IV.—RESEARCH.

MOTOR SENSATIONS ON THE SKIN.

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Our first problem in undertaking the following lines of research, which have now been carried on almost continuously for eighteen months, and which so far as we know are mainly new, was to devise a suitable apparatus. To this end a revolving drum of the Ludwig order, with Foucault regulator, capable of more than the ordinary variations of speed and of strong movement, was selected from among several as a driving engine. A band connected this drum with the triple wheel P of an apparatus most of which is represented by Fig. I. in Dr. Donaldson's paper "On the Temperature-Sense" in Mind XXXIX., to which cut (p. 403), to save space, we here refer the reader. An arm six inches long, but not shown in this cut, projects to the right, to which two cogged wheels are attached (both rotated by the triple wheel P above) in such a way that, by moving the end of this arm one way, it throws the periphery of one of these lower wheels into gear with a third wheel, and, by moving the arm half an inch the other way, the second of these lower wheels is geared into the same third wheel, causing it to rotate in the opposite direction. Intermediate between the two extreme positions of the gearing arm, in which it is held slightly by its vertical elasticity, which presses a screw into a dint in the metallic support, is a position in which neither wheel is geared with the third, which therefore remains motionless, although the wheels carried on the arm continue to revolve with the drum. Thus, by moving this arm at any instant half an inch, from one extreme position to the other, the third wheel is instantly, and without the least noise or jar, made to rotate with a velocity exactly equal, as tested by many preliminary observations, in an opposite sense. To this third wheel the car described in Mind XXXIX., 403, and in most of its finer adjustments devised, by Dr. Donaldson, is attached by an endless cord passing around a wheel on a spring at the other side of the brass table of the Kinesimeter shown in Fig. I., following upon which a full description, with a representation (Fig. II.), of the car is given. But, instead of the tube T of Fig. II., another counterpoise-cup like C was used to carry the various weights. On the under side of C, buttons or points of various patterns, sizes and material, to be described later, could be fastened to obtain the different kinds of contact desired with the skin. Thus the button under the one or the other arm of the counterpoise-cup, according to the direction of the motion (the weights being drawn and not pushed over the skin), could be brought into contact with any portion of the body, as the brass tablet which carries the car is wide and high enough to be placed over the body extended on a table with its legs on each side, while if, as in most cases, the arm was tested, the support S (Fig. I.) was used. By this device it is possible to give a constant and uniform movement, the rate of which can be varied within even wider intervals than that of the drum, while the direction of this is at any time reversible, and the weight which determines the amount of pressure on the skin, with the size of the point or surface of contact, can be regulated at will.

The further devices of the apparatus (which is furnished by the mechanist of the University) may here be briefly described, and by referring to Dr. Donaldson's cuts supplemented by his description the whole will be readily understood. A pointer attached to the car passes over the scale at L (Fig. I.), where the rate is read as determined by the rapidity given to the drum. On the swinging arm near C (Fig. II.) is fastened another vertical index, which ascends above the table T (Fig. I.) and records on smoked paper clamped to a vertical and adjustable brass plate standing parallel and near to the endless cord on the other side of L. By this means all irregularities in the surface of the dermal tract traversed by the button under the cup are exactly written on the smoked paper, which can be raised and lowered by a screw behind. This is found convenient especially when heavy weights are used or when unevennesses in the surface of the skin need to be noted as affecting the uniformity of the motor and other sensations.

Again, attached to each of the swinging arms, somewhat nearer their axis, are two vertical wires jointed at the arm and sliding in grooves held by a clamp (not shown in Fig. II.) to the upper part of R. At the level of the top of R, these are bent in a horizontal direction over L (Fig. I.) and carry two small spring clamp-grooves holding long needles, one of which dips, as either cup is depressed, into a trough of mercury, eight inches long, parallel with the scale and just outside it. By this means the instant the button under C falls on the skin electrical connexion is made, whereby a Hipp chronoscope is started, to be stopped by the finger of the percipient which breaks connexion by depressing a key the instant the observation is completed. This is needed only when the rate of motion is so rapid that counting half seconds by a metronome is not sufficiently accurate.

This instrument is, we believe, the first realisation of the kind of apparatus postulated by Czermak in a very vague and obscure yet suggestive paper as early as 1857,[1] and now practicable only with the aid of the kymographic clockwork and regulator.

[1] See his *Schriften* I. i., p. 417 : "Ideen zu einer Lehre vom Zeitsinn".

I. *Error in Judgment of Direction of Motion on the Skin.* In making these observations the part of the body on which the experiments were to be made—namely, the back, more commonly the leg, or much the most frequently the fore-arm—was placed on the support in a fixed position under the car, the eyes of the percipient being closed. The operator set the apparatus in motion and also a metronome, and, after the *avertissement* "ready," dropped the weight gently and noiselessly into the cup, which thereby pressed the button upon the arm. As soon as the percipient had determined whether the motion was up or down the limb, or (more generically) to or from the head, he said *plus* for up and *minus* for down. The time and judgment were recorded by the operator, and subsequent trials in the same way and over the same dermal tract, sometimes to the number of twenty or thirty in a sitting, were made till signs of fatigue began to appear. The following Table gives the gross results of many observations.

TABLE I.

Persons.	No. of Observations.	No. of Errors.	Errors in per ct.	+ J −	− J +	Ratio of last two columns.
H. H. D. - - -	2057	434	21	73	361	1 : 4·6
W. N. - - - -	1000	166	16	78	88	1 : 1·1
J. V. D. - - -	774	6	0·7	0	6	
G. S. H. - - -	515	68	13	29	34	1 : 1·4
C. D. - - - -	264	11	4	0	11	
H. T. - - - -	144	6	6	2	4	1 : 2
Total—	4754	691	14 +	182	504	1 : 2·7 +

The headings of the fifth and sixth columns mean respectively number of times when motion up the limb was judged to be motion down it, and *vice versâ.* In this Table no account of rates of motion, of weights or of the surfaces of skin tested is taken. For each of these conditions, so far as they were explored in our research, as well as for all in the aggregate, the following law appears. We are more likely when in doubt to judge motion on the surface of the limbs to be up rather than down their axis. On the breast, shoulderblades and back between them, the tendency was to judge movement to be towards the head although these parts were less fully tested. Man's experiences with sweat and rain, especially without or before clothing, must have made him more familiar with downward than with upward movement on the surface of his body, and the latter, as being more apt to be caused by living things—insects, parasites, &c.—or by aggressive outward movements with the limbs, would be more likely to attract his attention. Movement also against the direction of the hairs, "which strokes the wrong way," would for anatomical reasons seem at first view to be a stronger stimulus than motion coinciding with their direction. Mainly for this reason probably, *minus* or "from" movement often failed to be felt with the lighter weights which in the opposite direction caused a distinct sensation. Whether the general law above stated holds for all parts of the surface of the limbs cannot be inferred on the basis of our observations, which were made mainly on the upper and inner fore-arm and on the middle of the upper thigh, but it seems not unlikely that it may for most of it.

A few general remarks may be appended to this section. The percipient is quite prone, unconsciously and with the best intentions, to judge direction from accessories rather than from the simple elements of motor impressions. If there have been several consecutive judgments in one direction, he expects the other direction and often judges on general grounds without laboriously fixating the sensation. Even an inadvertent noise of the hand in adjusting or a squeaking of the apparatus is liable to enter as a factor of judgment. Again, when four or five consecutive movements are given in one direction, the time of the first and last judgment or judgments is apt to be longer than of the intermediate ones; also, after such a series is given, the first movement in the opposite direction is often wrongly judged. Thus a more frequent alternation of direction was found to constitute a better condition for correct judgment. The sense of motion is strongest during the first few seconds and slowly and irregularly diminishes with time. The fall of the button on the skin must not be too forcible or the direction of movement can be told by the swing inward toward the axis of the button, which, as it depresses the skin, stretches it slightly before it begins to slip over it. This sense of stretching, which seems from repeated notes to that effect in our protocol, to be a possible factor in making the skin over muscles more susceptible to motor impressions than skin immediately over bones, is the sensation which comes immediately after that of contact. It can be somewhat reduced by rubbing vaseline over the surface of the skin tested, but it does not necessarily interfere with the exclusive fixation of other elements of impression of motion. Then comes an indeterminate sense of motion, of which more is said later, sometimes preceding any judgment or even impression of direction. The first impression of direction is quite likely in all cases to be that the movement is upward even when it is downward, a reversal of this impression and sometimes an alternation of impressions leading at length to a correct judgment. This alternation has repeatedly led us to anatomical conjectures. Two nerve-fibres, *a* and *b*, could, *e.g.*, near their tips bend back and hook into each other in such a way that there might be a particular spot on the skin where a straight line would first stimulate the body of *a*, then the tip of *b*, then the tip of *a*, and finally the body of *b*. In almost every possible motion in this direction *a* is stimulated before *b*, and we have not learned to differentiate sensations finely enough, or dermal experience has not sufficiently educated this one spot, to rectify the general rule.

All the *observations in this section* are concerned with only two opposite directions, and those parallel with the axis of the body or limb. It may be added however that, with an apparatus to be described later, observations are being conducted involving discriminative judgments of any horizontal direction as a function of time, rate of motion and dermal area, by a drop-cup and button like the above which can be set by the operator to move out from a central starting-point along any radius. Enough results have already been reached to show not only the great complexity and indefiniteness of the sensations on which a judgment of the direction of motion over the skin is based, but the great inaccuracy of such judgments if not supplemented by muscular innervation; from which it seems not unlikely certain inferences to retinal action may be drawn.

II. *Time-relations of Judgments of Motion on the Skin.* The following Table is based on the same observations as Table I., the only difference being that a number of series available for direction and not for time are excluded, and a few new ones added. It is therefore also a gross Table in which several conditions of rate, weight and place are undiscriminated, with a predominance as before of values for the inside of the fore-arm. These variables, if we except rate, which is but little varied, cause, as will be seen later, no very high average error of time.

TABLE II.

Persons tested.	Number of single observations.	Average time * of all judgments.	Average time of judging + movements.	Average time of judging − movements.	Average time of correct judgments.	Average time of wrong judgments.	Average time of judging − to be + movement.	Average time of judging + to be − movement.
H. H. D.	1956	7·8	6·1	9·4	7·0	10·3	11·0	6·6
W. N.	985	4·09	4·4	3·9	3·3	7·5	7·4	7·9
J. V. D.	744	2·6	2·4	2·7	2·5	5	5	0
G. S. H.	416	3·8	3·9	3·7	3·4	6·8	7·5	5·8
C. D.	263	1·80	1·54	2·1	1·72	4	4	0
H. T.	144	4·42	4·36	4·44	4·37	5·5	6	4·5

* All the above times are in seconds.

The most uniform conditions of the above Table were with J. V. D., upon whom all observations were taken in groups of either eight or ten per sitting, with an equal number each way, on the volar fore-arm, and with very slight variation of other conditions. The least uniform conditions were those with W. N. From this Table it appears (1) that a judgment of motion down the limb takes more time than that of an upward movement; (2) that the time for a wrong judgment is much greater than—sometimes more than twice as great as—the time needed for a correct judgment; (3) that of the two errors it takes longer to judge *minus* to be *plus* movement than the reverse. Why it takes so long to mistake downward for upward movement, when that error is far more common than the opposite one and when also we are so likely to get an early though faint *plus* impression from all motions, it is not easy to say. That an erroneous judgment is given after so prolonged an impression, may be said to show the strength of the tendency. If, as would appear, *minus* movements are a feebler stimulus than *plus* ones, something might be due to less sharpness of attention; but then why should these verdicts be so much longer than correct *minus* judgments? The only explanation we can suggest is, that in these longest of all judgments the sense of time past since the movement began shrinks in consciousness faster than the sensory after-image arising from the moving point fades, so that there comes a moment when we interpret time past as vividness of seemingly shorter impression, and the more vivid the sense of motion, other things being equal, the more like a *plus* motion it seems. Beyond a certain length of time, varying with many conditions, this tendency, if such it be, would be corrected by a sense of distance and direction between the remembered spot where the point first touched the skin and its present position. Again, after all allowances are made for distracted attention, we believe that the short time of correct as compared with wrong judgments shows what has been often remarked in the course of this experimentation, *viz.*, that a too laboured fixation of attention confuses a more rapid and instinctive divination of the direction of motion, which is apt to be correct, though with the feeblest assurance of correctness, before the attention feels itself fully focussed and ready for its more self-conscious and artificial activity.

In another Table, which it is not needful to reproduce in full, the above results were worked out with each group of observations for one day taken as a unit, and these units averaged. This Table, when calculated for an equal number of similar observations, gives as the percentage by which the time of judgment of a *minus* motion exceeds that of a *plus*—

For	H. H. D.,	24	per ct.
„	W. N.,	5	„
„	J. V. D.,	5	„
„	G. S. H.,	9	„
„	C. D.,	30	„
„	H. T.,	1	„

Here, where not single observations but different diurnal verdicts and states are aggregated, even W. N. and G. S. H. fall under the general rule that *minus* judgments require the longer time. The results were once more tabulated by grouping together all experiments on the back, upper and lower fore-arm, ball of thumb, shin and thigh respectively, to see if the general law that *minus* judgments took longer than *plus* had local exceptions or was peculiarly great for any of these parts; but, although with three of our subjects many observations were taken on all these parts, the excess of *minus* judgments was so uniform that we can infer no such difference, and we believe it to be a general law valid in about the same degree for all these parts.

III. *Effect of varying the Rate of Movement or the Distance which must be traversed before the Judgment is made.* We now began to fix our variables. The following Table is accordingly made on one person H. H. D., with a constant weight of 15 grammes, with a circular metallic point 2 millimetres in diameter, and on a definite part of the volar surface of the right arm so arranged that the point traverses the same tract in moving up or down and in successive sittings.

TABLE III.

Rate per second in centimetres.	Total number of judgments.	Distance in cms. before a judgment was made.	Number of correct + judgments.	Distance before a judgment was made.	Number of correct − judgments.	Distance before a judgment was made.
·012	37	·5172	20	·381	4	·733
·034	55	·7888	18	·690	7	·707
·035	65	·5635	19	·427	13	·731
·044	34	·8492	12	·871	10	·836
·046	88	·6624	29	·587	27	·903
·050	11	·6050	4	·675	3	·650
·078	95	·7254	24	·577	30	·657
·086	87	·5782	33	·559	29	·498
·178	40	·5696	14	·569	13	·480
·200	27		8	·640	2	·300
·200	50		19	·680	11	·920
·200	50		23	·560	10	·580
·200	46	·7600	22	·660	8	1·060
·200	18		5	·880	5	1·080
·200	26		13	·820	11	1·340
·200	26		12	·500	6	·800
·200	26		11	·400	11	·500
·850	43	·4760	14	·425	14	·586
1·500	30	·5100	10	·570	6	·885

The most obvious result from this Table is that while the discriminative sensibility for compass-points on this part of the arm, measured longitudinally, could rarely be brought below 25 mms., even in single observations, motion is recognised and its direction discriminated at an average distance of between 6 and

7 mms. The next result is that, while the rate of motion increases more than one-hundred-and-twenty-fold and the time of judgment varies in proportion, the distance traversed at these great differences of rate remains relatively uniform. We may therefore assert the existence of smaller motor "sensory circles" (under the conditions of this Table) inside Weber's discriminative circles, with a longitudinal diameter about only ¼th as great, and with a transverse diameter yet to be reported on. Down to the lower limit of velocity here used it would seem that the after-image of the sensation caused by the moving point from the beginning persisted in consciousness as vividly, or at least as effectively, for 40 seconds as it does for $\frac{4}{10}$ths of 1 sec., or else that the two are judged in different ways. That these results are valid for other individuals and other dermal areas, many incidental observations lead us to think. The last four columns of the above Table, which is based mainly on experimental data entirely different from those used in the previous Tables, are added to show how distinctly the law of the increased time for *minus* judgments holds here. It should also be added that in these observations the time for wrong judgments does not exceed but barely falls short of the time for correct judgments. This is, without doubt, due to more rigorous conditions of experimentation employed here. Where the percipient is very eager to judge quickly on a faint assurance of correctness, as was the case here, the quick judgments are apt to be the wrong ones and the number of errors to be great—as can be readily inferred. We have here then only a different source of error from that discussed above, which was constantly distinguished from it during experimentation. Finally the important generalisation is valid here, as in earlier experiments, that the variations in the time taken for a judgment are mainly based on variations in the *minus* judgment. Computing from the above Table the average error both ways for *plus* and then for *minus* judgments, it is found to be nearly 1¾ths greater for the latter than for the former judgments.

IV. *Reproductions of Rate and Distance with the Other Hand.* For the study of this problem another apparatus was constructed, which consisted of a heavy brass table, 20 cms. high, 26 long, and 15 thick—large enough in fact to stand over a second revolving drum placed in a horizontal position. A slit 3 × 17 cms. was cut out through the middle of this table, and through it a pencil, sliding in a frame and carried by a small car 6 cms. long running in grooves on each side the slit, was gently pressed by weights down upon the paper of the revolving drum beneath. As the points of the apparatus previously described traversed, *e.g.*, the left arm, the right hand resting upon the brass table drew the almost frictionless car by a brass upright rod toward the body at the same rate as the point seemed to move over the skin. Then the lower horizontal drum was allowed to revolve till the record was hidden from sight and another made; great care being taken that the person recording should have no cue whatever except the tactile sense of distance traversed on the arm, and should have no visual knowledge of his own previous records. As the latter were made on millimetre paper they were easily tabulated. The following Table is based on fifty-two such observations, on the same spot of the left fore-arm of the same person, with the uniform conditions of rate 5 mms. per second, weight 75 grms., diameter of point of on the skin 12 mms.

TABLE IV.

Actual distance traversed.	Average distance recorded.	Actual distance traversed.	Average distance recorded.
−		+	
10 cms.	9·2	10 cms.	9·7
8	6·18	8	7·3
4	4·16	4	6·01
2	2·27	2	3·20

The results here, as in other Tables which need not be given for each of four other persons who recorded, were twofold: (1) that *plus* movements seem, as judged from the record, larger than equal *minus* movements; (2) that short distances are relatively longer in reproduction than long distances.

An effort was made to determine the influence of rate on reproduced distances as follows. The point was allowed to traverse the same spot, the same distance and direction four times; then the rate was accelerated for four more records, again accelerated still more, and finally retarded to the original rate; the limits being in these cases one cm. in ten and in one and a fourth seconds respectively, the record being traced simultaneously and with closed eyes. The results of nearly two hundred experiments of this kind show in general (1) that with fast rates distances are reproduced relatively shorter than when the same distance is traversed slowly; (2) that our judgment of such distances themselves and also of changes of rate is liable to great error and to great variations even in successive experiments at the same sitting with uniform conditions. The interval between two points touched on the skin (but not of course seen) can be reproduced with greater uniformity and accuracy than if the entire intermediate tract is traversed. Some individuals also constantly reproduce these dermal intervals larger than they are; and other individuals as constantly smaller. It is of course very hard for the attention to keep in view at the same time the sensation on the arm and a uniform motion by the hands, but practice aids much in this respect. The process seems to be as follows. We catch the rate almost at the first and start the hand at the rate judged. Once started the hand is not free to vary its rate much, but we instinctively strive mainly to keep up a uniform motion of the pencil, and thus within large limits we are satisfied with any initiated rate of pencil movement. An impression of the rate of movement commonly precedes a sense of its direction. This seems also to illustrate how much more dependent we are for accuracy of rate and distance of motion upon those active processes which for want of a better term are called innervation than upon passive sensations. Finally, by setting the drum upon which the tracing point writes in motion, we reproduce Vierordt's curves[1] by a better method than his, a result which could, we think, hardly be obtained if we were sensitive and responsive to fine variations of rate.

V. *Motor Sensibility of Different Parts of the Body.* The following is a specimen Table of observations made with the uniform conditions of a metallic point of contact of 12 mms. diameter pressed by a weight of 75 grms. and moving at a constant rate of 2 mms. per sec.

TABLE V.

Person.	Part of body.	No. of observations.	Average distance taken before a judgment of direction was formed.
G. S. H.	Fore-arm	65	·44
	Upper-arm	68	·40
	Back	24	·85
	Shin	8	·60
	Forehead	8	·20
	Palm	22	·74
H. H. D.	Fore-arm	144	·40
	Upper-arm	104	·54
	Back	82	1·17
	Thigh	54	1·17
	Shin	26	1·80
	Palm	15	·48
	Forehead	31	·84
W. N.	Fore-arm	66	·24
	Upper-arm	32	·31
	Back	28	·49
	Shin	8	·28

It is thus plain that there is a difference in the areas needful to discriminate motion upon different parts of the dermal surface as there is difference of sensibility in discriminating compass-points, far finer though the motor sensibility is. Whether it is more or less variable than the other, and whether it varies with locality in the same manner, our data do not yet enable us to say.

VI. *Effect of Change of Pressure or Weights.*

[1] *Vom Zeitsinn*, p. 92.

TABLE VI.

Person.	Diameter of point of contact in mms.	No. of observations.	Weight 15 grms.	Weight 45 grms.	Weight 75 grms.
J. V. D. - - -	2	50	·56	·41	·33
" - - -	8	88	·74	·49	·44
" - - -	12	48	·49	·37	·35
W. N. - - - -	12	56	·46	·21	·16
C. D. - - - -	12	60	·54	·32	·26
H. T. - - - -	12	48	1·53	·66	·35

In the above Table the rate was constantly 2 mms. per sec. and all other conditions were uniform. It here appears, as well as from other Tables which might be given with different uniform conditions, that the time needful for judgment of direction decreases as weights increase but far more rapidly for the increment from 15 to 45 than for the equal interval from 45 to 75 grms. With regard to the effect of the size of point, the inference from the record of J. V. D. alone that the intermediate size is unfavourable for quick judgment rests on insufficient data and would, we think, hardly be borne out by fuller experimentation. Thus this question still remains for us uncertain. We can attach relatively little importance for our purpose to heavy weights whether applied to a large or a small surface. They indent and stretch the skin, modify the circulation and perhaps the nerve-action and speedily fatigue especially with slow movement. They cause considerable vertical movement in passing over the various subcutaneous tissues, yielding real and apparent variations of pressure. The fact, however, that heavy weights seem to move faster than light ones going at the same rate shows that there is a summation of extensive or of qualitative data affecting our estimates of rate. If there be such a thing as a simple motor sense in the skin at the root of our inference, it is in such cases not independent of aid from other sources. As to the size of the point, we have not yet found a size more favourable for a definite dermal tract than any other. Too small a point presses in too much and by dinting the skin acts unfavourably. Too large a point does not press evenly on all its surfaces and is apt to cause distinct sensations at its opposite edges.

VII. It was at this point that we attempted still further exclusion of variables. A favourable area on the fore-arm 10 × 2·5 cms. was measured off and its corners permanently fixed by pricking in four dots of Indian ink, that we might henceforth confine ourselves to the study and education of this tract alone. We had observed that heat-spots and especially cold-spots greatly aided our judgment of direction. The following observations, *e.g.*, had repeatedly been made: A cold-spot of the first magnitude had been located, and a point placed at very varying distances above it had been allowed to run over it; every time in a long series of judgments the judgment of direction was made exactly when the cold-spot had been reached. This showed us that we had here to deal with a case not unlike that in which a long series of submaximal electric stimuli at length will cause a frog's muscle to contract, but before that threshold is reached another sudden and strong stimulus being applied will raise the curve of increasing excitability more steeply than it would otherwise have gone to the point of contraction. To eliminate the effect of heat-spots and cold-spots therefore, we first need a greatly enlarged map of them all over this area, by fixing the arm very steadily and running our drop-point 1 mm. wide over all its surface, as a field might be ploughed to locate the large stones. In making this cadastral survey, if in traversing it all five times heat-spots or cold-spots were identified every time, they were called of the first magnitude; if four times, of the second, &c. Having thus our map, by the aid of which we could touch or avoid any spot at will or dot them off for the day on the skin, it also seemed advisable to determine how warm metallic points must be not to stimulate cold-spots, and conversely how cold not to stimulate heat-spots. It was soon found however that these limits overlapped, *i.e.*, that an intermediate temperature of a metallic point could be so chosen that it would stimulate both heat-spots and cold-spots. We therefore had recourse to non-conducting cork points of such shape that the smoothed and rounded edge of a right-angled triangle was applied to the skin transversely to the direction of motion. Thus the sensations of temperature appeared to be entirely eliminated.

With a map of all the heat- and cold-spots over this large area before us, we now proceeded to select tracts vacant of these spots and found that, with this elimination, we still judged motion and direction within spaces far less than the average distance necessary for the discrimination of the compass-points. But we also found that, by going over the entire surface and including heat-spots and cold-spots, the spaces needful for these judgments were still less, showing thus again that the temperature-senses, with their highly saturated and probably more specific quality, are of material aid in these judgments. Cold-spots seemed more helpful in fixing locality and in judging motion than heat-spots, because of the fainter sensation and wider irradiation of the latter. We have not yet succeeded in locating pressure-points, as Blix and Goldscheider claim to have done, with sufficient definiteness for any experimentation. For this the points used by us were too large. If such points exist it will be of great interest to determine whether motion can be judged of independently of such points, on intermediate dermal spaces; although the practical difficulty of obtaining motor sensations even with hair-points of contact, without diffused stretching or tension of the skin, even when it is stretched for the purpose of experimentation, will not be readily overcome.

The next and most important elimination attempted was that of the hairs. This was done expressly with a view to determine whether their direction was not the cause of the greater ease in judging *plus* movements. It had been repeatedly remarked in the course of our experiments that these two opposite directions of movement over the skin gave sensations which sometimes developed almost specific differences of quality in consciousness; *minus* motion requiring not only greater weight to be distinctly felt but being thinner, smoother and more uniform. To test the effect of the hairs and their direction we first took—for four consecutive days, on an accurately marked line of the arm where hairs were numerous and pointed us the direction of the *minus* movements—records for the least time of correct *plus* and *minus* judgments under all the known favourable conditions, and averaged the time of all judgments for such directions. We then lathered and quickly shaved this portion of the arm, cutting off even all the lanugo-hairs, and afterwards soaked it till the epidermis slightly swelled, finally spreading vaseline on the surface after it was dried. All was done in a way to excite the skin as little as possible, and we were able to see with a magnifying glass that our tract was clear and that the stub of no hair projected above or even quite reached the surface of the skin. After a short rest the same experiments as before were repeated with the following results—the rate throughout being 1 mm. per sec. and the weight 10 grms.

TABLE VII.

	G. S. H.						H. H. D.					
	Number of correct judgments.		Average time in seconds.		Average time by sittings.		Number of correct judgments.		Average time.		Average time by sittings.	
	+	–	+	–	+	–	+	–	+	–	+	–
Before Shaving.	32	23	2·29	2·58	2·34	2·54	31	34	5·22	6·26	5·08	6·02
After Shaving.	48	35	1.6	2·7	2·3	2·9	65	44	5·5	7·8	5·5	8·7

So far as these figures go, they indicate not only no diminution but an increase of the difference between *plus* and *minus* time after shaving, even if we compare these results with Table II. That our method of eliminating the function of the hairs is entirely faultless or that the above figures are sufficient to be the basis of a law we are not ready to assert, but we are convinced that their direction or they themselves are not in any way the sole cause of the shorter time and greater ease of *plus* judgments, although just what is the action of our moving weights on the hair-bulbs beneath the skin or on the follicles is a physico-anatomical problem not by any means clear. The last two columns were added because here, as often before, promptness of judgment was uniformly greater on some days, and averages by days add to the value of relatively small numbers of observations.

VIII. A number of problems arose for further inquiry.

(1) Many series of records were taken to determine how long, if at all, the sense of motion preceded any impression of direction. This was done either by signaling for motion if it seemed to arise first and again for direction later, when the two were not simultaneous, as very often occurred, and then taking the average difference of time, or better by taking alternate series one for motion and the other for direction with constant place and conditions and comparing the two series. In all these observations the average error was so great that, while there is no doubt whatever that a distinct sense of motion occurs without giving any impression of direction in very many cases, it is uncertain whether the dermal area or the nature of the impression or the state of the attention is most involved. At one time it seemed that the papillary striation was a factor; but, by using a single stiff hair or whisker for the point of contact and working with a lever, it was found that drawing the end of a hair transversely across a single ridge—a distance of less than ⅜mm.—was sufficient to give both motion and direction with much distinctness. Whether the direction of the striæ or their size (which may be readily compared for different parts of the body by Kollmann's method)[1] is a function, is not yet clear. That the relation between the direction of the hairs and that of the motion is involved, seems not improbable. If a single long hair was taken and twisted with a constant tension in the direction of its growth, we were not able to tell from the sensation in which direction it was twisted, but we could tell with *some* accuracy in which direction it was pulled. When our drop-weights moved slowly up or down the arm over a spot where the direction of the hairs was transverse to the direction of motion, the latter often seemed for some time to coincide with that of the hairs. In such cases, as we knew the point was moving up or down the arm, the interval between a sense of motion and a judgment of direction was of course very great. Often where ciliary effects had been reduced by shaving and papillary effects perhaps lessened by oiling, with large and polished points of contact, the sensation was repeatedly described as that of a button twirling about without transverse movement, and then twirling again in another adjacent place. This, however, seems readily accounted for by the fact that at a given moment more papillæ, hairs or sensory elements were being stimulated under the button by rubbing against the successive parts of its surface, than were being newly stimulated by its advancing or were losing stimulus

[1] *Der Tastapparat der Hand, &c.*, von Dr. A. Kollmann; Leipzig, 1883.

at its receding edge. Though by polishing and oiling the point we had not reduced the intensity of the stimulus, we had perhaps increased its sensory effect by reducing it near to that minimal intensity, giving maximal impressions, which must exist somewhere within the degrees of slight contact that cause tickling.

(2) Incidentally, the great complexity and diversity of dermal sensations has been often and in many ways apparent. If a point be allowed to move over ten or twelve inches of dermal surface and if the weight is light, it is found that at certain spots the impression of contact is lost, and again the rate seems to change as if there were acceleration-points. If instead of weights we substitute a metallic point of a square millimetre in area, joined to the secondary coil of a Sledge inductorium, holding the other electrode in the form of a wet sponge in the hand, the experiences of its journey down the arm are manifold and vivid. For a time tickling is quite unpleasantly dominant, at other places the point seems to scratch, at others the thrilling quivering sensation familiar in electric stimulation seems dominant, while at others sharp sudden cutting pains and at still others no sensation save that of a moving point are felt. The nature of these sensations varies greatly with the strength of the stimulus, and very soon the arm in the vicinity of such application is so fatigued as to be quite worthless for experimentation for a long time. It is moreover extremely hard to sharply differentiate and identify sensations that seem to be so impacted and run together, and which language has never before been called upon to disentangle. We have a number of fragmentary records like the following. In five consecutive trips of such a point over the same tract for ten centimetres, three spots of cutting pain were identified every time, two four times, two twice, and three were observed only once. The same was the case with thrill-points, and less sharply with tickle- and acceleration-points. The identification of these sensations the next day from a dense and wide penumbra of other sensations which often obscure them has not yet been very satisfactory. No doubt, these stimuli act subdermally, and the differentiation of the sensations is in part to be explained from the grosser anatomy of the subjacent structures. We had no reason to think, however, that our stimuli were great enough to effect subcutaneous muscles. With different degrees of intensity or of fatigue, these results are greatly modified. An important point repeatedly verified was that, if these stimuli are at all strong, the time required to judge the direction of motion is longer than if the same point is used with the current turned off. As we used only currents of just sufficient strength to give quite vivid sensations, we are in doubt whether this rule would apply to feeble currents, although it seems probable that the latter would aid the judgment of direction. The effect of our currents, no doubt, was widely irradiated and somewhat distracting to the attention. It occurred to us that, by using strong wound magnets of soft iron as our points of contact, which

by a silently working key could be demagnetised by the operator without the knowledge of the percipient, the effects of magnetic action applied to the skin, or the power to judge direction, might be studied as an aggregate result of a large number of observations, after the method employed by Féré and Binet.

(3) Another problem left incomplete in our work is the effect of very fast and very slow motion over the skin. It was repeatedly found that, with a very slow rate of 1 mm. in from 10 to 18 secs., a drop-weight that could be distinctly felt seemed quite at rest on the arm while it really moved six or eight and in one case over eleven centimetres. Here not only must friction be reduced to a minimum but—what is far harder, in fact almost impossible for one familiar with the experiments—there must be no impression that can be remembered of the general position on the limb of the start; for, with that in mind, we are sure after a certain distance, even if we have no sense of motion, to observe that its position has changed. Again we were also able, by means of another yet imperfect apparatus, to produce motion over the skin of the arm for about three inches so rapidly that the percipient could not tell at which terminus the motion began and at which it ended. Motion seemed to be felt but may have been only inferred, as the conditions of the experiment were known and only motion applied. The fast and slow limits and the way in which their courses develop remain yet to be determined.

The effects of previous rubbing, blistering, stretching, &c., on the judgments of dermal motion are also incomplete. Hard rubbing with pressure greatly reduces sensibility to motion, and a slight amount of very superficial friction seems to increase it.

In conclusion, it would seem that "local signs" are quite heterogeneous, and that, in the strong tendency we have to move the touching dermal surface over objects in contact with it, we are seeking not merely to multiply but to diversify our sensuous data for judging the nature of the impressions and to fill up the dermal "blind spots" between which impressions are sifted in to us. The astonishing development which dermatology seems now undergoing is no less striking from the psychological than from a pathological or anatomical standpoint. The effect of disturbed dermal functions in affecting psycho-sensory sanity; the fact of the genetic origin of senses and central nervous system from the external embryological layer; the function of specialised dermal sensations in presiding over the exercise of the sexual activities; and the relation of what the old psychology roughly called Touch in giving us the primary qualities of matter—all indicate the skin as not only the primeval and most reliable source of our knowledge of the external world, or the archæological field of psychology, but as a just opening experimental domain of great breadth, where work seems now possible that may compare in both quality and quantity with that accomplished in physiological optics, and which may shed new light on some of the most fundamental problems of psychical action and unfolding.