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DISTURBANCE OF NUMBER-FORM IN A CASE OF BRAIN INJURY

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Attention was first drawn to individual peculiarities in visualizing numbers by Sir Francis Galton (1880) in the course of his classical studies of mental imagery. Galton pointed out that among persons who visualize numbers clearly there are many who notice that the image of the same figure invariably makes its appearance in the mental field in the same direction and at the same distance. When such an individual thinks of the series of numbers, 1, 2, 3, 4, etc., ". . . they show themselves in a definite pattern that always occupies an identical position in his field of view with respect to the direction in which he is looking." (Galton, 1883). This visualized pattern, to which Galton gave the name of " number-form," is by no means the same in different individuals and may assume a surprising variety of shapes. These are well illustrated in Galton's original monograph (1883). The form may consist of a mere line of any shape, or of a peculiarly arranged row or rows of figures. Often its various parts lie in different planes and occasionally the form is coloured. Galton estimated that this peculiarity is found in about 1 in 30 adult males or 15 females but detailed statistical inquiry was not undertaken.

It appears from Galton's investigation that number-forms, although differing widely in shape and distinctness from person to person, have certain characteristics in common. In the first place, they undoubtedly originate at an early age but may be further elaborated during youth. In the second place, they come into view automatically, i.e. independently of the will, whenever a numeral is thought of. And in the third place, each numeral has its own fixed place in the schema which remains more or less invariable for any given individual. On the other hand, number-forms vary greatly in their modes of appearance. In some cases ". . . the mental eye has to travel along the faintly marked and blank paths of a form to the place where the numeral that is wanted is known to reside, and then the figure starts into sight." (Galton, 1883.) In other cases, however, ". . . all the numerals, as far as 100 or more, are faintly seen at once, but the figure that is wanted grows more vivid than its neighbours." (*loc. cit.*) Various other individual differences in the size, shape, and mode of appearance of number-forms emerge clearly from Galton's protocols.

Galton was in no doubt that the forms were of genuine service to their possessors, at least in relatively simple arithmetical operations. Indeed his attention was first drawn to the topic by a prominent lawyer, himself the possessor of a number-form, whose powers of mental arithmetic were outstanding. But this subject stated that he made use of the form only in dealing with relatively easy mental arithmetic and it was liable to disappear when he was engaged in more exacting computations, e.g. mental multiplication of very large numbers. It must be added that there appears to be no regular correlation between ownership of a number-form and the level of proficiency in mental arithmetic which the individual attains.

The possibility that number-forms may be deranged or abolished as a result of cerebral injury or disease appears to have attracted little or no attention. Nevertheless, in view of the fact that visual memory may be markedly impaired by cerebral lesions, it is a possibility which appears to us to deserve consideration. In particular, it might be expected that the disorders of visual-spatial cognition not uncommonly associated with occipito-parietal lesions of either hemisphere might well involve the number-form in individuals in which this peculiarity was at all highly developed. If this should occur, one might expect an impairment of calculation secondary to the number-form disturbance, and this disability might differ in important respects from the typical verbal-symbolic dyscalculias. We are therefore describing a case of penetrating brain-injury in which a disturbance of this character was evident. The patient reported marked difficulties in the evocation of his number-form together with certain changes in its habitual appearance. These features led to its virtual loss of usefulness in calculation. The defect was associated with some degree of visual-spatial agnosia and a marked impairment of visual memory in general. So far as we have been able to ascertain, no precisely similar case has hitherto been reported in the literature.

Case History

(Case No. 10244) A. L., a right-handed man, had been a plasterer, and had been reasonably successful in all subjects at school.

He was wounded in October, 1944, at the age of 24 years, a metallic foreign body entering the left parieto-occipital region and crossing the mid-line to come to rest ½ in. above the right petrous temporal bone (Fig. 1a and 1b). Two hours later he was extremely restless and was thought to be unconscious. His pupils were widely dilated and did not react to light, but all limbs moved well; he responded to pin-prick everywhere and reflexes were normal. Thirty hours after injury the wound was debrided. Nine days after injury, when the patient was admitted to a military hospital for head injuries, he was still restless, fought when an attempt was made to examine him, and tried to masturbate when left alone. The pupils were dilated but reacted to light and there was a slight right facial weakness. No other abnormal physical signs were found, but his vision could not be tested. He showed marked perseveration of speech, but carried out, though imperfectly, simple commands such as, "Open your eyes". He gradually improved, and 29 days after injury was quiet and cooperative, but was grossly disorientated and used a lot of jargon. He had a severe nominal dysphasia, a complete dyslexia, and perseverated in words and actions. However, comprehension of speech was quite good, and he could demonstrate the purpose for which objects were used.

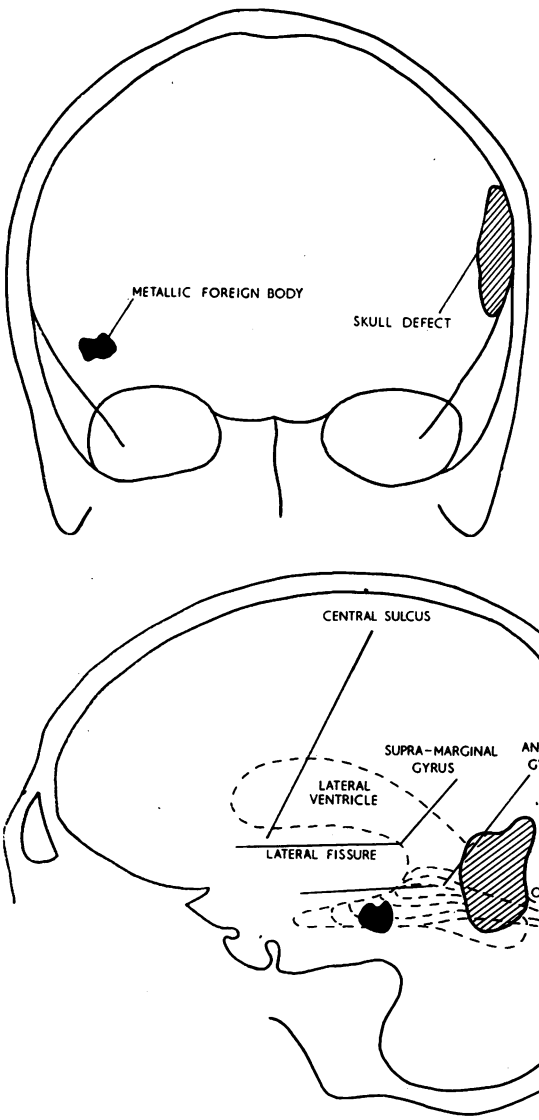

FIG 1*a*. and 1*b*.—Tracings from radiographs taken after debridement. The estimated positions of neighbouring anatomical areas are shown in 1*b*.

Two months after injury, when it was first possible to determine his visual fields, he was found to have an almost complete right homonymous hemianopia. Seven months after injury he had improved enough to make himself understood quite well, although he still had an expressive and receptive dysphasia with considerable dyslexia and dyscalculia. At this time he was first noticed to have a defect in spatial perception and to lose himself easily.

He returned to his home, and there had little difficulty in speaking and was little inconvenienced by his visual field defect, but when he first returned to a large town near his home he almost lost his way and was so distressed by this experience that he avoided revisiting the town for the next four years.

During that time he had eight epileptic fits. Before the first of these he had an organized hallucination of scenery in his right half field, and this reminded him that while in hospital he occasionally "saw things twice" in the right half field. For instance, immediately after passing through a doorway the image of the right door jamb would return for a few seconds. At home he lacked his former confidence, did not indulge in the pleasures he had enjoyed before his injury, and never took any work.

In July, 1949, nearly five years after injury, the patient was re-admitted for review. His chief complaint was that he was afraid of losing himself, and to this he attributed his loss of confidence. On examination there was a right homonymous field defect, more evident in the lower than in the upper quadrants (Fig. 2). Within the limits of his vision he could appreciate distance well in the affected field. There was no dystereognosis, no finger agnosia, and no dyspraxia for dressing.

On psychiatric interview he was cooperative but tense and lacking in confidence. He had a clear insight into his disabilities and thought they were more conspicuous to the observer than in fact

they were, and in consequence, he said, he avoided the company of people outside his family circle.

His intelligence quotient on the Wechsler Bellevue scale was 88 (scatter 62-110), markedly his worst performance being in the digit test. He appeared to have suffered little or no intellectual impairment apart from the specific difficulties described. In particular, there was little or no defect of " abstraction " in the sense of Goldstein.

He had only a confused memory of events which he could not date during the four months he had spent in France and Belgium before he was wounded. He had a post-traumatic amnesia of at least nine days, possibly much more.

He had slight disturbance of speech function, appearing mainly as some hesitancy in reading aloud and a few errors in writing and spelling. He read newspapers regularly and remembered what he read, but writing was an effort and he generally persuaded his father to write his letters. He had no difficulty in recognizing pictures or colours.

His chief disability was a defect in visual memory, which presented as (1) an impairment of topographical sense, (2) a difficulty in copying and drawing from memory, and (3) an impairment of number-form associated with dyscalculia.

Impairment of Topographical Sense.—The patient complained that he " had not got a plan " of places he knew well or that if he had a plan it was indistinct and did not correspond with the facts. When he first went home his village " did not look right", and though he had only a very vague " plan " of it, he seemed to " have twisted it the wrong way round". He approached along the side road in which his home stands (Fig. 3) and found that his " plan " of the village was twisted through two right angles relative to the points of the compass. This twisting, however, was not a constant feature, and he said that generally when walking in places which he had visited frequently, he did not know what was round the next corner and the scenery unfolded as though he were in country that was strange to him. He had no greater difficulty in appreciating landmarks on his right than his left. When he first returned home he had to ask the way to the lavatory, though he knew it " was outside", and the furniture at home " looked different", but he was quite unable to say in what way. He avoided all except the most familiar places, and even in his own street he had begun to enter the wrong house but had always recognized his error himself. He was reluctant to come into hospital because of the difficulty of learning the way about a strange building, and 13 days after admission he could not describe the way from the surgery to his ward, but could interpret correctly, though with difficulty and diffidence, a plan of the hospital. When given verbal directions he was unable to hold more than two changes in direction in mind, and was too slow to make the required turns mentally while the problem was being

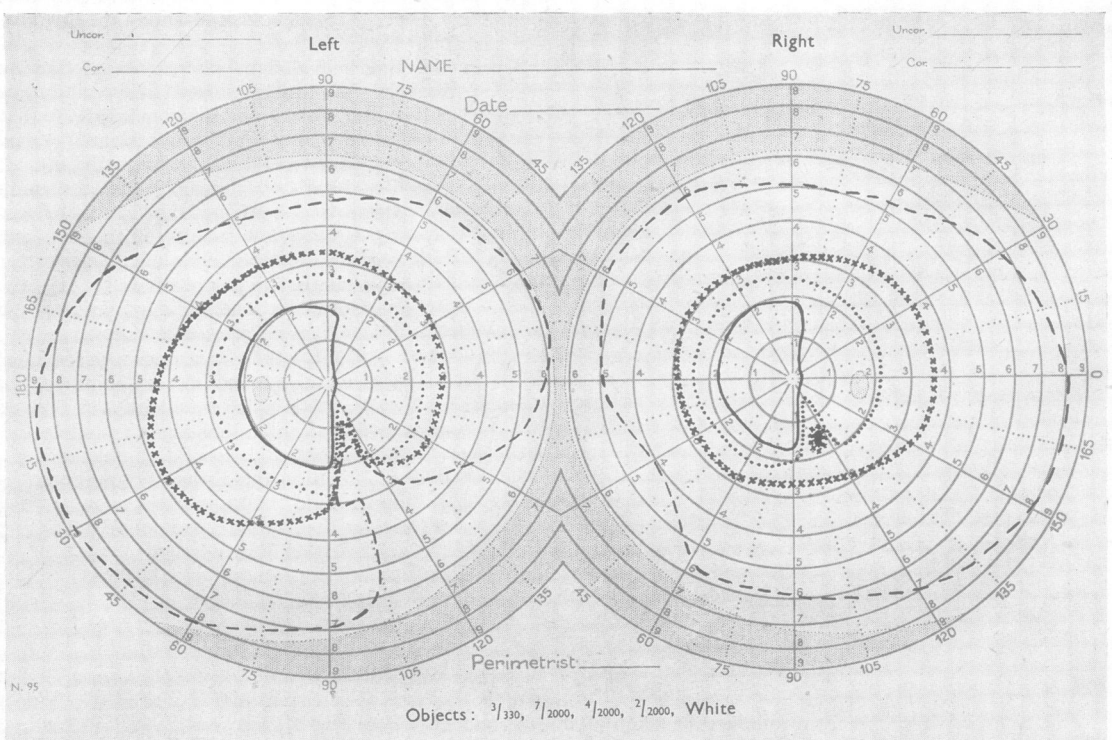

FIG. 2.—Visual fields.

stated, though it was repeated several times. He was able to make two turns on a map correctly, but could not hold more in mind.

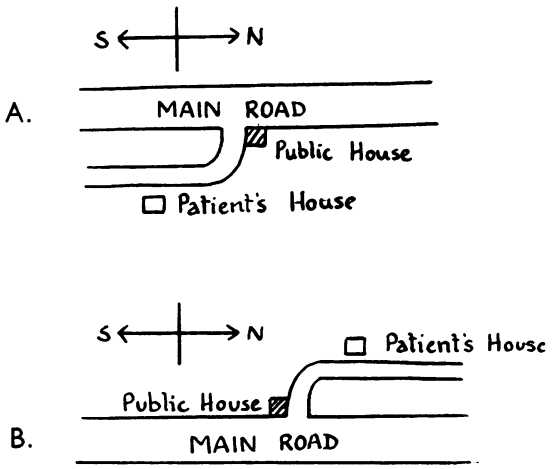

FIG. 3.—Plan of patient's village, A. as it is; B. as he expected it to be.

Tests of Visual Memory.—The patient could copy simple geometric designs well but was probably a little impaired in his ability to copy more complex designs. Reproduction from immediate memory was grossly

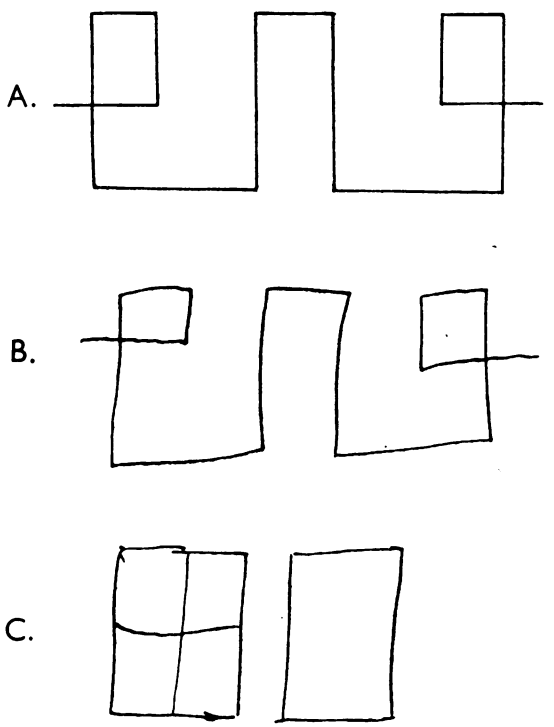

FIG. 4.—A. Model; B. copy; C. reproduction from immediate memory.

impaired (Fig. 4). Although his chief recreation had been bicycling he drew from memory a crude picture of a bicycle and omitted the pedals and chain until reminded (Fig. 5). He drew an adequate sketch map of England.

Though he could recognize pictures correctly he could only recall three out of six from immediate memory.

Match-stick mosaics were copied quickly and confidently with the model before him, but when reproducing from immediate memory he made as serious errors as in reproducing graphic designs from immediate memory. He was very slow in learning to correct his mistakes even when several demonstrations were given.

When given the Wechsler Bellevue block design test his score was 20 (equivalent weighted score, 9). He had considerable difficulty in the more complex patterns with

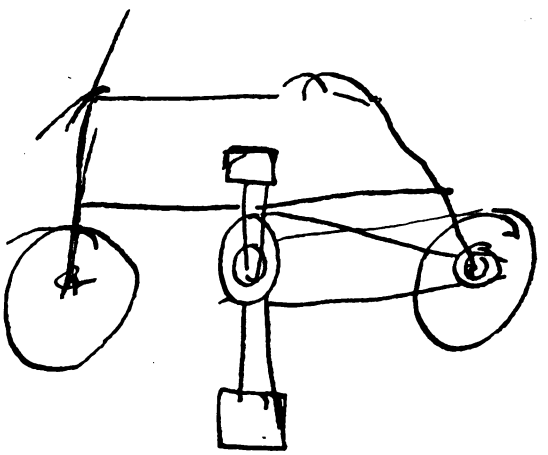

FIG. 5.—Bicycle drawn from memory. The patient omitted the pedals and chain until reminded.

occasional perseveration of errors. He was unable to reproduce from immediate memory even the simple patterns which he could copy easily with the model before him.

He could repeat correctly three times out of four numbers of five digits each, whether they were presented to him orally or in writing. He stated that to remember written numbers he had to say them to himself, and occasionally his lips could be seen forming the words.

Impairment of Number-Form and Dyscalculia.—The patient complained that he could not do simple arithmetic as well as formerly, and the following are examples of his answers.

Oral

s.	*d.*		*s.*	*d.*		*s.*	*d.*	
2	6	+		5	=	2	11	(2*s.* 11*d.*)
3	6	−		11	=	2	2	(2*s.* 7*d.*)
3	1	+		11	=	4	0	(4*s.* 0*d.*)
3	4	+	1	3	=	5	8	(4*s.* 7*d.*)

Written

s.	*d.*		*s.*	*d.*		*s.*	*d.*	
3	0	+	1	3	=	5	1	(4*s.* 3*d.*)
1	2	−		4	=		10	(10*d.*)
2	6	−	1	8	=	not known		
	3	×	6		=		18	
	7	×	7		=	not known		

He was slow in calculating and when his answer was right he often thought it was not.

He spontaneously said that he " used to have a plan of numbers, but had lost it", or, more accurately, it was no longer distinct. He drew this plan of numbers as far as 12, and the remainder was drawn under his instructions. A few days later he drew the complete plan himself. He was very hesitant and uncertain, but the two plans are similar, and from them and his comments on them the plan shown in Fig. 6 was constructed. It is evident that it represents a typical number-form of the type described by Galton (1883). He stated that this form was seen against a vague background which he thought might have been his old school playground. The bottom of it was on ground level a few yards from him and the form sloped away from him at an angle of about 40° to the horizontal. He saw all parts of the form simultaneously but the particular number he was seeking stood out with special distinctness.

Before his injury he had also had " forms " for months, days of the week, and the alphabet. He could recall them now with difficulty (Fig. 7). The form for days he thought was derived from a calendar, but he insisted that it began with Monday. The alphabet form had been " a really good plan", which he had perhaps devised from the chart from which he had learned his letters at school. It had become very indistinct since his injury, and though he was sure of the general arrangement he was uncertain whether it consisted (Fig. 7c) of five lines of five or six letters each, or of six lines of four or five letters each. He had no form for historical dates, and no form other than that for numbers had a background.

He could say the months, days of the week and letters of the alphabet correctly, but it was an undue effort to do so, and he had great difficulty in saying the days of the week backwards. He attributed these difficulties to the impairment of the respective forms. The forms had been with him as long as he could remember, and had remained unchanged until his injury. They were not associated with colours.

Discussion

It can hardly be doubted that the number-form described by this patient was a genuine phenomenon and that it had undergone significant deterioration as a result of his brain injury. In its original form, it displayed many of the typical characteristics to which Galton (1880 ; 1883) drew attention. Not only does it actually resemble rather closely one of the forms reproduced by Galton (1883), but it shows several features commonly reported by those who visualize numerals in this way. Among these are the facts that it runs upward rather than downward and extends into the third dimension. It is also interesting that the change in direction at the 12 is a regular feature in the majority of number-forms (Galton, 1883). Visualization of the months of the year as lying in an oval or circular form is also common (Galton, 1883). In short, the " forms " of this patient are entirely characteristic.

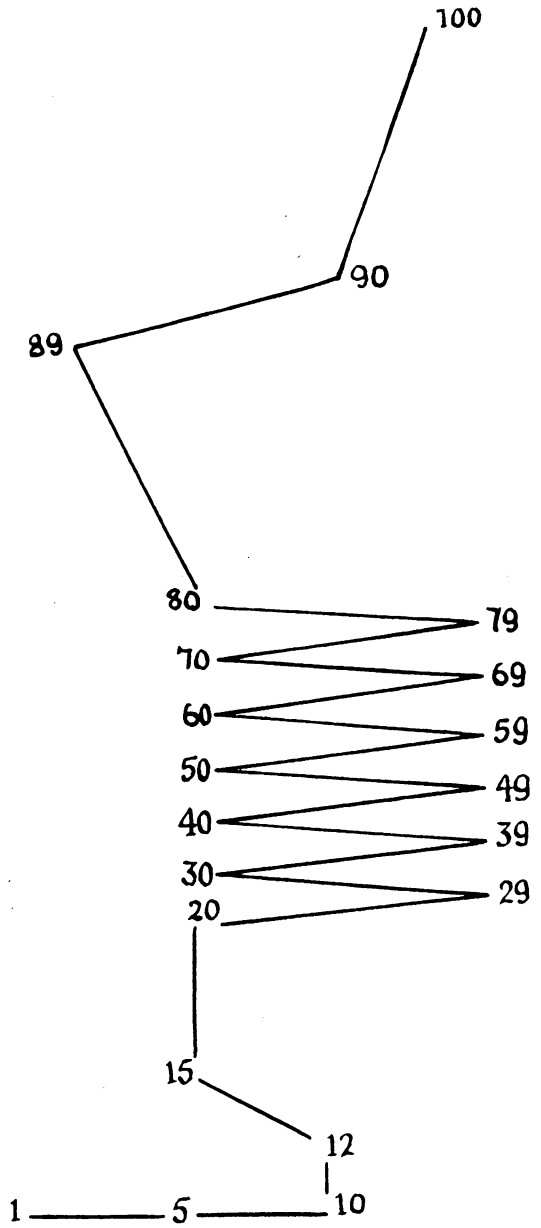

FIG. 6.—" Plan of Numbers " (number-form).

The changes undergone by his number-form as a result of brain injury are of two kinds : First, it has lost its former distinctness, and second, it can be held in mind with difficulty, if at all, for purposes of calculation. Its manifest loss of usefulness is clearly indicated by the patient's own statement that it is now more hindrance than help. The actual significance of this disability in relation to the poor level

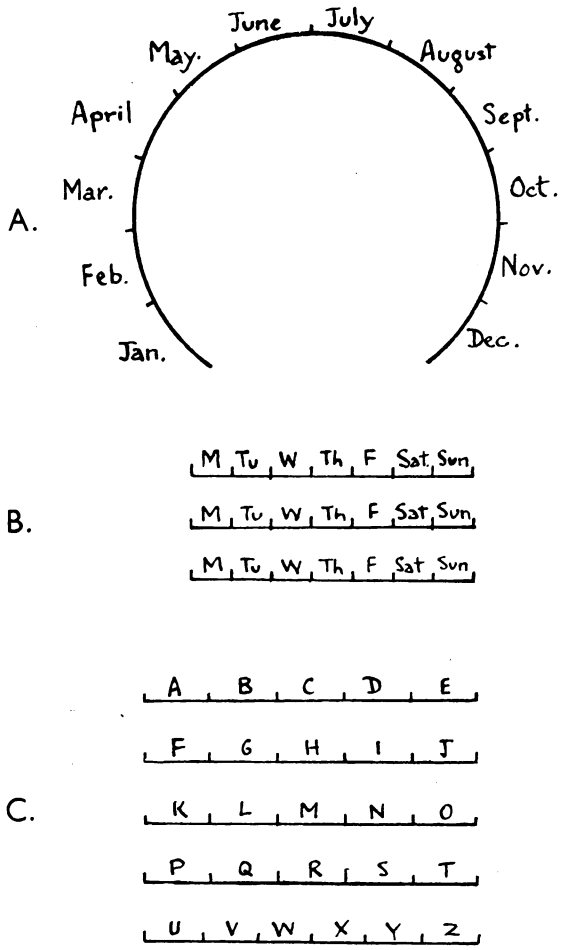

FIG. 7.—Forms for A. months; B. days of the week; C. alphabet. The patient was aware of an indefinite number of these lines one above another, the central one representing the week he was considering.

of arithmetic, both oral and written, is not altogether easy to assess. Although the patient showed no loss of understanding of arithmetical principles, it is entirely possible that his residual dysphasia contributed in some measure to the low level of arithmetical performance. Nevertheless, we consider that there is good reason to suppose that the defective number-form grossly augmented the dyscalculia. In the first place, the patient's performance on oral arithmetic was notably poorer than his performance on all other verbal but non-numerical tests of ability. In the second place, symptoms commonly associated with primary dyscalculia, e.g. dysgraphia, disorientation for right and left, and finger-agnosia, were little, if at all, in evidence five years after injury. The defect in calculation, on the other hand, remained extremely pronounced and was roughly proportional in severity to his visual memory defect. In the third place, the patient's own admission that the loss of his number-form gravely impeded calculation deserves recognition. This handicap, we believe, was due partly to virtual loss of the number-form itself, putting the patient somewhat in the position of a normal person who is accustomed to use pencil and paper for simple arithmetic (to present himself with the sum visually) but is specifically prevented from doing so, and partly to the loss of confidence which this deprivation engendered. In this connexion, we have already commented on the diffidence and lack of confidence habitually displayed by the patient in regard to his visual and topographical disabilities. We may conclude, then, that although a primary defect in the sense of verbal-numerical dyscalculia cannot be excluded, the evidence indicates that a large part of the arithmetical disability is to be ascribed to impairment of the visual-spatial number-form and its virtual loss of usefulness in calculation.

The probable site of the brain injury is indicated by Fig. 1. The point of entry, at which the most severe damage usually occurs, was probably just below the angular gyrus on the left side. The penetrating metal fragment must have damaged the upper edge of the left optic radiation and travelled downwards and forwards to pass below the right optic radiation leaving it undamaged.

Summary

The occurrence of number-forms (stereotyped modes of visualizing numerals) in a minority of normal individuals is described.

A case is reported in which a previously well developed number-form was grossly impaired as a result of a left-sided occipito-parietal gunshot wound. This impairment led to its virtual loss of usefulness in calculation. The defect was associated with a generalized weakness of visual memory and some impairment of topographical sense.

The significance of the number-form defect in relation to dyscalculia is considered. It is argued that although a primary verbal-numerical dyscalculia cannot be excluded, the greater part of the patient's arithmetical disabilities are to be ascribed to his defective number-form.

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