diverge widely from those by the compasses, and once more reveal the influence of the injury to the articular excitations; in this and all other respects they almost wholly coincide with the results by 'looking.'

The explanation is that, as in 'looking,' so in 'groping' the *first* indispensable phase is again a preliminary simple localisation, since this alone is responsible for the finger's original movement towards the spot; contact with the skin immediately reveals a discrepancy and the finger is accordingly shifted, but the rectification is then almost at an end; subjectively, the reagent feels that he has no

¹ *Journal de Physiologie de l'homme et des animaux*, 1863.

² *Injuries of Nerves and their Consequences*, Chap. vi.

³ This correspondence has been strenuously denied, on the ground that much smaller distances are gained by 'groping' than by the compasses. But this was inevitable, seeing that the former distances are mean errors, whereas the latter are 'thresholds,' which are always much larger. One might as well maintain that a German mark is not equivalent to an English shilling because the one contains 100 pfennige and the latter only 12 pence.

longer any clear idea of the position of the spot; objectively, it will be seen that, though his first correction is generally in the right direction, his subsequent gropings are just as likely to take him wrong. The finest accuracy will be attainable when no great error has been made in the preliminary simple localisation.

Even in the second or corrective phase, the analogy between the 'groping' and 'looking' procedures is much closer than might at first sight appear, for the 'groping,' too, is really effected through the mediation of a mental image. This image differs from the other one, however, not only in having a tactual instead of visual character, but also in arising later: a reagent prepared to localise by 'looking' is no sooner stimulated than he begins to form his image, so as to be ready for comparison with the real appearance; but in 'groping' the image seems to spring from the contact sensation given by the groping stick and, thence, to develop out to the original stimulus, resuscitating this, absorbing it and indicating the way to it. The image in 'groping' is much fainter than the image in 'looking' (partly because itself tactual and less easy to distinguish from the other simultaneous tactual events); but nevertheless on close observation it can be seen to engender the same curious doubleness and contention of process, as above described for the 'looking' procedure.

§ 9. *Analysis of the method with the compasses.* Here, at last, the influence of simple localisation and, therewith, that of the articular excitations, are excluded. Consequently—whether the points be applied to S. simultaneously or successively, and whether his judgment be of duality or of direction—he now localises just as well in the limbs that have lost all sense of movement as in those that possess it intact.

Less obviously intelligible is the fact, that localisation tested in this way shows itself unhurt by the grave permanent lesions, but crippled by the insignificant fatigue; whereas in all other tests the reverse occurred, for the permanent lesions seemed to do damage and the fatigue to be quite harmless. The strong influence exerted by fatigue naturally calls to mind the much criticised investigations and results of Griesbach¹; accepting these, S.'s insensibility after exercise could be attributed to general cerebral exhaustion. More pertinent still, perhaps, is the old observation of Leyden², that the '*Raumsinn*' is more affected by acute than by chronic disease; he was

¹ *Archiv f. Hygiene*, Bd. xxiv. Tl. II. S. 124.

² *Virchow's Archiv*, Bd. xxxi.

of opinion that the increased difficulty of tactile discrimination must lead a patient to devote more attention to the matter, and thus *in time* to regain intellectually whatever had been lost as regards crude sensation. But neither point of view attempts to elucidate the completely reversed behaviour of the localising faculty under all the other conditions of test.

The first step towards understanding the reversal of behaviour is to find out what difference of condition is essential for it. Now, the whole course of our tests has been so arranged as to eliminate gradually the unessential differences; the compasses test has been brought to the successive and purely spatial form described on page 295, while the spot-finding has been reduced to the second phase of 'groping' described on pages 305-6. We thus arrive at two processes seemingly equivalent, each consisting in touching the skin and then touching other places nearer and nearer until indistinguishable from that of the original touch. But we have further seen that in 'groping' the localisation turns out to make use of a mediating image. Is this the case with the compasses method also? On careful subjective examination, I find that here, too, an image is detectable, but playing a different rôle. In 'groping' (as in 'looking') the image is the prime factor; the later touches are merely shifted until their place in the image coincides with that of the original touch, while the quality of all these touches is not attended to; the whole process is easy and mechanical. But in the compasses test, especially when approaching the threshold, we come upon a *third manner of localisation* (in addition to those by pure 'thereness' and by images); now, the later and the original touches are compared with one another directly, attentively and, to some degree, qualitatively, the mental effort being very appreciable; the image no longer rises quite freely, but has become more or less dependent on the above intellectual comparison¹.

Though the above subjective observations have kindly been corroborated by other psychologists to whom I have appealed, I was very desirous of obtaining the more tangible evidence of experiment. It seemed that if the compasses method but not the spot-finding depended

¹ Of course due allowance must be made for the fact that in the compasses test the two compared touches are always in immediate succession, whereas in the course of the groping the nature of the original touch has time to become forgotten; but I cannot find that this memory factor makes any essential difference; with the compass method, even when the reagent's attention is purposely distracted and a long interval is allowed to lapse between the original and the later touches, these continue to be compared in a direct attentive manner not occurring in spot-finding.

upon direct discrimination of sensation, the former but not the latter should be disturbed by confusing the quality of the sensation; I tried, therefore, the effect of making the original touch as different as possible from the later ones (ringing the changes on pointed, blunt, warm, and cold). The result in the compasses test was actually to show that the change of quality produced somewhat more mistakes in every reagent; but the difference almost always vanished with two or three minutes' practice, so that by the time the threshold had been systematically ascertained this was just the same as without any change of quality. In spot-finding, on the other hand, the change of quality made not the slightest difference from start to finish. Another series of experiments produced much more striking divergence between the two sorts of localisation; here, my reagents had the self-sacrifice to allow the stimulus to be given firmly with a sharp point, so as to be seriously and distractingly *painful*; this had the remarkable effect of *making the results with the compasses worse, but those with spot-finding much better*¹; in the latter test, also, the act of localising seemed to acquire a more reflex character. The experiment has been repeated on several persons, always with similar results.

On the strength of all these observations and experiments², I would suggest that the strangely reversed behaviour of the localising faculty may be explained as follows. The spot-finding, whether simple, 'looking,' or 'groping' is a procedure continually occurring in ordinary life, and has long since hardened into a fixed association between the sensations and the spatial images. But the business of distinguishing two points as close to one another as possible is new to us; no associations have been established in place of thinking. Hence, any sensory organs not injured seriously may still be active enough to evoke automatically the 'thereness' and the images, though no longer producing the exquisite subtlety of conscious gradation required for directly discriminating very adjacent touches. Physiologically expressed, the nervous messages are still sufficiently intact to travel along the well-worn subcortical paths, but have lost the perfection wanted for the delicate interactions in the cortex. Nor is the converse any less probable, namely, that the cortical paths may possess much power of adapting themselves eventually to chronic perversions of the nervous messages, whereas the sub-cortical paths—once failing—are scarcely able to recuperate.

¹ This improvement refers to the variable error; the constant one depends upon other factors.

² It is hoped to complete the experiments and publish them in detail.

Thus, we have come upon three very different manners of localising; by direct comparison of sensations; by mediation of associated spatial images; and by mediation of associated pure 'thereness.' The skin can function in all three manners, while the joints are chiefly confined to the last named. It will be noted that *the three form a sequence in order of natural development by force of habit*; for the first can be conceived as growing into the second; the second into the third. We have to renounce the popular doctrine (so vigorously championed by Förster), that the movement-sensations from the joints are primitive and the spatial sense of the skin is merely a derivative therefrom: for the former seem to be in the less primitive stage of the two.

Still, there is no evidence for the contrary doctrine of Aubert and Kammler, that all spatial indications are wholly derived from those given by the skin; more probably all these functions have developed side by side, but the skin has been less hasty to part with earlier modes of function. Nor is there any reason, so far, to accept their assumption that even the most primitive mode of function now observable is ultimately innate; I find more evidence that even this is only a genetic product like the others, and that the psychologist has little more chance of observing directly the real original localising function than the geologist has of looking at the original condition of the earth's crust. In the ancient dispute of Aubert and Kammler with Leyden, the former had the merit of announcing the important fact, that discrimination of two points differs from groping for a spot; but their distinction, admittedly of philosophical rather than psychological character¹, was inadequately defined, involved unwarrantable assumptions and, above all, remained totally unproved; so that its rejection was justifiable enough. Reserving the difficult question of ultimate genesis for another occasion, the present practical inquiry has merely to note that spot-finding allows two additional factors to creep in: a preliminary step of simple localisation, and a mechanisation of the whole process by habit. The clearer meaning and more constant results of the method with the compasses, especially when applying the points simultaneously, have always secured for it the favour of the best authorities².

It may, perhaps, be remarked that throughout no allusion has been made to two old friends that generally enjoy the chief honour in tactile pathology, the 'active touch' and the 'muscular sense.'

¹ See Aubert's *Physiologie der Netzhaut*, S. 8 and 9.

² See Wundt's *Phys. Psychologie*, 5th ed. Bd. II. S. 441 and 444.

The former, or power to recognise objects by feel, has often been of practical use—and has sometimes been the occasion of new psychological theories¹. But there is good theoretical and practical reason for considering it merely a combination of two more elementary factors, the various spatial perceptions and the discrimination of pressure².

The more celebrated 'muscular sense' has not even the virtue of practical serviceability. Its name is bad, in that it attributes the function to the muscles, an opinion now generally discarded. Its denotation is no less faulty, for it throws together a motley group of disconnected activities; in its most moderate usage it confuses the sense of position and the perception of weight, two things both psychologically and physiologically independent of one another³; the former is based, as we have seen, upon the articular and segmental indications; while the origin of the latter is still rather obscure.

§ 10. *Inconsistency with the results of Förster.* This able investigator's conclusion, that the localising power is always completely dependent upon the efficiency of the movement-sensations, has thus had to be decisively contradicted. The question still remains as to whether the mistake has occurred in his work or in this. The latter alternative not being agreeable to the present writer, a brief attempt will be made to suggest the conceivability of the former.

Förster lays great stress upon precise *quantitative* tests and has—for the first time in the history of the question—determined his patients' localising powers in this, the only adequate manner; but as regards the other senses compared, those of contact and movement, he has unfortunately remained content with methods of the usual crudeness and unreliability; yet these two senses are, if anything, in still greater need of exact treatment⁴. This deficiency becomes vital when we consider that this argument is based throughout, not upon the broad difference between soundness and injury, but upon fine distinctions between injuries of believed greater and less magnitude.

Further, in most of his cases the degradation of localising power has not been ascertained by comparing together the two sides of the same

¹ For example, see Wernicke, *Arbeiten a. d. psychiat. Klinik in Breslau*, 1895.

² See Hoffmann, *Arch. f. klin. Medicin*, Bde. xxxv. and xxxvi.

³ The physiological independence of these two faculties was clearly demonstrated by Leyden, see *Virchow's Archiv*, Bd. xlvii.; again by Hoffmann, *loc. cit.*

⁴ On the impossibility of properly testing the movement-sensations without proper apparatus see Frenkel, *Neur. Centralblatt*, 1897, S. 688 and 734.

person, but by reference to supposed 'normal' values. Such reasoning, though legitimate enough in principle, requires very cautious application. Now, Förster's data for this purpose seem much too scanty to justify more than mere suggestion; for some parts of the body they do not at all coincide with my own experience¹.

Added to this, his whole system of comparative tests is based upon the assumption that "under normal circumstances the intensity of the stimulus makes no difference; a very fine touch is just as well localised as is a strong pressure²." He does not mention whether this assumption rests upon any exact evidence. My own work has happened to lead me to experiments indicating, on the contrary, that the strength of pressure is a very influential factor; and only thus can I explain the curious fact that his patients almost always localise actually better on the anaesthetic side than on the healthy one!

Finally, even if localisation really did prove to be wholly correlated with the so-called movement-sensations, as Förster believes, it would not thereby have shown any special connexion with movement but only with the articular excitations in general.

§ 11. *Principal Conclusions.*

I. Tactile localisation cannot be treated scientifically until it has been analysed into its several component factors. Any of these may or may not be influential, according to the localising procedure and to the part of the body under test.

II. The sensory excitations upon which localisation depends are of two distinct kinds, in this paper termed 'articular' and 'segmental' respectively. Among other differences, they differ notably as to their paths of transmission up the spinal cord and as to their sensory areas in the brain; the articular paths do not decussate below the medulla, and—both in spine and brain—are gathered into very compact groups for each joint.

III. These excitations may be effective in three independent ways: by directly producing sensations endowed with distinguishable gradations; by evoking mental images (visual or tactual) of the limb in question; or by transmitting merely physiological indications, which have to undergo an intricate combinative and assimilative process

¹ For instance, as 'normal' error of localisation on the lower part of the leg, Förster appears to rely upon three values obtained by himself and amounting to 0.7, 0.8, and 1.3 respectively; I have used just the same procedure very frequently and have found the average no less than twice as large.

² *Monatschr. f. Psychiatr. u. Neurol.* Bd. ix. S. 33.

before engendering any spatial percept. Though these three ways now present some remarkable contrasts, both normal and pathological, they appear to mean only different stages of mechanisation by habit.

IV. The so-called 'movement-sensations' have no present direct influence upon our power of localising; but debasement of the former is to a certain definable extent accompanied by that of the latter, because both are intimately connected with the articular excitations. (This conclusion, however, leaves untouched the question of genesis *originally*.)

S.'s SENSIBILITIES (WHEN UNTIRED): PRINCIPAL RESULTS OF THE TESTS.

Segment	Test	S.		Normal ¹
		Right	Left	
Thighs...	Localisation, simple	4.5 cm.	4.1 cm.	3.5 cm.
	" looking	5.5 "	3.2 "	2 "
	" groping	6.2 "	3.8 "	1.6 "
	Hair test	60 gm.	24 gm.	6.4 gm.
	Compasses.....	Over 8 cm.	Over 8 cm.	6.7 cm.
	Movement, hip.....	0.7°	1.0°	(5 ") 0.8°
Calves...	Localisation, simple	4.6 cm.	10 cm.	3.5 cm.
	" looking	3.6 "	3.1 "	2 "
	" groping	4.2 "	3.6 "	1.5 "
	Hair test	14.4 gm.	7.2 gm.	5.8 gm.
	Compasses.....	3.5 cm.	3.5 cm.	4 cm.
	Movement, knee	0.8°	20°	(4 ") 0.8°
Feet.....	Localisation, simple	3.1 cm.	9.7 cm.	3 cm.
	" looking	1.9 "	1.9 "	1.5 "
	" groping	1.7 "	1.7 "	1.1 "
	Hair test	12 gm.	12 gm.	4 gm.
	Compasses.....	2.2 cm.	2.2 cm.	4 cm.
	Movement, ankle.....	1.2°	Over 40°	(2.5 ") 1.5°
Toes.....	Localisation, simple	3.5 cm.	12 cm.	3 cm.
	" looking	1.4 "	1.7 "	0.7 "
	" groping	1.3 "	1.6 "	0.4 "
	Hair test	11 gm.	6 gm.	3 gm.

¹ The mean deviation is about 10% either way.

V. The sense of contact correlates with the power of localisation in a variable manner. If a dulness to contact be temporary, the sensational gradations may be debased, but the images and the physiological indications spared; if the dulness be chronic, the latter will more probably be affected, while the former escape unhurt.

VI. The above analysis appears to explain readily the hitherto unaccountable morbid state known as Allocheiria. It also solves the long-standing quarrel between the 'Sense of Space' (*Raumsinn*) and the 'Sense of Locality' (*Ortsinn*).

Values gained from S.

Those for localisation represent the median variable errors; on the feet and toes the tests were confined to the upper surfaces; on the calves they were applied to the area of the fourth lumbar nerve; on the thighs to that of the second lumbar nerve.

Those for the hair test represent the maximum weight that the hair which showed his threshold was strong enough to overcome; the weight was placed in one scale-pan and the hair was pressed down on the other. The diameter of the contact surface at the end of the hair was 0.8 mm. The stimulation was applied midway between the hairs on the patient's skin.

Those for movement represent the extent at which S. could just decide whether it was upwards or downwards (about eight times rightly out of ten). Rate, 1° per second.

The inaccuracy to be feared from mere chance fluctuations is not easy to calculate definitely, especially in the case of the hair and the movement tests. As before mentioned, the whole observational basis amounts to some 3800 single experiments; roughly speaking, any of the above 44 mean values finally attained may be expected to deviate by chance from the true mean (that which would be given by infinite experiments) to an extent of about 5 to 8%.

Normal values.

Those for movement were collected from the experiments of Leyden, *Virchow's Archiv*, Bd. XLVII.; of Goldscheider, *Archiv für Physiologie*, 1889; of Mülhens, *Diss.*, Bonn, 1897; of Frenkel, *Neurolog. Centralblatt*, 1897, S. 688 and 734; and of Pillsbury, *Amer. Journ. Psych.*, Vol. XII. All these agree remarkably well with one another and with my own results.

Those for localisation (all three procedures) and for the hair tests are derived from experiments of my own.

Those for the compasses are the classical ones of Weber; but my own experiences are shown also (in brackets), as they do not altogether coincide with those of Weber. For instance, Weber gave the same threshold for the foot as for the calf, whereas I have invariably found that for the former to be much less.

VARYING ACCURACY OF S.'S LOCALISATION, ACCORDING TO
REGION AND PROCEDURE.

Any semi-diameter gives the median variable error (about equal in every direction, except as regards the toes; for these, the front is represented by the top of the paper). Thus, each outline encloses about the best *half* of the localisations.