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STRATEGIES OF SEARCH

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ABSTRACT

A series of logically related experiments is described with the aim of identifying specific features of search strategies in diverse situations. Several distinctive characteristics, associated with increase in age, (9 to 15 years), emerge. The question of the relation of physical to mental searches is examined, and the thesis advanced that a theory of subjective information, with a network of supporting concepts, is required for psychology in general and for the study of search strategies in particular.

1. INTRODUCTION

Everyone must at some time or other have mislaid or lost an article the retrieval of which called for some search, however modest. Searching, by sight, sound or smell is common throughout the animal kingdom. Indeed the use of one and the same word to refer to an animal seeking its food or prey and to a man who is hunting for his lost umbrella may suggest that their respective search activities conceivably have something in common.

Methods of search have been studied in several contexts, for example, when the task is to locate an error in a flow system (DALE, 19:9) or to identify an enemy aircraft in laboratory simulations of actual flight (Experiments on Visual Search, 1958). There are many circumstances in which the observer can follow, step by step, an individual's path of search. We shall see, however, that there are other circumstances in which he can only determine the path indirectly by inferences from observations.

These studies may help to identify the heuristic elements in search strategies and thus facilitate computer simulation of complex human activities. The distinctive feature of human search, by contrast with mechanical search, is, in fact, the employment of heuristic devices. Even a young child will not make an exhaustive exploration of every possible place in which an object might be hidden. He will somehow limit himself to those few places which seem to him subjectively promising. The nature of these heuristic devices and intuitive short-cuts is unknown and presents a baffling problem to computer scientists who are anxious to simulate the *means a* man employs to arrive at his goal, and not merely to *arrive* at his goal.

Our aim in this paper is, first, to examine a rather novel range of experimental search situations so as to make explicit, if possible, the strategies employed. Secondly, we shall enquire whether the search for an immaterial object may be regarded as basically similar to the search for a material object. Thirdly, we shall consider the place of subjective information in the search for either a material or immaterial object.

There are five experiments. In the first two the subject has to reach his objective by the least possible effort. In the third his search reduces to one step. The fourth, in principle, replicates the third but allows many steps. Finally, the fifth experiment embodies features that enter into each of the previous four.

2. Experimental procedures and results

Experiment 1

In the first experiment to be described the subjects were given a page on which was printed a number of small circles. They were told the number and that the experimenter was thinking of two of the circles. Their task, it was explained, was to identify these two circles. They could do so by asking the experimenter questions, the only questions permitted being those which could be answered by 'Yes' or 'No'. First, they stated the number of questions they thought they would have to ask in order to identify the two circles, and then they tried to identify the circles by actually asking the questions. They were then given four further pages. On each of the five pages the number of circles ranged from 2^2 to 2^{10}. There were three groups of subjects aged 9 ($n = 50$), 12 ($n = 51$) and 15 ($n = 53$) respectively.

Examination of the data suggests that, broadly speaking, two types of strategy are discernible. The first type, found predominantly in the youngest group, is exclusively occupied with the individual circles as such. The child's search, so to speak, is object-bound, and he makes no attempt to detach himself mentally from the target circles. He does not suspect that the target circles might belong to sets or classes. For this reason he believes that a hit at any circle could succeed if he were lucky. The subjective feeling of luck outweighs, in his strategy, any logical structuring of the situation. Therefore he tends to plunge into action forthwith without any reconnaissance, detour, or preparation of the way for objectively sure success. He tries to do at the very start what the children employing better strategies are content to do towards the end of the task. In short, he is concerned only with the elements (i.e. the circles) and does not suspect that these elements might belong to sets or classes. Accordingly we designate this type of strategy the *Element-type*. Two sub-categories may be distinguished. In one the child asks 'is this (pointing) *one* of the two circles?' In the other he asks 'is the (pointing) *two*?'

The second type of strategy is characteristic of the two older groups of subjects and is one in which the child does not attempt to arrive at a final solution immediately. He is tolerant of delay, and is ready to wait and to work towards the solution by successive steps. His eyes are not glued to individual circles but scan the area in which the target circles might be located. This scanning varies in its efficiency, that is, in the extent to which its coverage is comprehensive and in the degree to which there is overlap in the areas scanned (objective redundancy). This strategy we call the *Set-type*. Here there are four sub-categories which may be represented by the following questions respectively:

(i) "are they in this (pointing) row (diagonal, column)?"
(ii) "are they in this (pointing) outer (or inner) ring of circles?"
(iii) "are they in this (pointing) group of circles?"
(iv) "are the two circles in this (pointing) half of the page?" This is a binary strategy which is the best to be expected from our subjects. [1]

[1] The optimal strategy is to apply the strategy for identifying a single element to the set of all pairs of circles. For example, suppose there are n circles numbered 1 to n. There will be $\frac{n(n-1)}{2}$ pairs. The subject can then apply a binary strategy to *this* set and thus the locate target pair. He will need, optimally, $\log \frac{n(n-1)}{2}$ decisions.

In comparing the performance of the 9-year-old children with the two older groups, we must bear in mind that the 9-year-olds are not preselected except with respect to mental defect and special physical or emotional handicaps, whereas the 12- and 15-year-old children have all been selected for secondary education.

Allowing for this factor of selection, we see in Table 1 that with increase in age there is an increase too in the ratio of Set-type to Element-type questions asked by those subjects who did, in fact, attempt a Set-type strategy. The subjects, at each group, who are not included in this Table only employed an Element-type strategy.

TABLE 1

Ratio of Set-type questions to Element-type questions asked by those attempting a Set-type strategy.

Age	No. using a Set strategy	Set/Element ratio
9	10	1.9 : 1
12	38	2.4 : 1
15	30	3.0 : 1

The age at which children begin to use a binary strategy is of particular interest because it indicates that they now appreciate what is, in fact, the optimal strategy. In earlier experiments we studied the manner in which children approach the task when only one circle has to be identified. We are now able to compare performance in a one-circle task with performance in a two-circle task.

In Table 2 we show the proportions, at the different ages, employing a binary strategy (i) when one circle has to be located, and (ii) when two circles have to be identified.

TABLE 2

Percentages employing a binary strategy

Age	One circle	Two circles
9	15	4
12	25	22
15	65	17

It appears that at all three ages, those who can hit upon a binary strategy with one circle are not necessarily capable of doing so with two circles. At each age a larger proportion can cope with the one circle situation, but most of these find the two circle situation beyond them in terms of a binary strategy.

The joint effect of increase in age and selection for secondary schooling is clear, as may be seen from figs. 1a, 1b, and 1c.

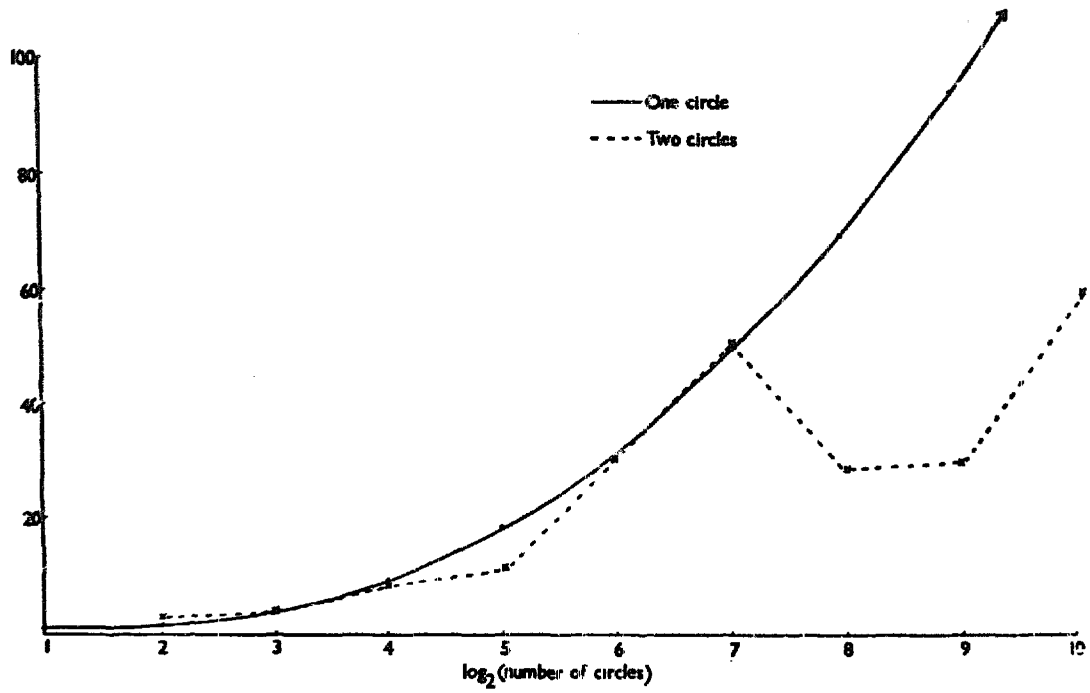


Fig. 1a. Median estimated number of questions plotted against $\log_2$ (number of circles). Age 9 yrs.

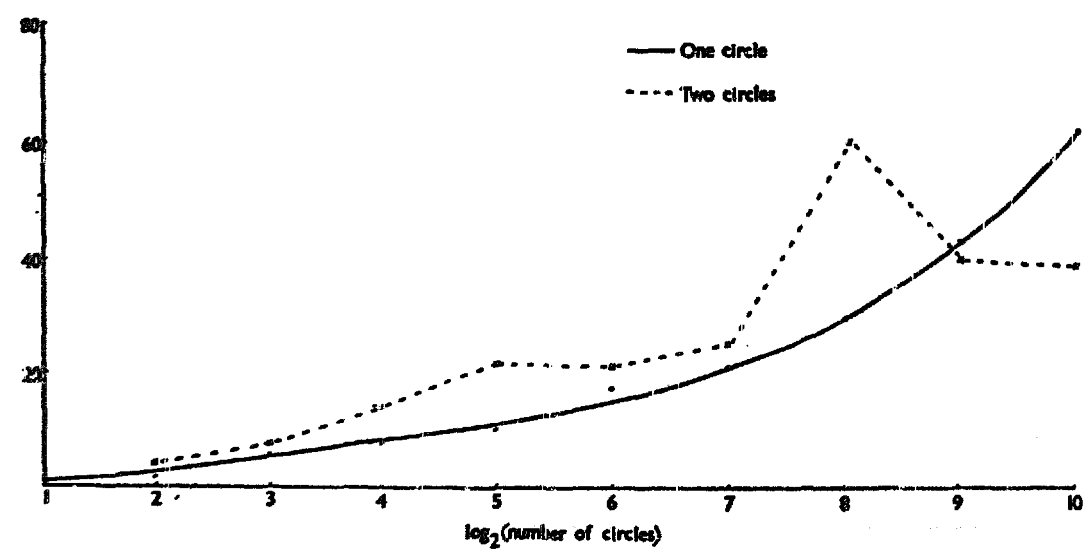


Fig. 1b. Median estimated number of questions plotted against $\log_2$ (number of circles). Age 12 yrs.

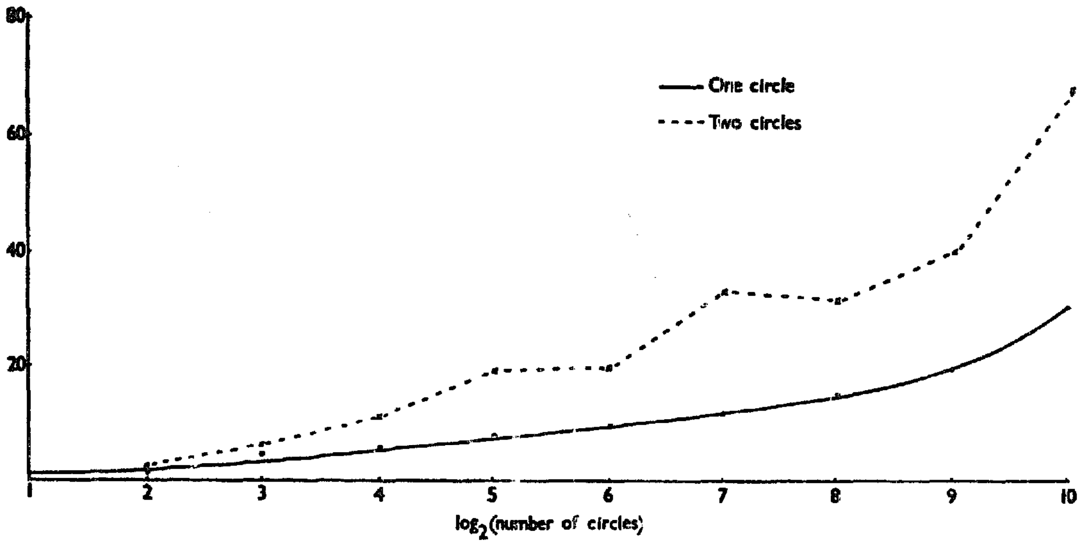


Fig. 1c. Median estimated number of questions plotted against $\log_2$ (number of circles). Age 15 yrs.

(i) At age 9, the children do not appear to distinguish between the one-circle and the two-circle tasks up to a value of 2^7 circles on the page. When the number of circles is larger, understanding of the two-circle task seems to break down whereas in the one-circle task they seem to treat values greater than 2^7 in the same way as they treated values less than 2^7.

(ii) At age 12 the two curves also run more or less parallel up to a value of 2^7, children at this age appearing to grasp that the two-circle task is more difficult. However, this understanding breaks down at 2^9.

(iii) At age 15 there is a realization at all values up to 2^{10} that the two-circle task is more difficult.

At all ages the subjects' estimates of the number of questions they need to ask, that is, their subjective uncertainty, is determined not so much by the amount of information on the page in terms of 'bits', but by the absolute number of circles. This becomes evident if we plot the number of estimated questions against the number of 'bits' (figs. 2a, 2b and 2c). For any given number of 'bits' the children give smaller estimates of the number of questions needed in the two-circle task than in the one-circle task. (The number of 'bits' in the two-circle task we define as $\log_2 \binom{n}{2}$ where n is the number of circles.)

The subjects' behaviour in the two experiments is similar in that the same strategy is not necessarily employed throughout the experiment. Furthermore, the strategy used for any residual number of circles, at

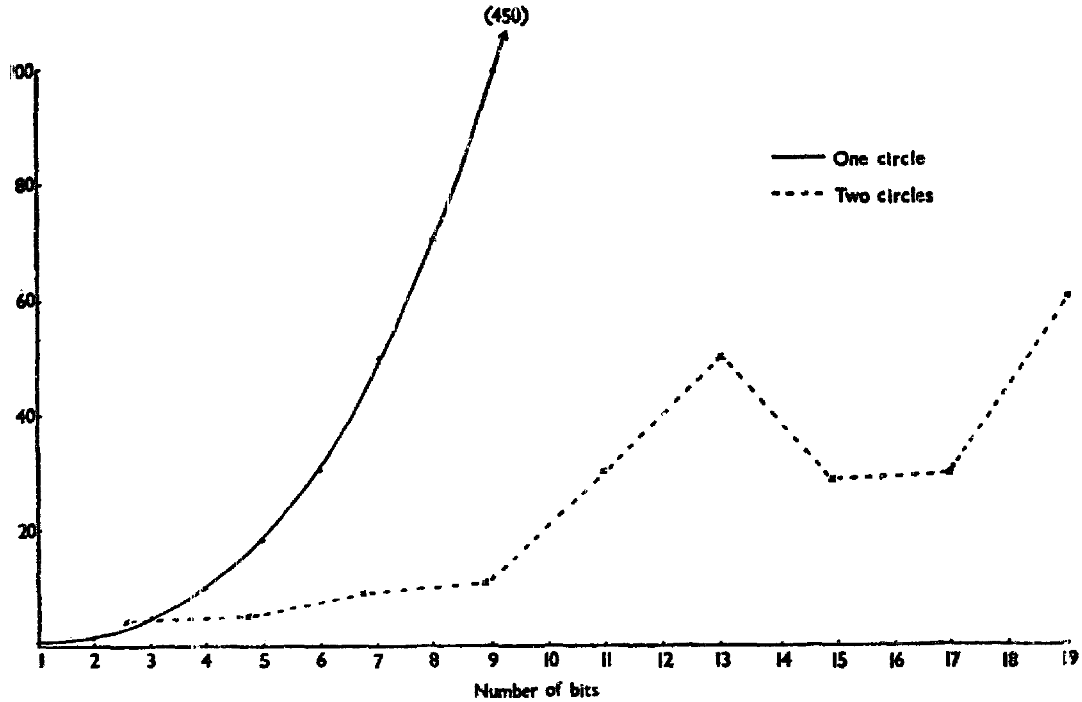


Fig. 2a. Median estimated number of questions plotted against the number of bits. Age 9 yrs.

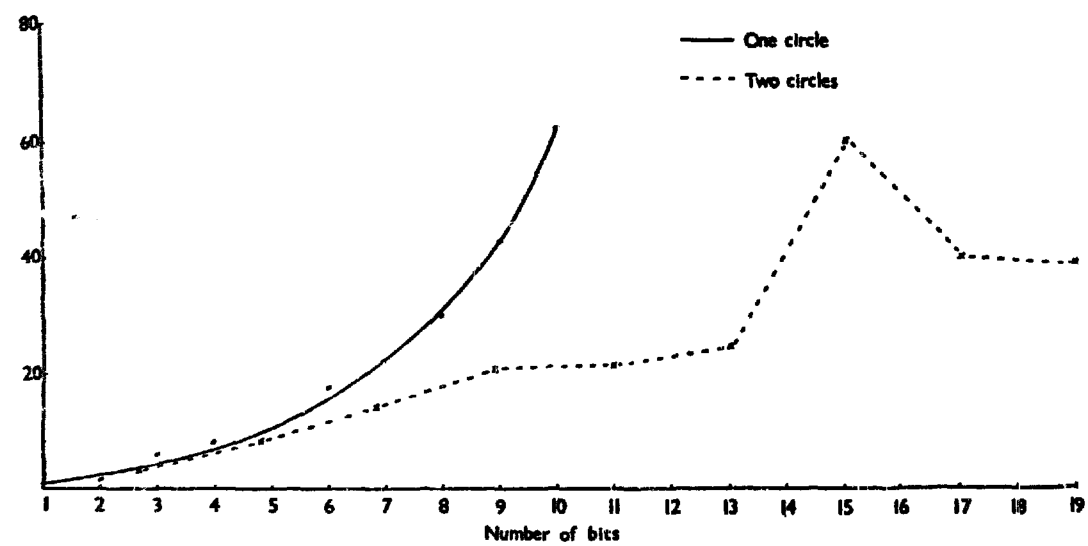


Fig. 2b. Median estimated number of questions plotted against number of bits. Age 12 yrs.

any given stage of the task, is not always identical with the strategy employed for the same number of circles *ab initio*. For example, a search which begins with the Element-type may end in the Set-type, and *vice-versa*.

In other (unpublished) experiments with younger children in which

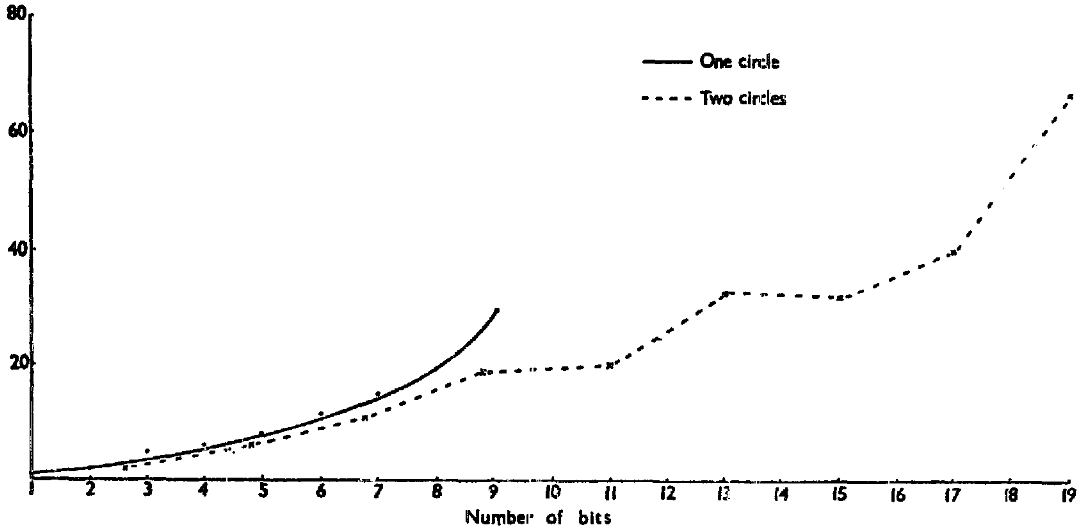


Fig. 2c. Median estimated number of questions plotted against the number of bits. Age 15 yrs.

the circles were replaced by pictures of animals or ships and in which the subjects were instructed in the manner of grouping this material, we found that, even under these simpler conditions, children aged 6 years are not yet ripe for a Set-type strategy. This first appeared at age 7 and was more common in the older age groups.

Experiment 2

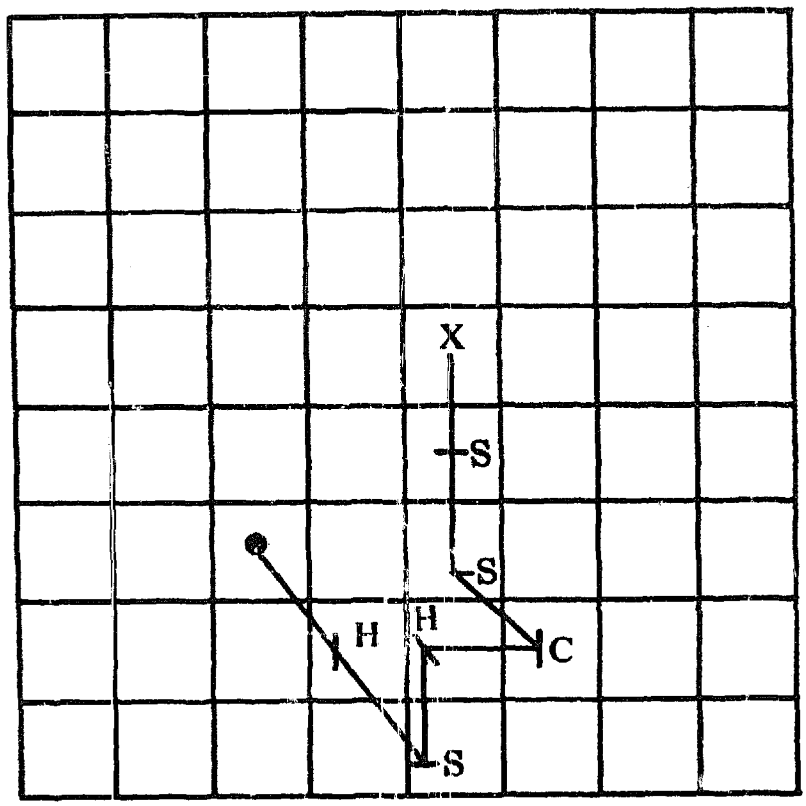
In the foregoing experiments each subject began with some uncertainty which he progressively reduced. This reduction of uncertainty was effected by gaining information from the replies to his questions. His initial uncertainty may be measured in terms of the number of yes–no questions he felt he would need to dispel it completely. His residual uncertainty after each reply may likewise be measured by the number of questions he felt still remained to be asked. By the same token, any reduction of uncertainty was, at the same time, a measure of gain in information. A step-wise reduction of uncertainty and gain in information may be exemplified in a different fashion in a further experiment.[2]

The floor of a room was divided in 64 squares. Each child was placed on a starting square and told that he could move in any direction one square at a time. His task was to find the 'magic square', that is, the one the experimenter was thinking of, in as few moves as possible.

[2] This experiment was conducted, at our suggestion, by one of our students, Miss Morgan.

After each move he would be told whether he was 'hotter' (nearer the 'magic square') 'colder' (further from it) or 'same' (same distance in terms of the number of moves). There were two groups of subjects aged 7 ($n = 20$) and 9 years ($n = 20$) respectively.

At the start the 'magic square' could be any one of 63. After the first move this number was reduced to one of a range of numbers, according to the particular move. The ratio (R) of the number of possible target squares after each move to the number of possible target



X Starting square
● Goal or magic square
H 'Hotter' (= nearer the magic square)
C 'Colder' (= further away from the magic square)
S 'Same' (= same distance from the magic square)

Number of moves	Fraction (R)	($R \log_2 R$) in bits
1	32/63	0.50
2	25/32	0.28
3	19/25	0.30
4	12/19	0.42
5	9/12	0.31
6	9/9	0.00
		1.81

squares before the move was taken as a measure of amount of information gained on each move; in bits this is $R\log_2 R$.

An example from a typical subject illustrates the experiment.

Average information per move in bits

$$\frac{R \log_2 R}{n} = \frac{1.81}{6} = 0.30$$

The average information per move was calculated for each child. The mean for 7-year-old children was 0.22, and for 9-year-old, 0.25 bits. These values are artificially low, however, since if a child is told that he is 'cold' he might well understand that to reverse his direction would make him 'hotter'. This information would therefore be superfluous to him but the circumstances of the experiment make him ask for it and the amound of information he gains on this move is less than the amount he would gain if he were told he is 'hot'. This situation is analogous to a subject in Experiment 1 who asks 'Is the circle on the right hand side of the page?' and given the reply 'No', proceeds to ask 'Is it on the left hand side of the page?'

Experiment 3

When an Element-type strategy of search is employed this is affected by the psychological probability (ψ) attached to each element, in other words by the confidence of a subject in the accuracy of his guess. In the one-circle experiment referred to above (with 2^{10} circles) each subject was asked to mark the particular circle the experimenter had in mind. Half of the subjects chose a target circle from the 20 per cent clustered near the middle of the page. Thus the circles do not have the same *a priori* chance of being chosen. That is, the distribution of subjective probabilities attached to each circle is not rectangular.

The same conclusion may be drawn from another experiment in which three groups of student subjects were given a page on which a square was drawn and divided into 16 equal squares. Those in Group A ($n = 63$) were told that the experimenter was thinking of one of the squares and they had to mark the one they thought it was. Those in Group B ($n = 47$) were told that the experimenter would think of a square *after* they had guessed which one they thought this would be Those in Group C ($n = 31$) were told to guess which square would be chosen by a random procedure (shuffling a pack of cards numbered

1 to 16, where these numbers relate to the squares from top left to bottom right).

If each square had the same *a priori* chance of being guessed under the three conditions, all the squares should have been marked by roughly 6 per cent of each group. The hypothesis that the target squares cluster in the centre of the figure may be tested by comparing (i) the number of times the four middle squares were marked with (ii) the number of times the twelve border squares were marked. The results are clear. The four centre squares were marked by 52 per cent of Group A, 51 per cent of Group B and 56 per cent of Group C. The expected value on the hypothesis of a rectangular distribution is 25 per cent in each case. Hence in these circumstances the patterns of choice of target do not conform to rectangular distributions but are influenced by psychological probabilities.

We noted above that there was a tendency to choose target circles from the middle 20 per cent of the page. The question may be asked whether, if the number of circles were to be increased above 2^{10}, those marked as target circles would remain a constant proportion of the total number (say, 20 per cent) or would remain a constant absolute number irrespective of the changing total. We have evidence from other situations that where subjects may choose either a ratio *or* a constant, absolute value, they choose a value which is intermediate. The tendency to dichotomise certain classes of situation as either conforming to Weber's law or to perceptual constancies (e.g. shape, size, colour) may be true only of a restricted range of relatively simple conditions. In more complex situations such as, for example, the interpretation of categories of words and gambling preferences (COHEN and COOPER, 1961; COHEN, DEARNALEY and HANSEL, 1958), as well as possible the situation under discussion, the subject's judgement is not wholly a function of changing circumstances but retains a certain stability which resists the change.

Experiment 4

In a further and related experiment with two groups of children aged 5 ($n = 25$) and 9 ($n = 27$) years respectively we were able to introduce two additional features. First, each subject could go on guessing until he succeeded in hitting the target, and second, after each guess, he indicated on a 7-point scale (0–6) how sure he felt that his guess was the correct one. The procedure was as follows:

Each child sat facing a wooden board holding 16 small tins in a square array. He was told that one tin contained a shilling and he was to guess which tin it was. He could go on guessing as many times as he liked until he hit upon the correct tin. Each guess was verified by opening the appropriate tin (and leaving it open) after each guess. However, before the lid of a tin was removed the subject indicated his confidence in his guess by means of a 7-point scale; he could move a metal pointer along a board marked with the numbers 0 to 6. The pointer set at 0 meant that the child was sure the shilling was not in the tin; the pointer set at 6 meant that he was sure it was in the tin. Steps were taken to ensure that every child understood the instructions. The shilling was in the same tin for all subjects.

The level of confidence a child attaches to each guess in the sequence is influenced, we may assume, by two opposing factors. On the one hand, as the number of tins becomes steadily smaller, confidence in each successive guess should increase. On the other hand, the earlier the guess in the sequence, the more confidence the child may be expected to repose in it; his first guess is the one in which he has most confidence. In the experiment just described we cannot measure these two influences separately. This would be possible, however, in an experiment in which the tins are not opened after the guesses. Consequently any ground for progressive increase in confidence would be eliminated as a result of a reduction in the number of tins. We would be left, therefore, with a measure of ψ after each guess. What we can show as the result of the present experiment is the net effect of positive and negative influences at the two age levels, as indicated in fig. 3 where the ordinate refers to psychological probability and the abscissa to the guesses in the order they are made. Two features may be noted. First, the younger children are more confident at each guess. Second, if the values of ψ were largely influenced by objective considerations, that is, by a steady diminution in the number of tins, they should progressively increase. As they do not appear to do so, except slightly in the younger group, we may infer that objective considerations are counterbalanced by subjective ones.

Experiment 5

In Experiment 1 it is possible, in principle, for a subject to gain a relatively large amount of information in any given move or step. He can, by adopting a binary strategy, considerably reduce his uncertainty

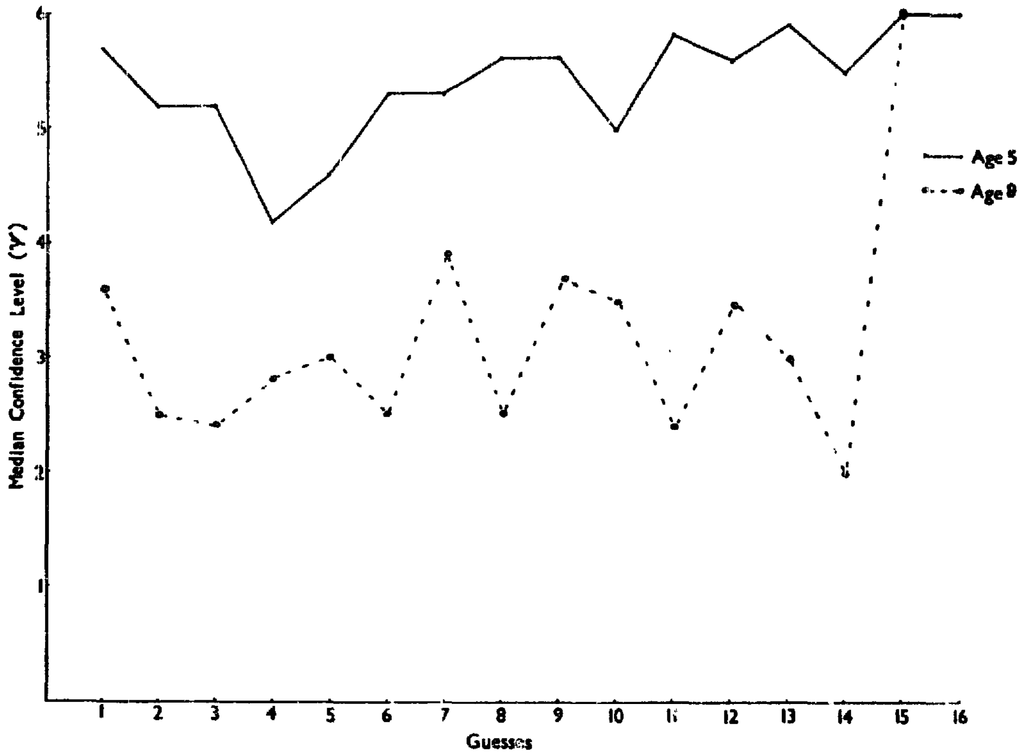


Fig. 3. Level of confidence at each guess.

at each move. The information gained by him, in the form of knowledge of results, is transmitted by the experimenter not by the experimental display. Indeed much the same results might have been obtained if the subjects had been asked to *imagine* the experimental situation.

There is another kind of experimental search, analogous to everyday experience, in which it is not possible to gain more than a relatively small amount of information at each step. This is so because the searcher gains information solely by his own efforts and owes nothing to feedback from an experimenter, who does not intervene once he has given the instructions.

Such a kind of search has been traditionally represented in mental testing by what is known as the 'ball-in-the-field' test. This involves, according to Burt (1962), 'marking with a pencil on a simple map the path to be followed in searching for a lost ball in a circular field entered from a gate; absence of plan fails; an imperfect plan (e.g. fan-shaped, wheel-shaped paths) is accepted for age 8; an adequate plan (parallel paths with no intersection or breaks, e.g. perfect spiral, concentric circles, transverse parallel paths) is required for age 12'.

In the Terman–Merrill revision of Binet (TERMAN and MERRILL, 1937) the 'ball-in-the-field' problem was changed to a plan of search for a lost purse and was assigned to age 13 years; the subject had to execute 'a plan of search that meets the logical requirements of the problem'. Solutions regarded as satisfactory include (i) a spiral path beginning at the gate or at the centre of the field; (ii) concentric circles; and (iii) 'transverse lines, parallel or almost so, and formed at the ends'.

We are indebted to Sir Cyril Burt[3] for throwing some interesting light on the history of this test. Although L. M. Terman was the first to include an age-scale in it he was not the first to employ the test. Many British doctors, including some working for the London County Council, used it in the first decade of the century when examining children suspected of being mental defective. Among these was Dr. Barrow Burt (Sir Cyril's father). If there was a field near the institution which he was visiting, he would ask the children how they would go about finding a ball lost in the field. In his consulting room he employed an indoor version of this situation. Sir Cyril himself, as a small boy, was frequently subjected to several forms of this indoor version in the form af a 'hunt the thimble', gave, viz.

(i) "Your mother has dropped her thimble on this hearthrug. Can you find it?" He was expected to pat the rug systematically in parallel rows from one narrow edge to the other, in a routine search.

(ii) "Your mother wants you to fetch her thimble. Where would you look?" He was expected to suggest certain boxes, baskets etc. in an *ad hoc* hunt of the more likely places, not of every possible place.

(iii) The thimble would be placed in a context where it blended with the background, and the young Cyril was expected to locate it.

According to Burt these or similar tests were, in fact, used by British certifying medical officers long before Binet came on the scene. They were also apparently used by French medical officers, and may have been invented by Seguin. In a joint paper with Moore (BURT and MOORE, 1911) Sir Cyril distinguished between analytic, 'fixating' or

[3] Private communication

mechanical scanning routines, on the one hand, and synthetic, 'fluctuating', intuitive routines, on the other.

So far as we know, no attempt has been made to determine the actual path taken by people to find a ball, purse or other object lost in a field. In order to fill this gap we conducted an experiment in which a coin was half inserted in the soil of a field, so that part of it was visible and subjects were asked to find it.

The subjects were 34 boys in the sixth form of the Manchester Grammar School. They were all highly intelligent and expected by the School to win open scholarships to Oxford or Cambridge universities a few months later.

There were two experimental conditions. One of these was structured: the field was marked out in 250 squares (each square 7′6″ × 7′6″); in the other, the field was unmarked. Each subject began his reach from the same corner square in the field and his search path was traced as he followed it. He was allowed ten minutes to find the coin, with the promise of a half a crown if he was successful.

Since the time spent in each square could be regarded as a measure of the psychological probability of detection, we had intended to measure the amount of time spent by each subject in each square. Unfortunately, this proved impracticable because the subjects spent about two seconds, on the average, in each square and another observer would have been required to record this time.

Given a finite search time the subjects' task was to allot this in a subjectively optimal fashion. At one extreme, he could, if he put all his eggs in one basket, devote his entire ten minutes to a search in one of the 250 squares. At the other extreme, he could spend two or three seconds in each square. As an indication of the subjective difficulty of the task, we may take the subjects' estimates, after the search, of the proportion of occasions in which they thought they would succeed, if they repeated the search. On the average, this estimate was about one in twenty. Since no subject succeeded in finding the coin this estimate may confirm a phenomenon we have frequently observed, namely, that people tend to overestimate their expected succes when the task seems to them difficult.

An examination of the search paths taken reveals that structuring of the field made little difference and that two main strategies were employed, viz. (i) up and down the field, or across it, depending on which direction the subject was facing, and (ii) the Terman–Merrill spiral strategy alone or in combination with some other strategy. Three boys employed the 'pure' Terman–Merrill strategy, another employed it in conjunction with an 'up-and-down' or an 'across' search, and another with an 'across' search alone. One walked across the field 'at random'. All the rest (i.e. 28 out of 34 boys) employed strategy (i). They virtually covered the whole field, spreading the 10 minutes more or less evenly over all the squares.

In the structured situation we strongly predisposed the subjects to scan the width of one square though we cannot exclude the possibility that some of them marginally scanned beyond it. The scanning of the width of a square by our subjects is akin to the concept of 'sweep width' employed in the analysis of search and rescue operations where it is defined as the width of scan such that the mean frequency of detecting scattered targets outside it is equal to the mean frequency of missing scattered targets within it (National Search and Rescue Manual, 1959). Some of the factors affecting sweep width are (i) type of target, (ii) speed at which the search unit is moving, and (iii) visibility.

The next step would be to determine the effect on the strategy by varying the search time. From our experiment we might predict that as the search time is progressively reduced, the subject would compensate by enlarging his scanning area so as to cover the entire field in the allotted time, rather than limit it so as to cover a smaller area more thoroughly. If this prediction is not confirmed, it would follow that there is a tendency to modify one's strategy in terms of psychological probability of success. For example, if a subject feels that, in the limited time available, he only has, say, a one in a thousand chance of success in any one square -- this being his psychological probability of the coin's being in the particular square, together with his psychological probability of finding it if it is there – he might feel that this value is negligible. That is, he might feel it is not worth investing search effort in circumstances where the combined psychological probability of success is so low; (the combined probability might be additive or multiplicative). Therefore he would limit his search area to allow himself a higher psychological probability of success in any given square.

3. Physical and mental searches

So far we have been concerned with the search for material objects, a circle on a page, a square on the floor of a room, a coin in a field.

The question may be asked whether this kind of search is similar to what is, metaphorically speaking, often described as a mental search: a search for the solution to a problem, for a name that is on the tip of the tongue but cannot momentarily be brought to mind or, indeed, the search for any word as it is used in everyday speech.

The verb 'to search' (late Latin *circare* = to go round) means 'to explore in quest of some object'. It may also refer to immaterial objects 'to examine rigorously (one's own heart, thoughts, etc.); to examine, penetrate the secrets of (another's mind or thoughts)' (O.E.D.). In current usage the word therefore normally denotes either a search for a material object which is lost, missing or hidden, or a conscious search for an immaterial object. It is also employed to denote what is, by contrast, a non-conscious search, for example, the way we gain access to our store of words in ordinary conversation. Oldfield (1966) has suggested that the average, educated person knows the meaning of some 75,000 words (lexical units). He emits words meaningfully at the rate of about two a second. His word store thus has somehow to be searched so as to gain access to, and retrieve, each required word in half a second.

An analogous search for a mental rather than for a physical object may occur in some diagnostic procedures in medicine where the doctor is systematically seeking first to elicit the symptoms presented by the patient, and second, intuitively, or in more or less orderly fashion, a diagnosis of, or an explanation for these symptoms. A comparable situation is encountered when a police officer interrogates a suspect or prisoner. Like the doctor, the police officer begins with a range of uncertainty which he attempts to reduce by eliciting items of information from the suspect. There is perhaps an analogy between the situation where a patient answers the doctor's questions without realising why they are asked and the situation where a witness does not appreciate the relevance of the questions put by the interrogator.

On occasions a doctor may search for both physical and mental symptoms. The expression 'clinical examination', we are told by a clinician (MacLeod, 1964) has a twofold reference to (i) eliciting an account of the patient's disability or his 'medical history', and (ii) a physical examination of the patient. In other words, there is a mental *and* a physical search. Furthermore, taking a history is often the more important of the two components in so far as it provides a greater amount of information on which to base a diagnosis.

There is another sphere of activity which may involve both physical and mental objects. This is the Customs Officer's examination. The Officer normally begins by asking the traveller routine questions about nationality, residence etc. When this interrogation has been completed to the Officer's satisfaction, he may decide to continue with an actual search of the luggage. The traveller is not in a position to protest and say 'If you intended to make a physical search for smuggled articles, why interrogate me in the first instance?' For the Officer could reply 'I make no decision about a physical search until I have completed my verbal interrogation'.

An unusual type of Customs' search, witnessed by one of us, illustrates the scope of the Customs' Officer's enquiries. A traveller was carrying a large cake. The Officer evidently suspected that this might conceal precious stones, and after a brief verbal interrogation, he obtained a long knitting needle and began to probe the cake until he was satisfied that it harboured no contraband. By this time the cake mostly consisted of perforations.

Possibly our experimental subjects were not only searching for material objects such as circles or coins. They may also have been searching for an immaterial object in the sense that they were trying to divine what the experimenter had in mind and, if so, made assumptions about his intentions in locating the circles. In general, a subject's response, performance or output in an experimental situation may not only be governed by the information presented in the display but also by his speculations, vague or systematic, about those aims of the experimenter's which are unspecified to the subject. Thus in a psychophysical experiment the subject's response is influenced not merely by the actual signals presented but also by his interpretation of the experimenter's intention.

4. Problem of subjective information and redundancy

We have said earlier that in some search situations, the seeker tries to reduce his uncertainty by adding to his information. Both uncertainty and information are here to be understood in a purely subjective sense. The psychologist, we suggest, therefore requires, to begin with, a measure of gain of information in terms of subjective units. It is not sufficient, in psychology, to measure gain in information in so-called objective units. With this consideration in mind, we have attempted to establsh a subjective scale of information, at least to a first approximation (Cohen and Cooper, 1962). Such a scale requires supporting concepts such as, for example, the concept of redundancy as subjectively experienced. Information may be tentatively defined as subjectively redundant when an individual ceases to register it, not because of distraction, fatigue or boredom, but because he feels he already knows it. There are practical difficulties in separating this last reason from the others.

Consider a teacher-pupil situation. The teacher is explaining a problem at length and perhaps repeating certain elements several times, in order to *assure himself* that the pupil has understood. If, however, the pupil feels that he has grasped the problem, he may no longer listen to or no longer assimilate the continued flow of information. Indeed this continued information, beyond the point at which it is felt by the pupil to be necessary, may subjectively act as noise. Thus we have the paradoxical situation such that what is felt to be 'redundant', in the sense of superfluous because it is unduly repetitious, at the same time acts subjectively and retroactively as noise.

Possibly we have here a clue to the curious fact that some children are more successful than their teachers in the explanations they give, success being judged by the number of other children who understand. Their success may be attributed to their greater economy of words and ideas. We have found that when an explanation (or method of solving a particular problem) is serially transmitted through a group of children, the essential core of the explanation tends to remain. This provides the vital information required for understanding the problem without redundancy or superfluities.

When an individual 'overlearns' something, this conventionally means that is is continuing his learning efforts beyond the point at which the teacher (or experimenter) thinks his performance is adequate. If, however, the learner feels that, judging by his own criteria, he can still profit from these continued efforts, he cannot be said to be *subjectively* 'overlearning' and hence there is no subjective redundancy. His continued learning may, for example, afford him a margin of safety to allow recall within an interval of time which is not necessarily the same as the interval laid down by the teacher or experimenter.

It is usual to speak of information being received by a person as if it were stored neatly in units, by a kind of self-stacking process. But this can hardly represent the true state of affairs. The wide ranging application of Information Theory to diverse systems leaves untouched those psychological issues which essentially involve information in a subjective sense. There are many unanswered questions which relate to intake, storage, accessibility and retrieval. It is possible that intake is regulated by a complex multiple filter system. The concepts of 'set', 'determining tendency', 'selective attention' and 'selective *in*attention' may perhaps be better expressed in terms of such a system. One filter presumably serves the purely economic aspects of information intake, that is, what is often referred to as 'channel capacity'. Others serve to regulate the reception of information which might be emotionally unpalatable and hence cause anxiety. It may well be that we register and store much information which never enters awareness. We may, for example, turn a 'blind eye' to some event of which we subsequently display no conscious knowledge, but the act of exclusion must, at some stage, have involved recognition of the significance of the event. Such effects may be produced at will, under suitable conditions in post-hypnotic phenomena. The dilation of the pupil in response to the application of a noxious stimulus before awareness of pain is a clear example of physiological registration of an event before ocnsciousness is alerted to it (A Perspective for Psychology, 1964).

The subjective aspects of storage or memory also remain to be explored. Attention so far seems to have been almost exclusively devoted to the study of Ebbinghaus-type memory for impersonal data to the neglect of Proustian-type memory for autobiographical data and the phenomena of spontaneous recall or evocation. Accessibility and retrievability, in some of their aspects, raise questions of search which may be related to the topics investigated in the present experiments.

Crucial in this context is the question of how information is generated in the first instance. One important aspect of this is the generation and interpretation of metaphor which has yet to be subjected to scientific analysis. Putting aside the study of the creation of metaphor, which would be too formidable a task, it seems possible to employ logical or mathematical methods in the ordering and grading of metaphorical material.

5. Conclusions

(i) Distinctive strategies can be identified which improve with age in the sense that the older the child the more information (objective and subjective) he gains at each step.

(ii) The older the child the more likely he is to structure a situation rather than treat it as the sum of discrete elements. We have called this age effect a move from an Element-type to a Set-type strategy.

(iii) The older the child the more aware he becomes of influences outside his control; this awareness is associated with less confidence in success at each guess.

(iv) The older the child the more uncertainty (objective and subjective) he reduces at each step.

(v) Similar strategic principles reappear in different experimental situations.

(vi) Search strategies are, to a considerable extent, influenced by psychological rather than by 'objective' probabilities, initially as well as throughout the course of an experiment. These two kinds of probability are not isomorphic (Expt. 3).

The foregoing conclusions relate to Section 2 above. Certain questions of a more far-reaching character are raised in Sections 3 and 4. Our experiments raise the problem of the comparability of physical and mental searches in a variety of domains, medical, legal, and in everyday situations. These issues cannot, we suggest, be resolved without a clear differentiation between concepts and measures of objective and subjective information. Furthermore, subjective information requires an analysis as systematic and as comprehensive as objective (i.e. selective) information. Only in this way could one hope to move from a model which is content with a relatively simple analysis of input-output relations to a model which concerns itself with what goes on in the individual as transducer.

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