# A COMPARISON OF SIGHT AND TOUCH. By H. P. BOWDITCH, M.D., *Professor of Physiology, Harvard Medical School*, and Wm. F. SOUTHARD, M.D. Pl. XVII.

Our knowledge of the position of objects in the external world is derived almost wholly through the senses of sight and touch, each sense aiding the other, and both receiving assistance from the muscular sense.

Without attempting a discussion of the question whether touch or sight furnishes the more primitive and fundamental data to consciousness, it is interesting to inquire which sense supplies us with the more accurate information as to the position of objects around us. The comparison may be made in several ways. In the first place, we may compare the smallest distances within which two impressions made upon sensitive surfaces can be recognized as separate and distinct. It has been found, for example, that the distance between two luminous points, as two fixed stars, must subtend a visual angle of at least one minute, in order that the sources of light may be recognized as distinct from one another[1]. A visual angle of one minute corresponds to a distance of 0·00438 mm. on the retina, which is about the diameter of the cones in the macula lutea according to Kölliker's measurements. Now, since the smallest distance upon the surface of the body at which two tactile impressions are recognized as distinct is, according to Weber's researches, 1·1 mm.[2] (upon the tip of the tongue), it follows that the retina is 251 times more accurate than the most sensitive part of the surface of the body in localizing impressions made upon it. It may be objected, however, that a comparison of this sort has little value, inasmuch as it is the optical image of the object which is applied to the retina, while the object itself is brought in contact with the surface of the body. It is interesting, therefore, to compare the absolute size of the smallest intervals by which two external objects must be separated in order that they may make distinct impressions upon the two senses. In

[1] Helmholtz. *Physiologische Optik*, p. 216.
[2] See Foster's *Text Book of Physiology*, 3d Ed., p. 532.

thus comparing sight and touch, it is, of course, necessary to limit the comparison to those distances within which both senses may be used to obtain information in regard to surrounding objects. The sense of touch cannot, of course, be used for objects beyond the reach of the arm, and the sense of sight is useless for objects nearer than the nearest point for which the eye can be accommodated. For all distances, however, greater than the near point of vision and less than the length of the arm, the two senses of sight and touch are in constant use in determining the size and nature of surrounding objects. The question is, which sense affords us the most accurate information? Seventy-five centimeters may be taken as the distance within which objects may be easily reached by the hand, and ten centimeters as the near point of vision. Using the above-mentioned minimum visual angle of 1′, we find that this angle is subtended at the distances of 10 and 75 cm. by lines of 0·03 and 0·2 mm. respectively. That is to say, two points, 0·03 mm. apart, at a distance of 10 cm. from the eye, are seen to be distinct and separate, and the same is true of points 0·2 mm. apart at 75 cm. from the eye. Now since, according to Weber, two points, in order to produce separate impressions upon the skin at the ends of the fingers, must not be less than 2·2 mm. apart, it appears that within the above-mentioned limits of 10 and 75 cm. the sense of sight is from 10 to 70 times more accurate than that of touch. Although the result of these comparisons is in favour of the sense of sight, it is important to bear in mind that by the methods here pursued, it is only the accuracy and delicacy of two sensitive surfaces that are compared together. As we use our senses, however, in daily life, the data of sight and touch are intimately associated with those of muscular sense. We must, therefore, proceed to inquire whether the relative superiority of vision over touch as determined by the above comparison of the delicacy of their recipient organs is maintained when each sense is aided, as in daily life, by association with the muscular sense. Several circumstances suggest that this may not be the case. It is, for instance, a matter of daily experience that we depend more upon touch than upon vision in estimating slight differences of level in contiguous surfaces. Thus we judge of the accuracy with which the parts of a piece of furniture are fitted together by drawing the finger-nail over the line of junction, obtaining in this way far more accurate information than the eye could furnish. The well-known experiments with prismatic spectacles[1], showing how important it is that the data

[1] Helmholtz. *Physiologische Optik*, p. 601.

of vision should be corrected by those of touch, are also to be mentioned in this connection.

For those reasons and also for the sake of obtaining more precise quantitative results than those above mentioned, it seemed desirable to select some test of the accuracy of our spatial knowledge which could be applied successively to the data of sight and of touch as ordinarily obtained in the daily use of our senses.

Such a test seems to be furnished by the power we possess of executing, under the guidance of our muscular sense alone, a movement toward a point the position of which has been determined by sight or by touch, the precision with which the movement can be executed, or, in other words, the distance between the point reached and the point aimed at affording a measure of the accuracy of our knowledge of the position of the object which has been seen or felt. In applying this test, the writers have made a large number of experiments, to record which is the object of the present paper.

The method of proceeding was as follows: The experimenter seated himself at a table covered with a large sheet of white paper upon which a small movable object was placed. After various experiments, the most convenient object for this purpose was found to be a small brass disc about 5 mm. in diameter, having in the middle of one side a small projecting point. This object was placed in different positions on the paper, a short rod being used for moving it about to avoid touching it with the hand. The experimenter then having observed its position closed the eyes, and endeavoured to place the point of a pencil, held in the right hand, as accurately as possible upon the disc. The error, *i.e.*, the distance between the disc and the pencil point, was then measured and recorded. In a second set of observations the experimenter closed the eyes and placed the disc in position with the left hand. Then, withdrawing the left hand and keeping the eyes still closed, he endeavoured to place the pencil point upon it as before.

In a preliminary series of experiments[1] comprising sixty trials, in half of which the position of the object was determined by sight, and in the other half by touch, the result was found to be as follows:— Location by sight: maximal error, 23 mm.; minimal error, 3 mm.; average error, 11·4 mm. Location by touch: maximal error, 38 mm.; minimal error, 8 mm.; average error, 19·2 mm. It would thus seem

[1] Reported to the Boston Society of Medical Sciences, Oct. 21st, 1879, and described in the *Boston Medical and Surgical Journal*, Nov. 11th, 1880.

that the knowledge of position in space obtained through the sense of sight is nearly twice as accurate as that obtained through the sense of touch. Several questions suggested themselves in the course of this preliminary investigation.

## Indirect Vision.

In the first place it is evident that when the position of an object is determined by fixing the eye or placing the hand upon it, the information is obtained less through the senses of sight and touch than through the muscular sense of the muscles which move the eye or the arm.

It seemed desirable, therefore, so to modify the experiment as to exclude the aid obtained from the muscular sense by the sense of sight, and to determine whether under these circumstances vision would still retain its superiority over touch. This could, of course, readily be done by directing the eye, not upon the object to be aimed at, but upon some fixed point upon the sheet of paper, so as to allow the image of the object sought to fall upon the lateral portions of the retina. To this end the observer always fixed his eyes on a point marked in the centre of the sheet preserving a constant position of the head by holding in the teeth a piece of wood, secured in a holder clamped to the edge of the table. Around the point of fixation were drawn lines indicating successive angular distances of 2° from the centre of the field of vision. Owing to the fact that the line of vision met the plane of the paper at an angle considerably less than 90°, these lines were of course ellipses[1].

In experimenting in this way it was, of course, more difficult to reach those portions of the paper lying beyond than those lying within the point of fixation. To overcome this difficulty and avoid any error which it might introduce, a series of experiments was made in which the paper instead of being laid upon a table, was fastened vertically against a wall. The eyes of the observer were secured in a fixed position opposite to, and about 60 cm. from, the centre of the sheet of paper, and circles instead of ellipses drawn round the point of fixation indicated successive

[1] It might reasonably be expected that the greater the distance between the macula lutea and the image of the object the less accurately would its position be determined, and it became of interest to inquire at what rate the accuracy diminished and at what point it becomes equal to that of touch. In order to determine this point it became necessary in this set of experiments to determine not only the error of the estimated position, *i.e.*, the distance between the disc and the pencil-point, but also the quadrant of the field of vision in which the object was placed and its angular distance from the centre of vision. Although many hundred observations were made and recorded in this way, the data were not found to be numerous enough to justify any precise statement upon this subject.

angular distances of 2° from the centre of the field of vision. As it was of course impossible to place a disc or other movable object upon the vertical sheet of paper used in these experiments, the following plan was adopted for obtaining an easily adjustable point for observation. The experiment was performed in a dark room into which a beam of sunlight from a heliostat was admitted through a narrow opening. The beam was received upon two small circular mirrors about 2 mm. in diameter[1].

One of these mirrors was fixed in its position and directed its ray upon the centre of the sheet of paper. The spot of light thus produced served as the point of fixation for the eyes of the observer. The second mirror, adjustable on a ball and socket-joint, was placed within easy reach of the hand of the observer, and served to produce a spot of light upon any part of the sheet of paper that might be desired. In other respects the experiment was conducted as already described.

*Effect of using the same or different Hands in Localization and in Search.*

In the experiments above described in which the position of an object was determined by the sense of touch, the localization was always effected by means of the left hand, while the right was used to execute the movement in search of the object. Opposite hands were used because it was thought that the employment of the same hand would give to the sense of touch an undue advantage over that of sight, and thus interfere with the accuracy of the comparison instituted between the two senses. It seems, however, desirable to ascertain how great this advantage might be, and for this purpose experiments were made in which the position of the object was determined by the same hand which was used to execute the movement in search of it.

*Effect of Time.*

In conducting these experiments it soon became evident that the time elapsing after the fixation of the object, by the eye or hand, before the attempt was made to place the pencil-point upon it, influenced the accuracy with which the movement could be executed. It might, perhaps, be supposed that this effect of time would consist simply in causing the mental image of the position of the object to become less and less distinct, and that the longer the interval between the determination of the position of an object, and the effort to execute a movement

[1] Mirrors of this sort were readily obtained by pasting bits of black paper pierced with round holes upon pieces of looking-glass.

toward it, the less accurate would be the execution of the movement. Experiment showed, however, that this expression of the relation between time elapsed and accuracy of movement did not correspond to the facts observed. In order to study this relation, each set of experiments with direct and indirect vision, and with touch, was divided into six series, in which the above-mentioned interval was 0″, 2″, 4″, 6″, 8″, 10″, respectively, the intervals being determined by the strokes of a metronome. In each series 100 trials were made, the results of which are shown in the table which will be presently presented.

### *Effect of Fixation of the Head.*

In the experiment with indirect vision the head was maintained in a fixed position, as above described, in order to secure a constant relation between the retina and objects in the field of vision. In order to ascertain the influence of this constrained position of the head upon the accuracy with which movements of the arm could be executed, the experiments in localization by direct vision, and also those in localization by touch with the same hand were performed in duplicate sets, the head being fixed during one set of experiments and free during the other. It will thus be seen that seven separate sets of experiments were performed, two with direct vision, two with indirect vision, two with touch with the same hand, and one with touch with the opposite hand. In each of these sets 600 trials were made. The results of these 4,200 trials are given in the following tables :—

TABLES showing the relative accuracy of the different modes of localization, by a comparison of the number of hits at different distances from the point aimed at, the surface of the paper being supposed to be divided into concentric rings, 6 mm. broad, around the point aimed at.

Column A. gives the radii in mm. of the outer and inner borders of the successive rings.

Column B. shows the total number of hits on each ring, and also the number of hits in each series of observations, corresponding to the intervals of time elapsing between the location of the object and the beginning of the movement towards it, as above described.

Column C. shows the area in $\overline{\text{cm.}}^2$ of each successive ring.

Column D. shows the number of hits per $\overline{\text{cm.}}$ in each ring. (The numbers in this column diminish from above downward, approximately as the ordinates of the binomial curve of Quetelet.)

## Table I.

Localization by Direct Vision. (Head Free.)

| A. Radii of rings. mm. | B. Number of hits. 0″ | 2″ | 4″ | 6″ | 8″ | 10″ | Totals. | C. Area of rings. cm.² | D. Hits per cm.² |
|---|---|---|---|---|---|---|---|---|---|
| 0—6 | 12 | 18 | 17 | 9 | 12 | 1 | 69 | 1·131 | 61·00 |
| 6—12 | 36 | 34 | 23 | 21 | 19 | 18 | 151 | 3·393 | 44·50 |
| 12—18 | 27 | 27 | 28 | 22 | 23 | 25 | 152 | 5·656 | 26 87 |
| 18—24 | 12 | 16 | 15 | 11 | 16 | 15 | 85 | 7·917 | 10·72 |
| 24—30 | 6 | 2 | 8 | 12 | 11 | 17 | 56 | 10·179 | 5·50 |
| 30—36 | 6 | 3 | 6 | 11 | 15 | 15 | 56 | 12·441 | 4·50 |
| 36—42 | ... | ... | 1 | 4 | 2 | 5 | 12 | 14·703 | ·81 |
| 42—48 | 1 | ... | 2 | 4 | 2 | 2 | 11 | 16·965 | ·64 |
| 48—54 | ... | ... | ... | 6 | ... | 2 | 8 | 19·227 | ·41 |
| Total No. of hits. | 100 | 100 | 100 | 100 | 100 | 100 | 600 | ... | ... |
| Average error mm. | 14·11 | 12·37 | 15·15 | 20·19 | 19·05 | 21·81 | 17·11 | ... | ... |

## Table II.

Localization by Direct Vision. (Head Fixed.)

| A. Radii of rings. mm. | B. Number of hits. 0″ | 2″ | 4″ | 6″ | 8″ | 10″ | Totals. | C. Area of rings. cm.² | D. Hits per cm.² |
|---|---|---|---|---|---|---|---|---|---|
| 0—6 | 10 | 10 | 7 | 10 | 7 | 11 | 55 | 1·131 | 48·62 |
| 6—12 | 21 | 27 | 22 | 12 | 14 | 19 | 115 | 3·393 | 33·86 |
| 12—18 | 31 | 28 | 19 | 28 | 29 | 23 | 158 | 5·656 | 27·93 |
| 18—24 | 17 | 14 | 27 | 18 | 18 | 16 | 110 | 7·917 | 13·89 |
| 24—30 | 11 | 13 | 13 | 15 | 18 | 14 | 84 | 10·179 | 8·25 |
| 30—36 | 5 | 6 | 8 | 6 | 9 | 9 | 43 | 12·441 | 3·45 |
| 36—42 | 3 | ... | 3 | 4 | 5 | 3 | 18 | 14·703 | 1·22 |
| 42—48 | 2 | 2 | ... | 7 | ... | 3 | 14 | 16·965 | ·82 |
| 48—54 | ... | ... | 1 | ... | ... | 2 | 3 | 19·227 | ·15 |
| 54—60 | | | | | | | | | |
| 60—66 | | | | | | | | | |
| 66—72 | | | | | | | | | |
| Total No. of hits. | 100 | 100 | 100 | 100 | 100 | 100 | 600 | ... | ... |
| Average error mm. | 16·85 | 16·04 | 18·37 | 20·00 | 19·95 | 18·98 | 18·36 | ... | ... |

## Table III.

LOCALIZATION BY TOUCH, SAME HAND. (HEAD FREE.)

| A. Radii of rings. | B. Number of hits. | | | | | | | C. Area of rings. | D. Hits per |
|---|---|---|---|---|---|---|---|---|---|
| mm. | 0″ | 2″ | 4″ | 6″ | 8″ | 10″ | Totals. | cm.² | cm.² |
| 0—6 | 9 | 17 | 10 | 6 | 11 | 3 | 56 | 1·131 | 49·51 |
| 6—12 | 19 | 25 | 19 | 13 | 10 | 13 | 99 | 3·393 | 29·17 |
| 12—18 | 25 | 14 | 31 | 16 | 15 | 19 | 120 | 5·656 | 21·21 |
| 18—24 | 17 | 17 | 15 | 28 | 19 | 22 | 118 | 7·917 | 14·90 |
| 24—30 | 13 | 11 | 10 | 14 | 18 | 13 | 79 | 10·179 | 7·76 |
| 30—36 | 14 | 9 | 8 | 13 | 12 | 16 | 72 | 12·441 | 5·78 |
| 36—42 | 3 | 3 | 5 | 6 | 6 | 4 | 27 | 14·703 | 1·83 |
| 42—48 | 0 | 1 | ... | 1 | 3 | 3 | 8 | 16·965 | ·47 |
| 48—54 | ... | 1 | 1 | 3 | 5 | 4 | 14 | 19·227 | ·72 |
| 54—60 | ... | 2 | 1 | ... | 1 | 3 | 7 | 21·489 | ·32 |
| 60—66 | ... | ... | ... | ... | ... | ... | ... | 23·751 | ... |
| 66—72 | ... | ... | ... | ... | ... | ... | ... | 26·013 | ... |
| Total No. of hits. | 100 | 100 | 100 | 100 | 100 | 100 | 600 | ... | ... |
| Average error mm. | 19·48 | 17·13 | 17·34 | 21·08 | 22·64 | 23·97 | 20·25 | ... | ... |

## Table IV.

LOCALIZATION BY INDIRECT VISION. (HEAD FIXED.)

| A. Radii of rings. | B. Number of hits, | | | | | | | C. Area of rings. | D. Hits per |
|---|---|---|---|---|---|---|---|---|---|
| mm. | 0″ | 2″ | 4″ | 6″ | 8″ | 10″ | Totals. | cm.² | cm.² |
| 0—6 | 9 | 16 | 13 | 4 | 12 | 2 | 56 | 1·131 | 49·51 |
| 6—12 | 23 | 23 | 12 | 14 | 10 | 18 | 100 | 3·393 | 29·47 |
| 12—18 | 17 | 29 | 21 | 25 | 17 | 20 | 129 | 5·656 | 22·80 |
| 18—24 | 21 | 14 | 10 | 23 | 14 | 17 | 99 | 7·917 | 12·50 |
| 24—30 | 14 | 7 | 16 | 16 | 19 | 11 | 83 | 10 179 | 8·15 |
| 30—36 | 11 | 7 | 19 | 6 | 11 | 14 | 68 | 12·441 | 5·46 |
| 36—42 | 4 | 3 | 5 | 8 | 6 | 4 | 30 | 14·703 | 2·04 |
| 42—48 | ... | 1 | 2 | ... | 5 | 8 | 16 | 16·965 | ·94 |
| 48—54 | 1 | ... | ... | 2 | 2 | 2 | 7 | 19·227 | ·36 |
| 54—60 | ... | ... | 2 | 1 | 4 | ... | 7 | 21·489 | ·32 |
| 60—66 | ... | ... | ... | ... | ... | 3 | 3 | 23·751 | ·12 |
| 66—72 | ... | ... | ... | 1 | ... | 1 | 2 | 26·013 | ·07 |
| Total No. of hits. | 100 | 100 | 100 | 100 | 100 | 100 | 600 | ... | ... |
| Average error mm. | 18·45 | 15·39 | 20·90 | 20·90 | 22·47 | 24·74 | 20·44 | ... | ... |

## Table V.

LOCALIZATION BY INDIRECT VISION. (HEAD FIXED.)
(EXP. WITH SPOT OF LIGHT.)

| A. Radii of rings mm. | B. Number of hits. | | | | | | | C. Area of rings. $\overline{cm.}^2$ | D. Hits per $\overline{cm.}^2$ |
|---|---|---|---|---|---|---|---|---|---|
| | 0″ | 2″ | 4″ | 6″ | 8″ | 10″ | Totals. | | |
| 0—6 | 10 | 5 | 5 | 7 | 8 | 7 | 42 | 1·131 | 37·13 |
| 6—12 | 27 | 19 | 15 | 11 | 13 | 10 | 95 | 3·393 | 27·99 |
| 12—18 | 15 | 23 | 27 | 22 | 23 | 16 | 126 | 5·656 | 22·27 |
| 18—24 | 19 | 21 | 13 | 21 | 13 | 21 | 108 | 7·917 | 13·64 |
| 24—30 | 11 | 12 | 21 | 11 | 11 | 7 | 73 | 10·179 | 7·17 |
| 30—36 | 6 | 8 | 9 | 10 | 12 | 13 | 58 | 12·441 | 4·66 |
| 36—42 | 6 | 5 | 5 | 8 | 9 | 16 | 49 | 14·703 | 3·33 |
| 42—48 | 5 | 5 | 3 | 5 | 4 | 3 | 25 | 16·965 | 1·47 |
| 48—54 | 1 | 1 | 2 | 3 | 3 | 3 | 13 | 19·227 | ·67 |
| 54—60 | ... | ... | ... | ... | 2 | 3 | 5 | 21·489 | ·23 |
| 60—66 | ... | 1 | ... | 1 | ... | 1 | 3 | 23·751 | ·12 |
| 66—72 | ... | ... | ... | 1 | 2 | ... | 3 | 26·013 | ·11 |
| Total No. of hits. | 100 | 100 | 100 | 100 | 100 | 100 | 600 | ... | ... |
| Average error mm. | 18·54 | 20·68 | 20·82 | 22·99 | 23·65 | 24·65 | 21·88 | ... | ... |

## Table VI.

LOCALIZATION BY TOUCH, SAME HAND. (HEAD FIXED.)

| A. Radii of rings. mm. | B. Number of hits. | | | | | | | C. Area of rings. $\overline{cm.}^2$ | D. Hits per $\overline{cm.}$ |
|---|---|---|---|---|---|---|---|---|---|
| | 0″ | 2″ | 4″ | 6″ | 8″ | 10″ | Totals. | | |
| 0—6 | 11 | 2 | 3 | 5 | 8 | 4 | 33 | 1·131 | 29·17 |
| 6—12 | 19 | 19 | 15 | 14 | 11 | 17 | 95 | 3·393 | 27·99 |
| 12—18 | 31 | 27 | 22 | 19 | 17 | 18 | 134 | 5·656 | 23·69 |
| 18—24 | 17 | 16 | 17 | 12 | 14 | 10 | 86 | 7·917 | 10·86 |
| 24—30 | 13 | 19 | 17 | 20 | 15 | 17 | 101 | 10·179 | 9·92 |
| 30—36 | 6 | 7 | 15 | 10 | 8 | 14 | 60 | 12·441 | 4·82 |
| 36—42 | 2 | 4 | 7 | 9 | 7 | 12 | 41 | 14·703 | 2·78 |
| 42—48 | ... | 2 | 3 | 7 | 10 | 4 | 26 | 16·965 | 1·53 |
| 48—54 | 1 | 1 | 1 | 3 | 3 | 1 | 10 | 19·227 | ·52 |
| 54—60 | ... | 3 | ... | 1 | 7 | 3 | 14 | 21·489 | ·65 |
| 60—66 | ... | ... | ... | ... | ... | ... | ... | 23·751 | |
| 66—72 | ... | ... | ... | ... | ... | ... | ... | 26·013 | |
| Total No. of hits. | 100 | 100 | 100 | 100 | 100 | 100 | 600 | ... | ... |
| Average error mm. | 17·16 | 21·20 | 22·22 | 24·01 | 27·10 | 24·00 | 22·61 | ... | ... |

## Table VII.

LOCALIZATION BY TOUCH, OPPOSITE HAND. (HEAD FREE.)

| A. Radii of rings. mm. | B. Number of hits. 0″ | 2″ | 4″ | 6″ | 8″ | 10″ | Totals. | C. Area of rings. cm.² | D. Hits per cm.² |
|---|---|---|---|---|---|---|---|---|---|
| 0—6 | 9 | 8 | 13 | 7 | 8 | 7 | 52 | 1·131 | 45·97 |
| 6—12 | 20 | 16 | 17 | 7 | 12 | 6 | 78 | 3·393 | 22·98 |
| 12—18 | 23 | 19 | 19 | 12 | 12 | 10 | 95 | 5·656 | 16·79 |
| 18—24 | 16 | 20 | 17 | 17 | 13 | 18 | 101 | 7·917 | 12·75 |
| 24—30 | 11 | 14 | 11 | 8 | 13 | 17 | 64 | 10·179 | 6·27 |
| 30—36 | 4 | 7 | 7 | 20 | 15 | 17 | 80 | 12·441 | 6·43 |
| 36—42 | 4 | 11 | 6 | 7 | 9 | 7 | 44 | 14·703 | 2·99 |
| 42—48 | 5 | 4 | 2 | 14 | 8 | 5 | 38 | 16·965 | 2·23 |
| 48—54 | 4 | 1 | 4 | 5 | 4 | 3 | 21 | 19·227 | 1·09 |
| 54—60 | ... | ... | 2 | 3 | 2 | 5 | 12 | 21·489 | ·55 |
| 60—66 | 3 | ... | 1 | ... | 3 | 3 | 10 | 23·751 | ·42 |
| 66—72 | 1 | ... | 1 | 1 | 1 | 2 | 5 | 26·013 | ·19 |
| Total No. of hits. | 100 | 100 | 100 | 100 | 100 | 100 | 600 | ... | ... |
| Average error mm. | 21·86 | 21·49 | 20·49 | 28·70 | 26·25 | 28·89 | 24·61 | ... | ... |

## Table VIII.

SHOWING AVERAGE ERROR IN MM. OF DIFFERENT MODES OF LOCALIZATION.

| | Mode of Localization. | Position of Head. | Interval between Localization and Movement. 0″ | 2″ | 4″ | 6″ | 8″ | 10″ | Totals. |
|---|---|---|---|---|---|---|---|---|---|
| I. | Direct vision . | free | 14·11 | 12·37 | 15·15 | 20·19 | 19·05 | 21·81 | 17·11 |
| II. | Direct vision . | fixed | 16·85 | 16·04 | 18·37 | 20·00 | 19·95 | 18·98 | 18·36 |
| III. | Touch, same hand. | free | 19·48 | 17·13 | 17·34 | 21·08 | 22·64 | 23·97 | 20·25 |
| IV. | Indirect vision . | fixed | 18·45 | 15·39 | 20·90 | 20·90 | 22·47 | 24·74 | 20·44 |
| V. | Indirect vision[1] . | fixed | 18·54 | 20·68 | 20·82 | 22·99 | 23·65 | 24·65 | 21·88 |
| VI. | Touch, same hand. | fixed | 17·16 | 21·20 | 22·22 | 24·01 | 27·10 | 24·00 | 22·61 |
| VII. | Touch, opp. hand . | free | 21·86 | 21·49 | 20·49 | 28·70 | 26·25 | 28·89 | 24·61 |
| Average error in each series | | | 18·06 | 17·76 | 19·33 | 22·55 | 23·01 | 23·86 | ... |

[1] In this set of experiments a spot of light was used as the object for localization.

## Results.

A study of these tables, and especially of Table VIII., in which the average errors of the different methods of localization are brought together for comparison, makes it evident that the most accurate spatial knowledge is obtained by direct vision. At all the intervals the average error was less when the position of the object was determined in this way than by any other method. The effect of fixing the position of the head is to diminish the accuracy of the localization, but even under these circumstances the errors are in nearly every instance less than those met with in the other methods of experimenting.

The method next in accuracy is that of localization by touch with the same hand by which the movement in search of the object is executed, the head being free to move. It may at first sight seem surprising that this method should be less accurate than that of direct vision.

It would be reasonable to suppose that the position of an object having been once determined by the sense of touch, it would be possible to place the hand *a second time* upon it with greater precision than would be possible when the position had been determined by the sense of sight. That the reverse is the case is probably to be accounted for by the fact that in our daily life all our movements are guided by the sense of sight to a much greater extent than by the sense of touch.

Next in order of accuracy of localization come the two sets of experiments with indirect vision, that performed with reflected sunlight giving results slightly inferior to those of the other set. In both these sets the head of the observer was fixed by the method and for the reasons above described ; and in both the results are slightly superior to those of the next set in which the position of the object was determined by the same hand with which the movement in search of it was made, but in which the head was fixed in order to introduce conditions similar to those under which the experiments with indirect vision were performed. Least accurate of all the methods employed is that of touch with the opposite hand. As compared with that of direct vision the average error of all the intervals is 24·61 mm., against 17·11 mm. ; but if a comparison is made at that interval at which the greatest accuracy is attained—viz., the 2″ interval, it will be seen that the average error is 12·37 mm. for determinations by direct vision, against 21·49 mm. for determinations by touch. These figures do not differ very widely from those obtained in the preliminary investigation above described. It should be here remarked that the relative positions in the scale of accuracy assigned to the methods of indirect vision and of touch with the same hand have been determined by averaging all the observations in all the series, and that if the comparison is made between the same series in different sets, very varying results will be obtained, according to the series selected.

Moreover, the differences between these methods, as expressed in the column of general averages, are small in amount.

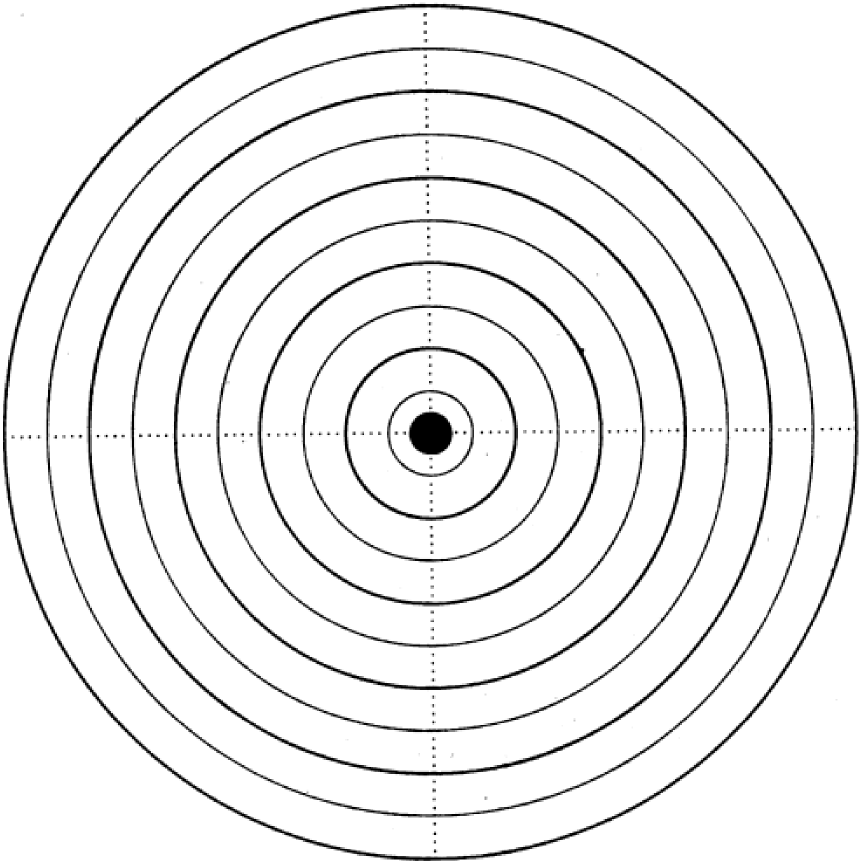
It is therefore probable that an increased number of observations might lead to some modification of the conclusions above formulated. It seems, however, to be sufficiently well established, that of the methods here employed for determining the position of objects around us, *that of direct vision gives the best results, that of touch with the opposite hand the worst, and that the other methods occupy intermediate positions.*

It seems also evident that fixation of the head, as above described, diminishes the accuracy with which objects around us can be localized.

*Effects of Time.*—A comparison of the results obtained in the different series of observations shows that in the 1st, 2nd, 3rd, and 4th sets the smallest errors were obtained in the 2″, in the 5th and 6th sets in the 0″, and in the 7th set in the 4″ series. The average errors in all the observations of a given series, irrespective of the sets to which they belong, are given in the lowest line of Table VIII.

From these figures it would seem that when an observer having determined the position of an object, either by sight or touch, waits two seconds with closed eyes before making a movement in its direction, the average error will be a little less than when he makes the movement as soon as he has determined the position of the object. In other words, it seems that when a mental image of position in space has been formed, its accuracy and definiteness increase for a brief interval, and then gradually diminish.

In order to investigate this phenomenon a little more accurately, two other sets of experiments with direct vision were undertaken, each consisting of five series of 100 experiments each, in which the interval was 0, 1, 2, 3, 4 seconds respectively. These experiments differed from those heretofore described in the fact that the object used was a card on which concentric circles, 5 mm. apart, were drawn, as shown in the accompanying figure, Pl. XVII. A black spot 5 mm. in diameter in the centre served as the point on which the eyes were fixed, and toward which the movement of the hand was directed. A needle set in a handle was used instead of a pencil, and the distance from the central point of



the holes thus pricked in the card could be easily read off by the aid of the concentric lines.

The time required for taking a set of observations was thus materially diminished. The two separate sets of experiments with direct vision which were made by this method gave the same result as regards the influence of the lapse of time, but the absolute values of the average errors in the first set were uniformly greater than the corresponding values in the second set. This is probably to be accounted for by the fact that the first set of experiments was made under rather unfavourable circumstances, in a low, badly lighted room, where the observer was subjected to frequent interruptions, while the second set was made in one of the laboratory rooms, and under the same conditions as in the experiments previously described.

The following table shows the average errors in each series of the two sets of observations, and also the observations in each series in both sets together :—

Table IX.

Localization by direct Vision. (Head free.) Average Errors (in mm.) in the Different Series.

| | 0″ | 1″ | 2″ | 3″ | 4″ |
|---|---|---|---|---|---|
| 1st set ... | 15·75 | 14·48 | 14·45 | 17·76 | 19·51 |
| 2nd set ... | 14·94 | 13·63 | 12·36 | 13·34 | 15·18 |
| Average ... | 15·34 | 14·05 | 13·40 | 14·05 | 17·34 |

An examination of these figures shows that with the increase of the interval between the determination of position of an object and the attempt to place the hand upon it with closed eyes, *the accuracy of this movement at first increases and then diminishes, the maximum of accuracy being attained after an interval of two seconds.*

From the figures contained in Table VIII. or Table IX. a curve may be constructed having for abscissæ the intervals of time in the different series, and for ordinates the average errors in the movement towards the object. A curve of this sort will be found to descend slowly towards the abscissa, reaching its lowest point at two seconds, then to rise rapidly at four or six seconds, and subsequently to continue its ascent at a slower rate. Such a curve, which may be called the curve of forgetfulness, gives a graphic representation of the effect of time upon the accuracy of a mental image.

*Conclusion.*

In conclusion it should be stated that, with the exception of the preliminary set of sixty trials, all the observations recorded in this paper were made by one of the writers (Dr. S.), who entered upon the investigation without any preconceived theory upon the subject, and who devoted himself to the research at various intervals during fifteen months. Great care was taken to avoid the influence of fatigue, by never continuing the observations more than half an hour at any one time, and also by alternating the different series of observations with each other. As a rule, no more than ten trials in any one series were made in succession. In this way any effect which practice might have in increasing the accuracy of the movement was distributed through the whole body of observations. The results having been obtained entirely on one individual, are, of course, liable to a personal correction, and it would be a very interesting extension of the research to inquire how far the various occupations of life affect the accuracy with which the movements in question can be executed. It might, perhaps, be expected that the power of the blind to determine the position of objects by the sense of touch, would be found, when tested in this way, to be much greater than that of persons possessed of sight. A few preliminary experiments, however, which have already been made, seem to indicate that this is not the case. It is much to be regretted that the data from which the conclusions in this paper have been drawn are not more numerous.

At the outset it was believed that one hundred trials in each series would be enough observations to furnish accurate average values for purposes of comparison. The result has shown that this is hardly the case, and were it not for the necessary departure of one of the writers (Dr. S.) from this part of the country, an attempt would be made to enlarge the experimental basis upon which the conclusions rest. Imperfect as is the investigation, it is presented as indicating a new method for studying and comparing the data furnished by our senses, and for expressing numerically the accuracy of the mental function, memory.