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DISTURBANCES OF SPATIAL ORIENTATION AND VISUAL ATTENTION, WITH LOSS OF STEREOSCOPIC VISION *

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The following case is placed on record as it is an excellent example of a type of special disturbances of vision which claim our interest, not only on account of their relative rarity, but chiefly because they throw considerable light on the functions and modes of activity of the cerebral cortex, and particularly on those processes which are concerned in the integration and association of sensations.

The case is described at length as the patient exhibited many symptoms which could be fully understood only when carefully studied and analyzed. We were particularly fortunate in that he was an intelligent, willing and objective witness, and had no disturbances of speech, or motor or sensory symptoms that could complicate our observations. On the other hand, we have made our discussion of his condition as concise as possible with due regard to clearness, more especially as one of us has recently recorded six other cases with more or less similar symptoms, apart from the loss of stereoscopic vision, and there dealt more fully with their nature and significance.

REPORT OF CASE

History.—The patient, Private W. F., aged 30, had been a circular saw operator and was an intelligent and fairly well educated artisan. He was wounded May 19, 1918, probably by a machine gun bullet, but as he became at once unconscious and remained so for several days, it was impossible to obtain an accurate history. He was admitted on the same day to a casualty clearing station with a perforating wound of the head; both entrance and exit wounds were excised, fractured bone removed, softened and extruding brain-matter evacuated, and the scalp excisions were then sutured. The patient, however, remained still unconscious, vomited repeatedly and had several epileptiform fits which affected chiefly his left side. On the sixth day he asked for food, and it was recorded in his notes that he could then see.

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Examination.—When he came under our observation in a base hospital on June 2, the wounds were healed. The entrance, on the right side, was represented by a horizontal incision 6 cm. in length, under which a trephine opening 4 by 5 cm. in diameter could be felt; its center was 6 cm. above theinion and $5\frac{1}{2}$ cm. to the right of the middle line of the skull. The exit wound was also represented by a horizontal incision over a trephine opening 2 by 4 cm. in diameter, with its center 10 cm. above theinion and $5\frac{1}{2}$ cm. to the left of the mesial line (Fig. 1). A roentgenogram revealed only these operative defects in the skull and a linear fracture connecting them.

When he arrived at the base his general condition was satisfactory, and he was alert and intelligent. There was no trace of weakness, incoordination or disturbance of muscle tone; he could move his limbs easily and

Fig. 1.—Posterior view of the patient's head on which is indicated the position of the wounds of entrance and exit. The central white line indicates the mesial sagittal plane.

employ them naturally in all actions. No affection of sensation could be detected, and his reflexes were also normal. The movements of his face, tongue, palate and jaw were undisturbed. There was no squint and he did not complain of diplopia. His pupils were large, but reacted perfectly to light, and hearing was also normal in both ears. Speech was unaffected; he expressed himself readily and correctly, understood fully all that was said to him, and named promptly all objects he recognized. He could write correctly though owing to his visual disturbances he frequently placed the words he wrote irregularly on the paper. His difficulty in reading, which did not depend on an aphasia, will be dealt with later.

During the three months he remained under our observation he appeared an intelligent and cheerful man; his attention, apprehension and memory were intact, and he was never unnaturally emotional. He also proved in all our investigations to be an extremely good and objective witness, who did not attempt to interpret his sensations, but merely described what he perceived.

Vision.—The acuity of his central vision was never seriously affected. Fourteen days after he received his wound he could count fingers and recognize objects, and when tested a few days later he read words in $\frac{1}{8}$ inch print; five weeks after the infliction of the wound his vision was 6/12 in each eye, and when his error of refraction—slight myopic astigmatism—was corrected it rose to 6/9 and Jaeger 1. His optic disks and fundi were normal. He had never noticed any visual *aurae* or spectra, as flashes of light or color. The visual fields were at first much contracted; Major G. Derby, who kindly tested him with a perimeter, found that he could recognize a white object 1 cm. square only in the right upper quadrants and within 30 degrees of the fixation point. On July 15 vision to small objects extended to the normal limits in both upper quadrants, but the lower remained permanently blind; the blindness reached to 2 degrees from the fixation points and corresponded approximately to the horizontal radii through them, except to the right where vision had recovered a slight distance below them (Fig. 2). This inferior horizontal hemianopia remained unaltered till he was transferred to England more than three months after the infliction of the wound. Though he was repeatedly tested, no scotoma or amblyopia could be found in the upper seeing quadrants. There was no agnosia, in the sense that he was unable to recognize the use and nature of objects which he could perceive by either central or extra-central vision.

Important Symptoms.—The special symptoms which give interest to this case were investigated repeatedly between 36 and 100 days after the infliction of the wound. They varied very little during this time, but they will be described here chiefly as they were observed in the later portion of this period.

There was no evidence of any ocular palsy; he moved his eyes to order readily and accurately in every direction, but from the day he first came under observation he had much difficulty in fixing objects which he could see. If spoken to suddenly he first stared in a wrong direction and then moved his eyes about until they fell, as if by chance, on the observer's face; he was extremely slow and inaccurate in his attempts to fix or bring into central vision any object when its image fell in the periphery of his retinae, especially if it were small. When, however, requested to look at his own finger or to any point of his body which was touched he did so promptly and accurately, moving as a rule both his head and eyes in the normal manner. Except in the early stages of his illness he had no difficulty in maintaining fixation on an object that was in central vision; each time, for instance, his visual fields were examined he succeeded in keeping his eyes on the fixation point of the perimeter, but if they deviated from it for even a moment he was slow and awkward in finding it again. When an object at which he was staring was moved at a slow and uniform rate he could keep his eyes on it, but if it was jerked or moved abruptly it quickly disappeared from his central vision.

This difficulty in obtaining fixation and in bringing objects seen into central vision diminished considerably, but did not disappear completely while he remained under our observation. He generally turned his eyes promptly and accurately toward any unexpected sound, but not to light; when at night

Fig. 2.—Visual fields recorded with 10 mm. square white and colored objects on Aug. 3, 1918. The broken line indicates the limit of red vision; the dotted line the field for green.

an electric torch was suddenly flashed at various points around his bed he turned his eyes slowly, and less accurately than a normal person, in the direction of each flash.

Accommodation for near objects was even more severely affected; when a pencil was moved slowly toward his eyes these failed to converge, and his pupils did not contract; when it had come within 8 or 10 inches (20-25 cm.) he could no longer see it distinctly and was conscious only of the presence of a moving object, the shape or form of which he was unable to recognize. If, however, his own finger were moved passively toward his face, or if he brought an object held in his own hand toward it, his eyes converged normally on it, his pupils contracted briskly and he accommodated so that he could see it distinctly when it was only $4\frac{1}{2}$ inches (12 cm.) distant from his eyes. He also converged accurately and his pupils contracted promptly when he was asked to look at the tip of his own nose.

Another noteworthy symptom was the complete absence of the blinking reflex; if the observer's hand or any large object, as a book, was unexpectedly swung toward his eyes he never blinked, withdrew his head, or reacted as the normal person does, unless the movement produced a current of air sufficient to attract his attention. On one occasion he explained, "Your hand seemed to come nearer to me, but I had no idea how near it came, I thought it was plenty far off." But on another day he said, "I did not see that it was coming toward my face." If, however, his own hand was suddenly jerked by the observer toward his eyes he always reacted normally to the threat.

His visual memory, for both form and color, of impressions obtained in earlier years was apparently intact; he was evidently a strong visualist and described as a visualist does his house, his family, a hospital ward in which he had previously been, etc. But, on the other hand, he had complete loss of memory of topography; he was totally unable to describe the route between the house in a provincial town in which he had lived all his life and the railway station a short distance away, explaining "I used to be able to see the way but I can't see it now." From his statements it was evident that he had formerly a clear visual picture of it which he could no longer evoke. He was similarly unable to say how he could find his room in a barracks in which he had been stationed for some months, or describe the geography of trenches in which he had served. His visual retentiveness was also defective; when he was, for instance, shown in rapid succession four objects, as a key, pencil, scissors and knife, he could never name them all or remember the correct sequence after an interval of 20 seconds, though after an even longer interval he could always repeat accurately four or more words which were uttered to him.

Visual Inattention.—There was one disturbance of vision which had so much influence on his other symptoms that it must be more fully described. As mentioned already he had, as far as could be judged, normal or practically normal vision to the natural limits of the upper quadrants of his visual fields; these were repeatedly explored and even when small white objects, 2 mm. in diameter, were used no defects could be discovered, and the color fields within them were also normal. When the observer's two hands were held up, one on either side of his visual axes and at equal angles from them, he could always perceive the slightest movement of either when it alone was moved, but he failed constantly to recognize the simultaneous movement of both hands and saw indiscriminately that to his right or left only.

It mattered not whether the observer's two hands were near his visual axes or far lateral to them, he failed to perceive the simultaneous movement of both though he always recognized the slightest movement of one or the other. Even when he held up his own hands in the seeing portion of his visual fields he stated that while his eyes were fixed on some other object he could see only one at a time, either that to his right or to his left, according as his attention was attracted by it.

In one test, while he fixed his eyes on a needle which was stuck in a table, two pencils, a red and a yellow one, were placed 5 cm. on each side of it, at a distance of 50 cm. from him; then while gazing at the needle he could see one pencil only, and indiscriminately that to his right or left. Similarly when a box was placed in front of him so that two of its sides made equal angles with his visual axes he could, while he looked at its edge, see one side only but not both simultaneously; he explained, "I can see one side, but my eyes can't get past the corner." Even if his two index fingers were placed on the two visible surfaces he could see one only if he fixed the edge of the box; and when one side was colored blue and the other remained white he saw only one, but in addition a blue or a white "streak" which he did not associate with the idea of a box.

This inability to perceive and recognize movement and objects under certain conditions cannot be attributed to blindness or hypo-esthesia of parts of the seeing quadrants, for in the first place no such disturbances could be detected though searched for several times; and secondly, he constantly failed to perceive the images of objects that fell on portions of his retinae which immediately before or afterward were obviously sensitive to the same impressions. The essential feature was his inability to direct his attention to, and take cognizance of, two or more objects that threw their images on the seeing portion of his retinae. As this occurred no matter on what parts of his retinae the images fell, it must be attributed to a special disturbance or limitation of attention, but visual attention only was so affected as he did not behave similarly to tactile or other impressions.

It might be expected that as a result of this affection of visual attention he would be unable to see the whole of large objects presented to him at a near distance; but, provided part of the image did not fall on the blind portions of his fields, this was never obvious in examination. He recognized objects and even complicated geometrical figures as promptly as normal persons, and apparently without exploring them fully by movement of his eyes. He explained this by saying, "I seem to see the whole figure in the first glance," though he occasionally failed to do so if some peculiarity or prominent portion of it at once claimed his attention. In one test, for instance, a large square was drawn on a sheet of paper and he recognized it immediately, but when it was again shown to him after a cross had been drawn in its center he saw the cross, but identified the surrounding figure only after considerable hesitation; his attention seemed to be absorbed by the first object on which his eyes fell. He could recognize as promptly and as accurately as several normal persons who were tested as controls, the shape and nature of small objects placed in various portions of the seeing fields, when they were exposed singly to him by allowing screens in front of them to drop.

Spatial Orientation.—The most prominent symptom, however, from the time he came under our observation till he left the hospital three months later, was his inability to orientate and localize correctly in space objects

which he saw. When within the first few weeks he was asked to take hold of or point to, any object, he projected his hand out vaguely, generally in a wrong direction, and had obviously no accurate idea of its distance from him. His failure to touch or point to objects seen could not be attributed to ataxia, or to any motor or sensory disturbance, as both the movement of his limbs and their sensibility were intact, and he employed them naturally and expertly in all action that did not require visual control. Other observations which will be recorded will leave no doubt that these symptoms were due to his visual disturbances only.

It was only during the first few weeks that he made gross errors in pointing to a test object that was in central vision, but even thirteen weeks after the infliction of his wound he frequently failed to bring his finger accurately to or pick up small objects, though he had learned by experience their distance from him. His errors were indiscriminately to either side of, or above or below his aim, and not predominantly in any one direction. If the object was not in central vision his errors were much greater; when, for instance, he attempted to touch the observer's finger while his eyes were fixed on his face he generally brought his hand several inches to one or other side of it. This inability to localize in space objects outside central vision was repeatedly investigated by the aid of a perimeter. A piece of white paper 10 mm. square was suddenly presented to him on the arc of the perimeter while his eyes were directed on its fixation point, and he pointed to it immediately on recognizing it.

In Figure 3 the Arabic numerals indicate the actual positions of the test object and the corresponding Roman figures the positions in which he judged it to be. As a rule he estimated the object seen to be nearer his visual axes than it actually was, but this was not constant. As he was aware of the distance of the arc from his eyes and knew that this did not vary, erroneous estimation of the distance of the object cannot account for these mistakes, and it is improbable that they were due to any disturbance of retinal sensibility for none could be detected. Further, when the same test was applied to two men who, as a result of occipital wounds, had large scotomas with surrounding zones of amblyopia in which white appeared indistinct and colors could not be recognized, it was found that both could localize the object correctly when they could see it, even if it lay in the amblyopic area of their visual field. An acromegalic with a large area of temporal amblyopia in one eye also orientated objects perceived in this amblyopic region much more accurately than our patient.

This defect could be observed in all actions of his ordinary life in which he relied on visual guidance; he had to grope for his food and any thing he wished to pick up, but his trouble ceased the moment he touched it.

His errors in the estimation of the distances of objects seen were even greater and more obvious, whether they were in or outside central vision. If the object he wished to touch was within easy reach he almost invariably projected his hand beyond it, and there was consequently an apparent tendency to overestimate distances; but when it was beyond his arm's length he often attempted to grasp it before his hand had reached it. He was consequently liable to overestimate or underestimate distances. In these tests he frequently complained that he had "no idea how far it was from him."

He had never any difficulty in *localizing by touch*; when any point on his own body was touched while his eyes were covered he brought his finger to it with normal promptness and accuracy. The contrast between the

Fig. 3.—The binocular visual field to represent the false localization of objects seen by extramacular vision. The Arabic numerals indicate the true positions of the objects; the Roman figures the positions into which the patient projected them.

defective spatial guidance he received from vision and the accurate knowledge of space that contact gave him, was excellently illustrated when he attempted to take soup from a small bowl with a spoon; if he held the bowl in his own hand he always succeeded in placing the spoon accurately in it and in obtaining a spoonful of food, but when it was held by an observer or placed on a table in front of him he could rarely bring his spoon to it at once, but had to grope for it till he had located it by touch.

His defects in spatial localization by vision were equally obvious when he attempted to estimate the relative positions of two objects. When a silver and a copper coin were placed on a table he usually said both appeared the same distance from him, or if urged to decide, often described the one which was further away as the nearer one, and vice versa. Similarly, when a man in blue hospital uniform stood 7 yards and one in khaki 14 yards away, he described both as at the same distance; when the man in blue approached to 5 yards, he recognized that he was the nearer, but when later he moved 3 yards further away he was certain that they were at the same distance from him. "Everything seems practically the same distance from me," he remarked on one occasion. A yellow pencil was held up 30 cm. and a blue one 60 cm. from his eyes; he could form no idea of their relative positions, but he recognized it at once when he was allowed to touch them in succession with his hand. When the pencils were at such a distance apart that they made a wide angle with his eyes he explained, "They seem the same distance from me because I can see only one plainly at a time; I have to shift my eyes from one to get to the other," but this was certainly not the correct interpretation as he still failed to recognize their relative positions when one was almost behind the other, so that both were practically in central vision. If a screen was placed between his hand and any object he wished to reach, he invariably brought his hand against the screen even though he had seen it; he then became confused and evidently could not appreciate the spatial relations of the two objects.

His judgment of the distance from him of objects seen was repeatedly tested; it was as defective three and a half months after the infliction of the wound as during the first two weeks. On one occasion he estimated that a man 20 yards from him was 100 yards, while a chimney at least 150 yards distant he thought was only 50 yards away. A pencil was held up at various distances from him; when it was 24 inches he estimated it at 12 inches, when 5 feet he said 18 inches, and later did not recognize it had been moved when it had been brought to 8 inches from his face while his eyes were momentarily closed; when at 2 feet he said it was about 7 feet away. He underestimated or overestimated distances indiscriminately.

When, however, he was asked to place his hand at a certain specified distance from his face, or to indicate by his two hands the extension of ordinary standards of linear measurement, as an inch, a foot, or a yard, his replies were approximately correct. He could also indicate the lengths of familiar objects, as his rifle, bayonet, etc.

Appreciation of Length and Size.—If two lines of different length were drawn obliquely to one another so that their retinal images were not easily superimposed he could rarely distinguish their relative lengths even when the difference was considerable. Lines 5 cm. and 8 cm. long appeared to him equal, nor could he recognize that one was shorter than the other though they were 10 cm. and 15 cm., respectively. If, however, the lines were

parallel and close together he could generally distinguish, though not as readily as a normal person, their relative lengths. He also made gross errors in comparing the lengths of such objects, as two pencils, which were shown to him, though his replies were invariably correct when he touched them. In the early stages of his illness he was unable to recognize any difference in the sizes of such objects as a franc and a 50-centime piece, but three months later he could distinguish sizes more certainly, though not within the normal limits of discrimination. His attempts at dividing a line, or at finding the center of a circle, were generally very inaccurate, but he always seemed satisfied with his results.

Though he failed to distinguish any difference in the lengths of lines, even if it was as great as 50 per cent., he could always recognize whether a quadrilateral rectangular figure was a square or not. In one test when an oblong of which the pairs of opposite sides were 4.2 cm. and 4.5 cm., and a square of the same area were drawn on separate pieces of paper, his judgments as to whether both were true squares, and if not whether the one figure was the higher or broader, were invariably correct. He explained that in order to decide whether a figure was or was not a square he did not compare the lengths of its sides but "on the first glance I see the whole figure and know whether it is a square or not." When he decided that a figure was a square we could never convince him that it was not, or vice versa. Similarly he never confused a slightly elliptical figure with a circle. He could also appreciate to some extent the sizes of angles; a rhomboid even when its sides stood at almost right angles was always "a square shoved out of shape."

It is therefore obvious that though he could not compare or estimate linear extensions he preserved the faculty of appreciating the shape of bidimensional figures. It was on this that his ability to identify familiar objects depended.

Recognition of Movement.—When an object in central vision was moved at a slow and uniform rate he was often uncertain whether it approached toward or receded from him, but he always appreciated the movement and recognized its direction when it made an angle with his visual axes. This was demonstrated by a piece of simple mechanism; one end of a rod 50 cm. long was fixed to an axis that could be rotated by clockwork at an extremely slow and uniform rate, while its other end carried a small luminous point. The patient was placed in an absolutely dark room, so that he had no background against which to compare the movement, with his eyes at the point of rotation, and his gaze directed on the luminous point. He made a signal when he perceived the slightest movement and then described its direction. His replies were as prompt and as accurate as those of controls tested similarly. The smallest movement could be recognized also by peripheral vision, but unless its range was much greater than a normal person requires he made many errors in describing its direction. When, for instance, a piece of paper fixed on the end of a holder was brought from behind him into the periphery of his visual fields he was often unable to recognize whether it was moved up or down, backward or forward, or laterally unless its range was large. Even when the object was near his visual axes but outside macular vision, he was often uncertain of, or mistook, the direction of its movement if this were small.

The patient began to walk sixty days after he received his wound, and then many other interesting symptoms could be observed. From the first there was no obvious abnormality in his gait, but he progressed with

short, slow steps and his hands held out in front of him, like a man groping his way in the dark. When asked to go across the ward he invariably walked into any obstacle in his way, even though it was large and prominent and he had observed it before he started; he walked with considerable force into a wall, collided with a large red screen that stood in his path, and when asked to come to the observer he continued on his course till he had bumped heavily into him. When told to sit down on a chair some yards away he proceeded till he had knocked it over with his knees, but immediately on touching it he righted it and placed himself correctly in it. On colliding with such obstacles he showed great surprise and considerable discomfiture, and generally explained that he had not realized he was so near to them. The fact that he frequently stopped and searched with his hands toward objects still some yards from him is clear evidence that he also underestimated distances. Further, when he had run into a large obstacle, as a table or screen, he had considerable difficulty in getting around it; he could not understand how to circumvent it immediately unless he placed his hands on it and felt his way out of his difficulty.

These symptoms remained practically unchanged during the time he was under observation. Even if before starting he was made to describe and point out the obstacles in his path he still ran into them, though by experience he learned to grope continuously with his hands in front of him if he saw or suspected the presence of anything against which he might hurt himself.

He frequently failed, too, especially during the first weeks after he left bed, to walk in the correct direction toward any point he wished to reach. On one occasion, for instance, he was led a few yards from his bed and then told to return to it; after searching with his eyes for a few moments he identified the bed, but immediately started off in a wrong direction. Later he occasionally failed to take the straight course to a chair on which he wished to seat himself. Three months or so after the infliction of the wound this rarely occurred, provided he kept his eyes fixed on his aim, but immediately his eyes deviated from it he generally turned into a wrong direction and wandered aimlessly about till it had again come into central vision.

Some of the most interesting observations were made on a large flat roof that was divided by a wooden paling, about 4 feet high, with an open gate in it through which it was possible to pass from one into the other portion; there was a step about 1 foot high at this gate. Day after day he was brought to this roof and told to walk from one spot in its larger division, which will be referred to as A, to a point at the balustrade around the smaller portion, which we will call B. He always remembered that he had to pass through the gate and that there was a step there, but even after he had been repeatedly over this route he frequently set out in a wrong direction unless his eyes had been fixed on the gate; his course was often at right angles to the correct one, but as a rule he walked into the paling some distance from the gate and then guided himself to it by a hand which he kept on the paling, rather than by vision. When he had succeeded in passing through the gate he often took a wrong direction toward B, and reached it only by groping with his hands along the balustrade. When asked to return to the observer at A, he almost invariably ran into the paling again. He was never able to give even an approximately correct description of the way he had taken, or should take, to go from A to B, and though he passed along it several times day after day he never "learned his way" as a blind man would. When,

in fact, he was blindfolded he succeeded in finding his way about as well as when he had the aid of vision, and to one of us he seemed to walk with more confidence.

If after he had walked some distance he was questioned as to what he had passed he could recount the more prominent objects he had noticed, but could never give an accurate description of their spatial relations to one another. On one occasion he was taken to the edge of the roof and from there saw and recognized several objects, as two men in a boat about 500 yards away, the distinguishing features of an aeroplane at the same distance, and several ships. When his eyes were then covered he described these separate objects, but was quite unable to point to the direction in which he had seen them, or to say what their relations in space were to one another.

This and many other tests showed that he possessed good visual acuity, for he could see and recognize distant objects almost as well as persons with normal vision, but the associated sense impressions gave him no idea of the spatial relations of the individual objects, or of the topography of an area or surface that he had viewed; he could never evoke a memorial image of them.

Localization of Sound.—His power of localizing by sound was tested on several occasions. While he was still in bed he was asked to point in the direction of a sound made by striking two pieces of metal together, and this he seemed to do as accurately as a normal person can. When he was able to walk a more satisfactory experiment was made by blindfolding his eyes and making him approach from some distance one of several persons who called him; in this test he succeeded as well as controls who were similarly blindfolded. His ability to orientate sounds was, as his power of localizing by touch, intact.

Exploration of Surfaces.—Though after walking through the ward or around the large open space in which we frequently examined him the patient could generally say what he had passed, he certainly failed frequently to take cognizance of prominent objects which would scarcely have escaped the notice of an equally intelligent person with normal vision. This was especially so if his attention were focussed on one thing. When, for instance, he was asked to walk across the flat roof toward a tall chimney in the distance he kept his eyes steadily fixed on this and passed—without perceiving them—men, etc., standing along his course. The nature of this phenomenon was investigated by asking him to count a number of similar coins laid on a table, directing in the first place his eyes in such a manner that the images of all fell on the seeing portion of his retinae. He was extremely slow in this test; he generally stared fixedly for a time at one and then moved his eyes about the surface irregularly and unmethodically without making a systematic attempt to explore the whole. When four or five coins were placed irregularly he generally failed to see them all, frequently included one or more a second time in his count, and eventually became so confused that he gave up the attempt. That this was due to his inability to form a clear picture or idea of the spatial relations of those he perceived was made probable by his own explanation, "I seem to lose myself when I look from one to the other," and by the fact that when the coins were placed closely in a horizontal or vertical row he counted them promptly and without difficulty.

His horizontal hemianopia cannot be held responsible for this symptom, as it was frequently the coins furthest from him, the images of which fell on the seeing portions of his retinae, that he failed to perceive. One factor

was that objects outside central vision did not excite attention readily when this was claimed by another visual impression, but it was possible to attract attention to them, for he always perceived each coin and turned his eyes to it, when a pencil was moved above or around it. Another cause was the absence of any tendency to explore even a limited space by sight; he seemed satisfied with that small portion of space included in his central vision, and ignorant or unconcerned with its extension unless some object in it claimed his attention strongly.

Reading.—These disturbances help us to understand his difficulty in reading. When at first he was given large type (Jaeger 14) he read out with hesitation one or two words only, and gave the impression to the observer that his sight was not sufficiently good to allow him to distinguish the print; yet he immediately recognized words in the smallest type (Jaeger 1) quite as easily. Further, he rarely read words in their proper sequence but picked them out at random from the paragraph, and recognized long and unfamiliar words as readily as short or common ones, if his eyes happened to fall on them. When, however, only one word was presented to him he always read it promptly no matter what size the print was, though if shown the whole paragraph he appeared confused and frequently did not for a time identify a single word in it. His slowness in obtaining proper fixation and in moving his eyes over words in their proper sequence was certainly one factor, but his inability to recognize or picture to himself their spatial relations on the page was the chief cause of his apparent confusion; as he said himself, "When I move my eyes from a word I cannot get back to the right place." Later, when he became able to read a few words in sequence he could rarely bring his eyes to the left of the succeeding line—"That's where I'm done, I can't get my eyes down to the next line."

He always understood fully every word and phrase which he read. He wrote without mistakes but his letters to his wife were scarcely decipherable, as the words, though correctly written, were placed irregularly on the page, and the lines were often scrawled obliquely across one another.

Stereoscopic Vision.—It became obvious early in the course of his illness that the patient could not see tridimensional objects in perspective or appreciate depth in them, and this remained unaltered during the time he was under our observation. When, for instance, shown a cardboard box 18 cm. square and 8 cm. deep he described it as a piece of flat cardboard no matter at what angle he saw it, and was surprised when it was placed in his hands to discover it was a box. When its sides were folded down the only difference he noticed was the presence of "lines" which were not there when it was open. Similarly, he could not distinguish between a complete match-box and the broader side of a similar one which was cut off with half of the striking surface attached and bent into the same plane. A glass tumbler appeared "a piece of flat glass" the shape of which varied according as it was presented to him, and he described his impression of a man who stood in front of him by the words, "I can only see the front of him, I do not notice that he is thick; I cannot tell the depth of anything." He was so objective and honest as a witness that we had no difficulty in ascertaining the nature of his visual perceptions, even of objects which he knew were tridimensional.

He recognized no difference between a book which was fully open and one half closed with its pages at right angles to one another. On one occasion when standing beside a table with his hand on it he remarked spon-

taneously, "I would not know that this is a table by looking down at it; it seems to my eyes to be at just the same level as the floor I am standing on, but when I see its legs and its edges I know it is a table." He spoke frequently of "angles" and "edges," and explained that it was by means of these that he recognized the nature of objects which he saw; "I seem to be able to spot everything that is edged."

While standing in front of a flight of stairs he saw only "a number of straight lines on the floor," and when his eyes were fixed on the ground he failed to recognize steps and differences in level, though by experience he learned to associate shadows and differences in color on the floor with the idea of obstacles over which he might trip and depressions into which he might fall. Houses built on the side of a sloping cliff, one above the other, appeared to be the same distance from him and constructed on top of each other. Drawings and photographs which when fixed in a stereoscope appeared as tridimensional figures to normal persons, as a rule seemed to him flat when viewed in this instrument, though he occasionally described them as figures seen in perspective; but as this occurred even when he used only one eye it was more probably due to the association of a flat image with the idea of the object represented than to stereoscopic vision.

If he was asked to say whether a book held up in front of him was or was not at right angles to his line of vision he frequently replied correctly, but then explained that he knew it was oblique only because he could see its edge. When a sheet of paper was substituted he could never form an idea whether it was held obliquely to him or not; if almost parallel to his visual axes it was "a small piece of paper," and when vertical to them "much longer."

Final Result.—The latest information we have received of this patient was by a letter written on Sept. 30, 1918, that is, four and a half months after he had been wounded; in it he stated, "my sight seems to be quite at a standstill, I'm afraid." When he passed from under our observation most of his symptoms had remained practically unaltered for several weeks and seemed to be more or less permanent.

COMMENT

Our observations on this patient can be now briefly summarized. His chief symptom was inability to orientate accurately in space objects perceived by either central or extra-central vision, and especially to recognize the absolute and relative distances of things seen, though by touch and sound he localized sensible objects as readily as normal persons. His power of distinguishing and comparing lengths and sizes was similarly affected. Stereoscopic vision was abolished; he was unable to see tridimensional objects in perspective and to recognize depth in anything. These symptoms disturbed the performance of various actions in which he relied on sight for guidance.

He also presented a severe disturbance of visual attention, which made him unable to perceive readily or at all objects outside macular vision when his attention was held by that on which his eyes were fixed, and a failure to explore space spontaneously with his eyes; yet objects which threw even large images in his retinæ were generally

perceived whole. Further, he was unable to evoke topographical memories acquired in the past and to learn his way in new surroundings. Finally, he had various anomalies of the ocular movements and reflexes, as failure to fixate promptly objects seen, to accommodate near objects, and to blink reflexly to threatening gestures.

His visual fields were reduced by blindness of both lower quadrants, but the acuity of central vision was good. The absence of aphasia and of serious mental deterioration, his intact faculties of motion and sensation, and the fact that he was an exceptionally reliable and objective witness, made it possible to carry out many tests and observations on the nature of the special symptoms he presented.

Certain of these deserve further consideration as they throw light on the cerebral processes which are normally concerned in spatial orientation and in the synthesis of the simpler visual impressions into that physiological product which is the basis of our recognition of, and reaction to, visible objects of the external world.

VISUAL ATTENTION

The disturbances we have interpreted as a local and special affection of attention may be first considered shortly as they do not form an essential part of that complex of symptoms which is of greatest interest in our case, and often occurs apart from and independently of it.

Repeated examination with small objects showed that in the whole of the upper quadrants of his visual fields retinal sensibility to both white and colors was intact; our frequent examinations with the perimeter and with Bjerrum's screen placed this beyond doubt; he could also distinguish familiar objects by peripheral vision. But while his eyes were fixed on anything, he noticed at the most only one other image that fell in the seeing portions of his retinas; when he gazed at the observer's face he could perceive a hand moved on either his right or his left side, but never the simultaneous movement of two hands. Even when he held up his own hands, one on each side of his visual axes, he could see only one, but indiscriminately that to this right or left. If the objects he looked at were small and fixation required attention he occasionally failed, as long as his eyes remained accurately fixed on it, to recognize another object even if near the fixation point. His failure to explore surfaces presented to him, or identify objects on them, and his obvious lack of interest in space outside his central vision were related to this symptom. As he lay in bed or sat in the ward he rarely moved his eyes or exhibited any interest in what was happening around him unless his attention was claimed by sounds, but he always evinced an intelligent interest in all that came into his

macular vision by accident or design. Similarly, on walking he passed unnoticed or collided with prominent objects, though their images fell in seeing portions of his retinas.

This condition has been recognized by several authors and has been recently dealt with by one of us; it is not uncommon as a unilateral phenomenon when lesions involve the cortex of the posterior parietal convolutions. It is essentially a disturbance of visual attention; retinal impressions no longer attract notice with normal facility, and if two or more images claim attention this is liable to concern itself exclusively with, and to be absorbed in, that which is at the moment in macular vision, since such images are naturally more accessible to consciousness than those that fall on the periphery of the retinae. Or, as is more common, when an object in central vision has attracted attention consciousness can take cognizance of one only of a series of other retinal images no matter how conspicuous or insistent they may be. There is, consequently, a restriction of attention, and the feeble call that objects outside macular vision can make on it explain its lack of spontaneity and mobility, and the little tendency it exhibits to direct itself to other visible objects.

Despite the failure of extramacular images to attract attention he generally saw even large objects whole, provided that part of them did not fall on the blind portions of his retinas; this is due to the rule that the mind when possible takes cognizance of unities, unless some detail in them excites special interest. In one experiment, for instance, the patient always recognized a large square drawn on a sheet of paper, but occasionally failed to perceive the whole of it when a prominent mark made in its center arrested his attention.

Head and Holmes have described an analogous disturbance of "tactile attention" when cutaneous sensibility is affected by parietal lesions. Though there may be no actual loss of sensibility or raising of the threshold only a certain proportion of tactile stimuli applied to the skin is then appreciated, and this proportion bears no relation to intensity of the stimulus provided it remains purely tactile.

SPATIAL ORIENTATION

It is unnecessary to refer again to the numerous observations which showed that the power of localizing accurately in space objects which he saw was seriously disturbed. This symptom was certainly not dependent on the large defect in his visual fields, or on a diminution of his visual acuity, for in the first place he always saw distinctly and recognized the test objects, and in the second, we have seen a large number of men with more or less similar defects in the visual fields who exhibited no evidence of affection of spatial orientation. Some

influence might be attributed to the abnormalities of the movements of his eyes, but it will be shown later that these were an effect and not the cause.

It is evident from our observations that our patient was unable to recognize the actual position of an object in any of three planes of space, that is, its location in the plane at right angles to his visual axes as well as its distance from him. It was, however, only during the first few weeks that he made gross lateral and vertical errors in orientating objects in central vision, though in this he never became quite accurate; but, as Figure 3 shows, he could never point to an object perceived by extramacular vision only. Localization in this plane of space depends mainly on the local signs of the retinal elements that are stimulated; by virtue of these we arrange our visual perceptions according to the arrangements of the excited retinal points, and by this means determine the relation in space of the object seen to the fixation point, and the relative positions in this plane of any two visible objects. Central lesions which affect the local sign function of cutaneous sensibility produce a very similar condition; the locality of a tactile stimulus on the surface of our body can be no longer recognized, though there may be no affection of the threshold of sensibility, or of the quality of the sensation evoked.

An intact local sign system can, however, assure only the correct recognition of relative spatial relations, and relying on it alone we cannot determine the absolute location of objects in space in relation to self. For this we need information on the position of our eyes, the attitude of our heads and the orientation of our bodies in space; only when given these can we form correct judgments on the positions of objects in central vision. Even this faculty was temporarily affected in our patient and probably never became normally acute.

The inability to recognize lengths and sizes and to compare the dimensions of two similar objects also resulted from disturbance of local sign function, as this made the patient unable to estimate correctly the magnitudes of the images that objects threw on his retinae. This judgment was further complicated by his inability to estimate distances, since the magnitude of the retinal image stands in an inverse relation to the distance of the object, but his failure to compare the lengths and sizes of lines and drawings on a sheet of paper proves that the loss of distance perception was not the only cause. Another contributing factor was his difficulty in transferring his attention quickly from one object to another, and in bringing them promptly in succession into central vision; this alone rendered comparison difficult and inaccurate, but it was obvious that this factor had not the importance which the patient himself attributed to it.

It is interesting that he preserved the idea of size and extension, and could indicate approximately the lengths of conventional standards; as a yard, foot, etc., and show the sizes of such familiar objects, as his rifle and bayonet.

His power of recognizing promptly the shape of simple geometrical figures demonstrates that in this we do not naturally depend on the comparison of lines and angles, but that we apprehend shapes as a whole and accept them as unities; only when questions and doubts arise do we resort to deliberate comparison and measurement. Similarly, though when asked to read he frequently paused some seconds before identifying a single letter, he never spelt these out one by one, but recognized the words as totals.

The perception of both absolute and relative distance was, as is the rule in such cases, much more severely affected. Our observations make it evident that his errors in estimating the distance from himself of objects in central vision were very gross, and that even when one was twice as far from him as the other he could not distinguish the relative distances of two objects. His own statement that everything appeared at the same distance from him emphasizes this defect better than any description can.

The nature of this symptom can be understood only when we consider the processes on which the estimation of distances normally depends. This, as Berkeley originally pointed out, is not a simple visual sensation or an innate quality of retinal impressions, but must be an intellectual operation based largely on nonvisual experience, as on the testing and controlling of visual perceptions by tactile and muscular sensations from all parts of the body. Even in adult life we judge distance only by indirect means; by the effort of accommodation and convergence when the object is sufficiently near for these to come into play; by the apparent size when the real magnitude is known; by the difference between the retinal images that the object forms in the two eyes; by the parallax obtained on either movement of the object or of ourselves, and by various empirical data, as clearness, light intensity, etc. Our patient's symptoms cannot be attributed to loss of any one of these elementary physiological factors. It is true that he did not accommodate or converge properly, but as he succeeded in this when he was aware of the distance of the object from him it was obviously an effect rather than the cause; his inability to judge apparent size may have contributed but could not have been the sole reason of such a gross disturbance; while his central vision was sufficiently good to allow him to perceive such qualities as clearness and light intensity, and by central vision he could appreciate the smallest lateral movement.

The cause of his inability to estimate distance must be sought rather in his failure to correlate and assimilate with past experiences those apparent impressions on which perception in the third dimension may be based, and consequently to supply to consciousness the data on which a correct intellectual judgment can be made.

His disturbances of spatial localization were limited to those which depend wholly on visual impressions; he orientated himself and external objects by touch and recognized the origin of sounds quite as accurately as normal persons.

APPRECIATION OF MOVEMENT

The slightest lateral or vertical movement of a visible object could be perceived and attracted attention whether seen by macular or peripheral vision, unless its displacement were directly toward or from him; then he often failed to observe its motion, or could not determine whether it approached or receded. But when its image passed in succession over a series of retinal points it immediately aroused a sensation of movement. Even then the direction of the movement was recognized by extramacular vision only when its range was considerably greater than the normal person requires; the simple retinal faculty of perception of movement was preserved, but the appreciation of the spatial relations of the retinal points excited was affected.

VISUAL MEMORY

Another interesting group of symptoms was due to a special affection of his visual memory. His recollection of the ordinary events of the day and of his past was certainly good; he spoke without hesitation of what had occurred during previous examinations and in the periods between them, and related events of his past life as coherently and intelligently as could be expected from a man of his education. But he could never give us any idea of how he would go from the house in which he had lived for years to the railway station of his town, or to his workshop, which he could only say was close by. "I have no clear picture of it," he complained, "I used to be able to see the way, but I can't see it now."

Further, he did not succeed in learning his way about even when his path was simple; he would often set out in a wrong direction though he had been time after time over the same route, and when asked to return along it, failed to utilize his immediately previous experiences; unlike a blind man he seemed to acquire or retain no memory or picture of the route he had passed along. His inability to determine accurately the spatial relations of objects seen, his tendency to neglect visual impressions that did not attract attention strongly,

and his difficulty in bringing objects quickly into central vision, must have all contributed to his failure to form or retain a distinct idea or memory of his path, but in this he was so much inferior to the blind man, or to a person temporarily deprived of sight by blindfolding, that a further explanation must be sought.

The fact that he did not retain any memory of routes and topographical relations that were familiar to him before he received his injury and could no longer recall them, suggests that the cerebral mechanisms concerned with spatial memory, as well as those that subserve the perception of spatial relations, must have been involved. And as it is predominantly from visual impressions that we form our idea of space, a disturbance in the functions of this mechanism made him, unlike the blind man, unable to utilize or profit by the knowledge of space that he would have otherwise acquired from tactile, muscular and other sensations.

This was probably not a pure isolated loss; to such tests as we employed he seemed to retain simple visual impressions less well than the average normal person, or than he himself retained words spoken to him. The paths and centers which are the physiological basis of visual memory were affected, but it was chiefly those that subserve the retention and recollection of spatial relations that suffered.

STEREOSCOPIC VISION

Stereoscopic vision, or the power of recognizing depth and thickness in solid objects, was completely lost in our patient. Everything appeared to him flat and bidimensional; he identified familiar things only by associating their areal shape with previously acquired experiences, just as the normal person interprets flat drawings as the objects they represent.

This symptom might be regarded as a natural consequence of his inability to appreciate relative distances, since, it might be argued, he could not therefore discriminate the different depths of various portions of a tridimensional figure. But as stereoscopic vision was not affected in any of Holmes' six cases or in other similar ones which have been recorded, although the appreciation of distance was severely disturbed, it is obvious that loss of distance perception does not necessarily abolish it, though it must be a contributing cause. Neither are the muscle changes associated with convergence and accommodation, which make possible the focusing and exploration of the depth of an object, an essential factor, as the patients just referred to possessed stereoscopic vision, though they were unable to accommodate external objects accurately; and as our patient recognized differences in light and shade it is evident that it is not on this alone that stereoscopic vision depends.

These may be all contributing factors, but the essential basis of seeing in relief or perspective is the fusion of the two noncorresponding images that a solid object forms in the two eyes into a single visual concept; like space perception it depends therefore on a higher process in the hierarchy of our cerebral activities than do sensations and simple perceptions. Our patient received such noncorresponding images in his two eyes, and in this sense he had binocular vision, but owing to the cerebral lesion these, when transmitted to the cortex, failed to be properly fused and assimilated with other visible qualities of the images, into a single concept that could give him the idea and power of discrimination of depth in the object seen.

OCULOMOTOR SYMPTOMS

The remaining symptoms presented by our patient were due to a disturbance of the motor and reflex functions of the eyes. There was no palsy of any of the ocular muscles, and he never had diplopia, but, especially during the first part of his illness, he had difficulty in fixing accurately and in bringing promptly into central vision objects which he saw, and in keeping his eyes fixed on a moving point. Further, when anything at which he looked was approached toward his face his eyes failed to converge, he did not accommodate, and his pupils did not contract; he could consequently see nothing distinctly that was within 25 cm. of his eyes.

All these symptoms were secondary to and dependent on the loss of spatial orientation by vision, for they disappeared when he was aware of the position in space of the object which he should fix or accommodate. He turned his eyes promptly and accurately to any point on his own body that was touched, and when his own finger was moved passively toward his face his eyes converged and accommodated on it naturally. There is evidence, however, that this affection of fixation and accommodation is not always directly dependent on loss of spatial orientation; two of Holmes' patients, as well as two similar cases published by Förster and Riddock, were unable to fix their own fingers or bring central vision promptly to points on their own bodies. In some of the recorded cases, too, convergence of the eyes, accommodation and contraction of the pupils did not supervene when the patients attempted to keep their own fingers in distinct vision as they were moved toward their eyes.

Finally our patient failed to react by blinking or withdrawing his head when an object was jerked suddenly toward his face, or to any other threatening gesture. His own explanation that he could not recognize the nearness of the threatening object was probably correct,

as he invariably blinked if his own hand was swung passively toward his eyes, or if the movement of the external object produced an appreciable current of air. The abolition of the blinking reflex in this patient was consequently in all probability due to his loss of spatial perception.

ANATOMIC SITE OF THE LESION

It is not possible in the absence of an anatomical examination of the brain to determine accurately the site of the lesion produced by a gunshot wound of the head, the extent of the damage, or the centers and tracts that may be involved by it, but craniometric measurements enable us to form at least an approximate idea of the portions that are injured.

A necropsy was obtained in one of Holmes' patient, and from this and an analysis of the positions of the wounds in his other five cases and in those recorded by Inouye and Riddock—the only other instances at present known to us of similar conditions due to gunshot injuries—he concluded that this symptom complex appears only as a result of bilateral injuries, and when the lesions on the lateral surfaces of the hemispheres involve the angular gyri or their neighborhood. The fact that more or less similar symptoms have been produced by vascular lesions limited to these portions of the lateral surfaces of the hemispheres (Pick, Bálint, van Valkenburg) and by experimental destruction of this region in dogs and monkeys, by Munk, Schaefer and Ferrier, is evidence that damage of the cortex or subcortical tracts in the region of the angular gyri is the anatomical basis of the condition. The measurements of the positions of the wounds and of the cranial defects in our patient suggest that the missile entered through the posterior portion of the right angular gyrus and made its exit through the upper part of the corresponding gyrus of the left side. Its track consequently conforms closely to that in the other recorded cases in which gunshot injuries produced the same or similar symptoms. We cannot, however, ascertain more accurately the cortical areas and tracts that were involved.

The symptoms we have described cannot be, however, regarded as a direct result of the destruction of centers that subserve the spatial orientation of visual impressions and allied functions, since these functions are not purely sensational, but are the result of the mental synthesis of more elementary visual perceptions, with the afferent impressions derived from the proprioceptive organs of the ocular and neck muscles and from the labyrinths. They should be rather interpreted as the effect of an injury of association paths between those portions of the occipital cortex which are concerned in visual perception and the rest of the brain.

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