THE SENSATION OF MOVEMENT

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A number of psychologists and physiologists have undertaken the study of the location of the sensation of movement in its various phases with varying results. Among those who have reached different conclusions, in greater or less degree are Nagel, Strümpell, Goldscheider, Angier and Pillsbury. Goldscheider¹ reached his conclusions after experimenting along three different lines: (1) Moving the finger by means of weights, (2) passing a current through the joints, and (3) rousing reflexes by means of tapping on the joint, applying acids, etc. (1) He experimented on the index finger by means of weights. The hand was placed in a static position with only the end of the finger free. A cord fastened at one end to the tip of the finger was passed over a pulley and a delicately poised scale was attached to the other end. By putting weights on the scales the finger could be moved until the subject detected the sensation. A needle attached to the scales recorded on a revolving drum the results of the experiment. The pressure of the string on the finger naturally produced a skin sensation, but Goldscheider asserts that in addition to this sensation another sensation was also recognized, easily distinguishable from the skin sensation, and located apparently in the joints. (2) To substantiate this result further experiments were made with an electric current passed through the fingers at different places, particularly the joints, with the result that when the electrodes were placed over the joints sensitivity was in every case reduced greatly. (3) He then experimented on the reflexes in frogs and rabbits. He attempted to produce a reflex in frogs by stimulating the surface of the hip and shoulder

¹ GOLDSCHIEDER. Ueber den Muskelsinn und die Theorie der Ataxie. *Gesammelte Abhandlungen*, 9-96. Ueber die Empfindlichkeit der Gelenkenden. *Ibid.*, 282-287

joints. An ordinary contact stimulus gave no reflex, while a light tapping on the joint produced movement, although Goldscheider himself admitted that in tapping other factors might have entered in to produce movement. Acids which did affect the adjacent skin had no effect whatever on the joint. With the rabbit the breathing reflex was used as an index of sensitivity but no uniform results were obtained. The skin of the leg was cut open to lay bare the bone and experiments were made on the periosteum, capsule and marrow. A light stimulus applied to the joint produced no reaction and when a stronger stimulus was used it sometimes resulted in reactions and sometimes not. Thus it might be inferred that sensation can be produced by mechanical means in the joint but it is not thereby proven that the joint is the seat of sensation. Reflexes were also produced by stimulating the periosteum and the marrow.

Goldscheider came to the conclusion that sensations of movement arise (1) from the rubbing of the articular surfaces and the wrinkling of the capsule, (2) strain on the tendons of one set of muscles and relaxation of their opposites, (3) change in the form of muscles. This opinion was very generally accepted until the first conclusion was criticized by Pillsbury¹ who proved first, that by passing a current through the wrist there followed nearly as marked a decrease in sensibility as when the current was passed through the elbow itself; and second, that the sensory innervation of the joint has not been definitely proven by histologists.

Angier² experimented with the lower arm and confined its movements to a horizontal direction. His problem was to determine the accuracy of judgment in comparing the distances of points by movements of the elbow. The details of his work are irrelevant to our discussion but some of his inferences are of interest. Angier believes with Goldscheider that sensation of movement comes largely from the joints. The condition of the muscle, whether normal, flexed or extended did

¹PILLSBURY. Does the Sensation of Movement Originate in the Joint? *Am. Journ. of Psych.*, 1901, 12, 346-353.

²ANGIER. Die Schätzung von Bewegungsgrößen bei Vorderarmbewegungen. *Zeitschr. f. Psychol. u. Physiol. d. Sinnesorg.*, 1905, 39, 429-448.

not materially affect his results, nor did the position of the arm within certain limits play an important rôle. In my experiments, however, I found that the angle of the arm and its position with reference to the body profoundly influenced results.

Strümpell¹ is inclined to ascribe the chief sensation of movement to the muscles, but he gives no reason for his opinion. He proved, however, that muscles could stand great lesions without disturbing the accuracy of perception. This would seem to combat his own theory, though it is not necessarily a disproof.

Nagel's² opinion is that sensations of movement cannot be derived from the skin. As Pillsbury believes that sensations of movement come from the tendons and muscles, the conflict seems to be chiefly between the rival theories, the joint theory and the muscle and tendon theory.

In Pillsbury's experiments little attention was paid to introspection but conclusions were drawn from an interpretation of physical results supplemented by an appeal to well-established physiological data as to the location of sensory endings. In our experiment there was also a minimum of introspection, the subject being merely asked occasionally whether he felt movement in any particular place. In one set of experiments, however, no heed was given to limina and the subject was asked to concentrate his whole attention in an endeavor to locate the place of sensation.

The following investigation was conducted at the suggestion of Professor W. B. Pillsbury, to whom as also to Dr. J. F. Shepard, the writer is indebted for suggestions and criticisms.

The subjects were Professor Pillsbury (*P*), Dr. Shepard (*S*), Messrs. Work (*W*), Woodrow (*Wo*), Cook, Osborn, and the writer (*Wi*), all of whom had had previous psychological training. Experiments were confined to measurements of the limen of movement of the elbow, normal and with current through the upper and lower arm, elbow, wrist and hand.

¹STRÜMPELL. Ueber die Störungen der Bewegungen bei fast vollständiger Anästhesie. *Deutsche Zeits. f. Nervenhe.*, 1903, 23, 1-38.

²NAGEL. Die Lage-, Bewegungs- und Widerstandsempfindungen. *Handbuch des Physiologie des Menschen*, III., 733-806.

The apparatus was the same as that used by Professor Pillsbury in his experiments in 1900. Since Spearman¹ criticized Pillsbury on the ground that the speed was too slow, four speeds were used. A hinged board served to support the arm which was raised by a cord passing over a pulley in the top of an upright. The cord was attached to one of a series of pulleys which were connected with a worm gear and run by means of an electric motor. A pointer in the end of the board passed over a millimeter scale on the upright and served to measure the amount of movement of the arm.² In all the experiments the subject sat with his arm resting upon the board, the elbow near the hinge. The angle of the elbow varied in the successive experiments from 75 to 150 degrees.

As indicated in the tables the first series of experiments were taken with the arm normal; then a series was taken with an induction current running through the elbow, wrist, tips of fingers, palm of hand or muscles and tendons of the lower arm. A series was also taken using ether for anæsthesia in place of an electric current. The apparatus was arranged so that the downward movement could be measured as well as the upward movement. The figures in the tables represent the averages of experiments ranging in number from 10 to 210.

When all was in readiness the motor was started and the operator gave a signal about two seconds before the board began to rise. The signal was given at this time in order that the subject might concentrate his attention to catch the first sensation of movement. A few experiments were taken without signal to test the subject's error of anticipation.

Of the four speeds used the first was the slowest, the second a little faster and the fourth was the fastest of all. A comparison of these speeds in terms of seconds is given below (Table IV).

A study of the tables given herewith will reveal among other things the following:

1. *The Influence of a Particular Angle.*—In Table I. the

¹ SPEARMAN. Fortschritt auf dem Gebiet der Psychophysik der räumlichen Vorstellungen. Tastsinn. *Arch. f. d. ges. Psych.*, 1906, 8, 1-51.

² The length of the arm board from hinge to pointer was 52.4 cm.

angles for each respective set of experiments were uniform and hence allow of no generalizations. In Table II. *Wo's* results in general, both normal and with current, in speeds 1 and 2, going up, show a limen for angle 135 to 150 degrees about twice as large as the limen for angles 75 to 80 degrees. In speed 4, this judgment is reversed, and in speed 3 the results obtained on different days are so various that other factors, physical or mental, must have entered. The results going down vary apparently without any relation to the size of the angle.

Wi's results in speed 2, going up, also show a larger limen for the larger angles.

TABLE I

	Elbow Angle		Speed		Normal		Cur. to Elbow		Cur. to Muscle		Cur. to Wrist	
	Up	Down			Up	Down	Up	Down	Up	Down	Up	Down
W.				Tests	210 mm.	20 mm.	50 mm.	20 mm.	40 mm.	20 mm.	50 mm.	20 mm.
	113	91	1		4.7	3.0	7.2	4.0	17.5	7.4	7.1	4.9
	113	91	2		5.2	3.5	6.0	3.2	16.8	5.0	6.0	3.0
	113	91	3		5.5	3.5	7.1	3.9	19.0	6.8	7.6	5.5
	113	91	4		4.6	3.7	5.8	5.0	11.8	6.0	5.9	4.6
P.				Tests	60	30	20	10	20	10	20	10
	123	51	1		4.9	6.9	5.3	5.6	14.3	6.1	13.3	6.9
	123	51	2		5.4	6.1	7.3	5.7	13.0	4.8	10.0	8.6
	123	51	3		6.8	4.6	9.0	4.3	15.3	5.6	12.2	7.6
	123	51	4		4.8	4.9	13.5	6.5	9.2	4.0	9.6	14.7
S.				Tests	20	10	10	10	10		10	
	135	117	1		2.8	5.9	8.9	9.8	6.1		4.5	
	135	117	2		4.6	4.0	6.8	9.5	6.0		5.3	
	135	117	3		5.6	4.7	8.1	9.2	7.5		6.0	
	135	117	4		5.7	4.8	7.1	8.3	5.6		3.9	

Speeds 1 and 3 partly reverse this order, but a new factor enters here,—the position of the arm with reference to the body. With the lower arm parallel to the line of the chest, angles 75 to 80 degrees gave a smaller limen than angles 135 to 150 degrees; but with the arm at right angles to the chest and with the elbow close to the body, the sensitivity with the small angles was greatly reduced. This was undoubtedly due to the extra pressure of the muscles against each other at the elbow. Inasmuch as the joint is little affected by the position of the arm in these experiments and the muscles are greatly

affected and the sensitivity reduced, the results would seem to corroborate Professor Pillsbury's theory of muscular sensation.

TABLE II

	Tests	Elbow Angle		Speed	Normal		Cur. to Elbow		Cur. to Muscle		Cur. to Wrist	
		Up	Down		Up mm.	Down mm.	Up mm.	Down mm.	Up mm.	Down mm.	Up mm.	Down mm.
Wo.	15	150	135	1	12.5	8.3	6.7	7.6	12.3	8.3	11.2	4.0
	18	75	75	2	5.3	6.1	10.3	4.0	16.8	6.2	10.5	6.0
	15	135	135	1	13.0	2.5	15.3	3.6	11.2	4.4	11.2	6.0
	18	180	80	2	6.3	4.5	8.1	3.0	7.7	4.9	7.5	7.2
	18	130	130	3	6.3	9.0	5.3	9.9	6.7	9.9	7.5	4.8
	18	130	130	3	15.6	5.2	23.1	15.7	28.	17.	30.5	5.4
	17	115	140	4	4.6	4.1	5.4	8.1	6.4	7.9	5.8	7.3
	18	130	130	4	3.1	5.4	2.5	5.7	4.4	2.7	3.1	4.0
	18	130	130	4	3.8	2.2	4.1	2.6	3.6	2.8	2.4	4.5
	15	130	130	1	6.9	2.6	16.4	2.5	28.6	11.6	30.6	9.4
Wi.	18	60	60	2	15.4	2.6	27.5	4.5	15.9	7.5	19.8	6.5
	15	130	150	1	17.9	6.3	35.1	10.8	30.0	16.8	29.7	13.4
	18	80	80	2	8.5	3.2	35.1	16.2	15.0	13.5	28.2	9.6
	15	150	130	3	6.3	4.6	12.8	10.5	22.8	17.1	22.2	15.0
	18	88	88	3	25.2	8.8	44.1	15.8	55.2	7.9	43.2	18.3
	18	85	85	3	18.1	4.2	43.7	9.6	48.6	6.9	51.7	7.5
	15	150	150	4	8.6	8.8	11.2	10.8	17.8	20.4	18.3	15.8
	18	175	176	4	9.1	7.1	19.3	9.3	24.2	6.2	25.8	9.4
	18	85	85	4	8.9	3.0	22.2	7.4	16.4	8.3	39.0	10.4

2. *Comparison of Ups and Downs.*—*Wo's* results for speeds 1 and 2, going down, have predominantly the smaller limen. This is true of all of *W's* results, of *P's* speeds 2 and 3 and my speeds 1 and 2. With the other speeds the results either vacillated or were reversed. *S's* results show that for normals the up movements had the larger limina and when the current was applied the down movements had the larger. Thus there seems to be little uniformity and the results warrant no generalization.

3. *Factors Influencing Judgment.*—(a) Accuracy of judgment is greatly influenced by the physical condition of the subject, and also by the peculiar position of the body. With the head leaning forward on the hand the limen immediately increased, as it did also when the head was allowed to hang forward. Remarkable differences in results, using the same angle and same position but on different days, are seen in *Wo's* figures for speed 3, the limen ranging from approximate equality to a ratio of 4 to 1.

(b) The time of giving the signal. This is an important factor. Suggestion plays a strong rôle. The subject soon gets into the habit of expecting to feel movement at a certain time after the operator says 'now' and this causes large errors of anticipation. If the signal is given at a stipulated period of time, known to the subject, it is impossible to tell exactly just how many judgments are real judgments of movement. The number of zeros or mistaken judgments revealed by the records by no means tells the whole story. Often the subject was sure of movement sensation when the board was perfectly still. Occasionally the unevenness of the electric current was responsible for errors. Anæsthesia by means of ether obviates this difficulty to some extent. But if the subject was deceived once when he was positive he felt motion, why is it not possible that every other judgment of movement was only the result of imagination? This applies particularly to speed 1 which is so slow that even when the subject knows his arm is moving he frequently is unable to detect the sensation.

Again, in speed 1 we experimented to ascertain whether the sensation remained constant after movement had been (apparently) felt, and we found that sensation was not continuous but would be lost to consciousness at intervals and after a few seconds reappear. This indicated, then, a fluctuation either of attention or of the sensation of movement. This phenomenon offers an interesting problem to be worked out, although its presence detracts largely from the reliability of the results as a basis for scientific inferences regarding the location of kinæsthetic sensations.

Giving the signal about two seconds before the arm rises affords a uniform and constant expectation and the error of anticipation is perhaps reduced to a minimum. Varying the interval between signal and rise of board from one to ten seconds increases the error of anticipation. Giving the signal just as the board begins to rise vitiates the experiment as it scatters the attention for the moment, during which time movement might have been felt. The same is true if the signal is given shortly after the board begins to rise. Experiments show that under these conditions the limen rose considerably. The

constant gradual motion had already begun before the subject fixated his attention and there was no period of change from no-motion to motion in his attention.

(c) Degree of attention is also an important factor. Occasionally when the subject had been giving several judgments whose limen was found to be much larger than ordinary, he would 'buckle down' and the limen would immediately decrease.

(d) Elimination of the signal. A number of experiments were taken without giving a signal,—the operator at first following the old method of allowing the board to rise or fall at stated intervals, and later holding the board from 1 to 90 seconds. The results are here given.

TABLE III

	Tests	Elbow Angle		Normal		Cur. to Elbow		Cur. to Muscle		Cur. to Wrist	
		Up mm.	Down mm.	Up mm.	Down mm.	Up mm.	Down mm.	Up mm.	Down mm.	Up mm.	Down mm.
Wo. . .	15	145	80	5.5	8.0	6.2	4.8	6.5	4.0	9.9	3.2
Wi. . .	18	160	85	21.1	9.0	26.7	16.0	26.8	15.7	50.8	19.0

Naturally the long waits increased greatly the error of anticipation, and many erroneous judgments were made. The figures which show only the averages really give a deceptive idea of the experiment. In reality the limen varied from zero judgments to 88 millimeters. All of my results without signal were much larger than those with signal, but *Wo*'s limen without signal was as small as the smallest of the others. He seemed all along to be possessed of very keen sensitivity. My results show that several times, after waiting as long as from 50 to 90 seconds, I yet made a wrong judgment.

4. *Comparison of the Speeds.*—Spearman (6) criticized the low speed used in Professor Pillsbury's experiments. To obviate this difficulty we used four speeds whose rates were as follows:

TABLE IV

Distance traversed, 0 mm. to 10 mm.

Speed.	1	2	3	4
Seconds.	13.34	5.24	4.30	1.90

Speed 1, it will be seen, is very slow, the board moving only ten millimeters in thirteen seconds, while speed 4 is rapid. The results obtained with speed 1 were the least satisfactory, especially when a current was used. The subject would frequently say, "I think I feel movement but am not sure," and even when the subject knew his arm was moving he frequently could not detect sensation.

5. *Location of the Seat of Sensation.*—Anæsthetizing one part of the arm is sure to result in a partial anæsthesia of the neighboring parts by a kind of irradiation. This complicates the problem, as we cannot tell just how large a share of the effect we are to attribute to the anæsthesia of the particular part in question. Acting on the general principle, however, that the part to which the current is applied will be most affected by it, we may say that to establish Professor Pillsbury's theory from experimental results it will be necessary to show that when the current is applied to the muscle, or the union of muscle and tendon, the sensitivity is reduced as much as when applied to the joints. *W*'s records show in practically every case that when a current was applied to the muscle of the arm the sensitivity was less than with the current applied to either the wrist or elbow. *P*'s record, going up, generally coincides with *W*'s. His records going down show no uniformity. In *S*'s case, the sensitivity was most reduced when the current was passed through the elbow, and in *W**o*'s case and my own there is absolutely no uniformity.

A comparison of the limina with current applied to the wrist and elbow, in succession, fully substantiates the contention of Professor Pillsbury that anæsthesia of the wrist causes almost as great a decrease in sensitivity as anæsthesia of the elbow. In several cases the limina for the wrist were greater than those for the elbow. A series of experiments were taken also with a current applied to the upper arm, and it is significant that the limen thus obtained was about twice as large as the limen for the normal experiments.

It has seemed to the writer that introspection during the experiment should play a larger rôle, and that its results would be more conclusive than the objective study of limina. In our

experiments the subject was sometimes asked where he felt sensation, and the answer showed that most of the sensations were located in the finger tips and hand, while scarcely any sensations were felt in the joint or muscle. *Wo* insisted throughout that his sensations were nothing but skin sensations, and in the experiments conducted as those described above I incline to the same view. With the up movements there was a sensation of 'pushing up' from beneath, and with the down movements there was a kind of 'sinking' feeling throughout the hand. With regard to this sensation it may be well to note that if they are in reality skin sensations they are entirely irrelevant to the problem and should be ignored; for it is certain that they would not be felt if the arm were raised without the aid of the board underneath. If, on the other hand, these sensations are more deeply seated, though seemingly located in the skin, the probability is that they are muscle and tendon sensations stimulated by the contraction of the muscles and tendons at the elbow with which they are intimately connected.

To obtain a little more introspection, a series of experiments was taken in which the subject was asked to attend, not to the moment *when* sensation was felt, but *where* it was felt. Almost every conceivable answer was given, showing conclusively that mere introspection could never solve the question as to the location of sensation. Here are a few of the answers given: skin and muscle; under wrist; elbow; finger tip; wrist to finger; muscle at elbow; whole arm; arm and shoulder; muscle under arm; near wrist; skin at elbow, etc., etc.

The last series of experiments were the most interesting and, I believe, the most fruitful of results. It was found in the preceding experiments that running an electric current through the finger tips and the ball of the thumb did not result in perfect anæsthesia of these parts. The sensation was still located there more than anywhere else. To make sure of the anæsthesia of these parts, as well as the skin under the muscle, ether was applied on sponges with the result that no sensations were felt there. The introspective results are noteworthy. The subject announced that he no longer had a skin sensation

of any kind but that a different sensation was now felt (different in kind) and located very perceptibly in the muscle and tendon. It would seem that these results come nearer a solution of the problem than the former ones. Ether produces an unnatural state of the organs, to be sure, but not so unnatural a state as the electric current produces. The current produces motion through the whole arm and increases the difficulty by compelling the subject to discriminate between movement caused by the rising board and that caused by the current. The element of false movement is at least eliminated with the use of ether, thus giving a better opportunity for introspection.

Before giving a summary of our results it might be well to mention the statement of Dr. Shepard that most of his laboratory students in the last ten years, several hundred in all, have obtained results similar to those given here.

If we bring together the results of the experiments, it seems that the effect of passing a current through the elbow is not as Goldscheider assumes to anæsthetize the surface of the joints but to anæsthetize the muscles and possibly the tendons about the joint. That this is true is seen from the fact that a similar current passed through the muscles anywhere else has the same effect, and in much the same degree. The current passed through the upper arm, the forearm, or the wrist tends to increase the limen and in many cases more than when passed through the elbow. This conclusion is confirmed by introspection. The sensation of movement is almost without exception assigned to the fingers, muscles of the forearm and other muscles or tendons or the surface of the body over them. It might be noticed in this connection that the illusion of pushing up at the elbow when mercury is poured from a beaker or when a heavy weight is lowered upon a cushion is always referred to the muscles below the elbow, not to the joint, and is to be explained from the sensations in the muscles themselves, not to the pressure that they exert upon the joint surfaces. In fact there is no single bit of real evidence that the sensations of movement come from the joint surface. This experimental result is in harmony with the statements of the histologists that there are no sense endings

on the joint surfaces. The sensation may come from the capsule, from the ligaments and from the muscles and tendons that are involved in the movements but not from the joint surfaces.

SUMMARY

1. Passing a current through the wrist reduces sensitivity as much as passing the current through the elbow. This would seem to refute the evidence offered by Goldscheider for proving the joint to be the seat of movement sensation.
2. An apparently better way to indulge in introspection is to use ether to anæsthetize the skin.
3. The results obtained with the use of ether tend to corroborate Professor Pillsbury's theory that the muscles and tendons are the seat of the sensation of movement.