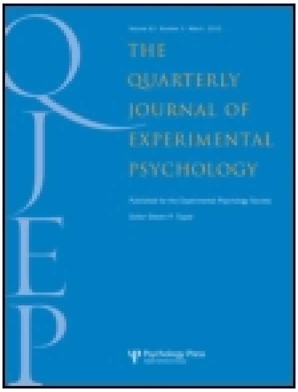

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Independent functioning of verbal memory stores: A neuropsychological study

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INDEPENDENT FUNCTIONING OF VERBAL MEMORY STORES: A NEUROPSYCHOLOGICAL STUDY

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Five experiments are described concerning verbal short-term memory performance of a patient who has a very markedly reduced verbal span. The results of the first three, free recall, the Peterson procedure and an investigation of proactive interference, indicate that he has a greatly reduced short-term memory capacity, while the last two, probe recognition and missing scan, show that this cannot be attributed to a retrieval failure. Since his performance on long-term memory tasks is normal, it is difficult to explain these results with theories of normal functioning in which verbal STM and LTM use the same structures in different ways. They also make the serial model of the relation between STM and LTM less plausible and support a model in which verbal STM and LTM have parallel inputs.

Introduction

Clinical studies have made a substantial contribution to the understanding of memory, despite the small amount of theoretically oriented work in this field. Observations on the completely irretrievable few seconds or minutes of the retrograde amnesic period helped to give consolidation theory a certain plausibility. Investigation of the amnesic syndrome, particularly the quantitative studies of Milner (1966), provided strong support for the distinction between long and short-term memory by demonstrating a marked defect of new learning in patients whose short-term memory is intact. In fact, Atkinson and Shiffrin (1968) considered this the most convincing demonstration of the dichotomy.

The strongest objection to the use of clinical material has been made by Gregory (1961). Using engineering analogies, he was primarily objecting to the inference of a brain centre for a particular function when a lesion damaged that function. Weiskrantz (1968) has pointed out that, in general, Gregory's assessment of ablation studies is much too pessimistic, and this seems particularly the case for "flow diagram" models. Engineers often produce the analogue of a lesion when testing whether a particular model is appropriate for some physical system (Milsum, 1966). It therefore seems appropriate to use clinical data when generating or evaluating such models.

Occasionally individual patients show a particularly striking behavioural deficit, specific and limited to one functional system or process. The mere occurrence of

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such a dissociation of function provides *positive* evidence of cortical organisation which needs to be explained by theories of normal function. What has not so far been reported is a case where the long-term memory system (LTM), including trace formation and retrieval, appears normal, even though the short-term memory system is damaged. Such a case, besides further supporting the distinction between the two systems, could provide information about how each of them operates and, in particular, how the two systems are related. A case we have been investigating appears to be of this type. The patient has a profound repetition defect (in the neurological literature this deficit is the cardinal feature of "conduction aphasia"), his digit and letter span being reduced to two items or less; yet on tests of long-term memory his performance is normal. Warrington and Shallice (1969) reported a clinical case study of this patient (K.F.), together with evidence to support the view that the repetition defect cannot be accounted for in terms of motor defect, auditory perceptual impairment or more generalized language or memory disturbances. However, the interpretation of the defect as one of auditory verbal short-term memory (STM) cannot be conclusive on the basis of negative evidence.

The terms LTM and STM were used loosely in the previous paragraph as the lack of agreement among theorists has resulted in there being no generally accepted terminology. Indeed there are likely to be more systems than these two. A strong case can be made for one or more relatively peripheral auditory stores (Neisser, 1967; Crowder and Morton, 1969) and also for one or more visual stores (Sperling, 1967; Posner, Boies, Eichelman and Taylor, 1969). Yet it is widely agreed that auditory verbal span performance is primarily mediated by a single system. This is the primary memory of Waugh and Norman (1965), the auditory information storage of Sperling (1967) and the auditory-verbal-linguistic STM of Atkinson and Shiffrin (1968). This we will call STM. The secondary memory of Waugh and Norman (1965) we will call LTM.

This paper reports K.F.'s performance on five experiments. The aim of the first experiments is to provide "positive" evidence that K.F. has a defect of STM. An account is given of his performance on so-called "two-component" tasks, where, according to present theoretical views on memory, retrieval from both STM and LTM can be inferred from different aspects of the results. Theoretically these tasks should identify the effects of circumscribed impairment of STM: free recall and the Peterson procedure are the examples of this type of experiment. Evidence on the nature of pro-active interference operating in K.F.'s performance is also presented, as this provides another source of "positive" evidence for an STM defect.

Given that K.F. suffers from an impairment of STM, it is important to determine which stage in the processing of STM traces is defective and particularly whether K.F. suffers only from a retrieval defect, since on various LTM tasks his performance is approximately normal (Warrington and Shallice, 1969). To test this, his performance on alternative methods of retrieval is contrasted with his performance on recall. If his defect is one of retrieval by recall, his performance should be in the normal range on these tasks. If his defect is not one of retrieval, then his performance on these tasks should be comparable to his performance on recall tasks.

Experiment I—Free Recall

A widely used two-component task is that of immediate free recall on lists of words longer than the span. For a normal subject the serial position curve resulting from this task is thought to have two components (see Fig. 1). These are the rising portion of the curve over the last few serial positions—the recency effect—and the

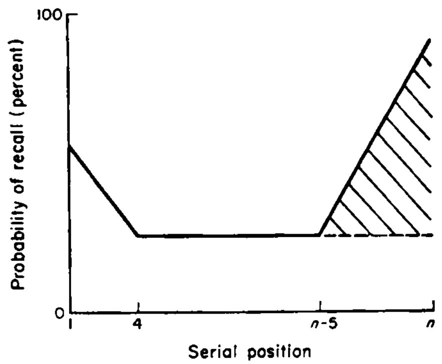

FIGURE 1. A Schematic serial position curve for a list of length n. Curve A is shown by the solid line. Curve B is identical to curve A except for the last s serial positions where it is shown by the dotted line. The shaded area can be used to obtain an estimate of S.T.M. capacity.

earlier part of the curve, which can itself be divided into a primacy effect and a flat section. If the subject counts backwards for 30 sec. before recall, the recency rise disappears (Postman and Phillips, 1965; Glanzer and Cunitz, 1966). This is usually explained by assuming that, of the two components of curve A, one results from retrieval from LTM and the other from retrieval from STM, while curve B has only the LTM component.

Method

Strings of ten high frequency words each of 4 or 5 letters were read to K.F. at a rate of 1 word/2 sec. Immediate recall was tested. K.F. was instructed to report as many words as he could and was given 1 min. for recall. In all, 30 strings were presented over three testing sessions.

Results

The number of words correctly recalled (out of 30) at each serial position is shown in Table I. K.F.'s curve is almost flat over the middle eight points, but no simple statistical procedure is available to substantiate this qualitative statement. However, by using Kendall's S statistic, no trend, significant at the 5 per cent level,

TABLE I

Free recall scores for each serial position

Serial Position	1	2	3	4	5	6	7	8	9	10
No. correct	15	10	7	7	7	10	12	9	9	25
Per cent correct	50	33	23	23	23	33	40	30	30	83

can be found over any set of these eight points; but if either of the extreme points is added, significant trends are found. This means that the recency effect is limited to one serial position (10th) instead of the normal value of about five or six (Murdock, 1962; Postman and Phillips, 1965), while the primacy effect is also limited to one or possibly two serial positions instead of the normal value of about three or four. The reduction in the recency effect clearly supports the hypothesis of a reduction in STM capacity. The reduction in the primacy effect can be accounted for by a reduced rehearsal capacity; this is compatible with Atkinson and Shiffrin's (1968) views about the effect.

Experiment II—the Peterson Procedure

The technique of presenting verbal items and then attempting to prevent the subject from rehearsing for a number of seconds (Brown, 1959; Peterson and Peterson, 1959) has become widely used. The simplest explanation of the decline in recall over seconds is that it results from a decrease in the STM trace strength (e.g. Waugh & Norman, 1965; Peterson, 1966; Baddeley, 1968). While this view has been challenged (Keppel and Underwood, 1962; Melton, 1963), it has recently received support from the work of Baddeley and Warrington (1970) on amnesics, in which they find that amnesics who have a defective LTM system show the typical Peterson decay curve.

Method

Modifications were made to the normal Peterson procedure (Peterson and Peterson, 1959). K.F. had performed better with visual input than auditory input (Warrington and Shallice, 1969); therefore to prevent K.F. from using his relatively well-preserved visual STM, three three-letter words were spoken to him at a rate of 1/sec. In addition, instead of counting backwards, which he could not do efficiently, he was asked to count forwards in ones from 1 as fast as he could. The end of each counting interval was signalled by the experimenter saying "now" and a new trial began as soon as K.F. indicated he could recall no more. Ten sets of trials were carried out. Each set consisted of five initial trials with a 10-sec. counting interval, followed by 16 trials in which four each of 0, 5, 10 and 15 sec. counting intervals occurred in varying random orders. The five initial trials of each set were discarded so that only the "steady state" results were analysed.

Results

Figure 2 gives the proportion of trials in which all three items were correctly recalled and also the proportion of items correctly recalled. Normal Peterson-type curves show a decline over an interval of 15 sec. from 95 per cent (with zero delay) to under 25 per cent (at 15-sec. delay) in number of trials all correct, with the curves still declining after 15 sec. (Murdock, 1961). When assessed by the criterion of all items correct, K.F. clearly showed no comparable decline. It should be noted that K.F's failure to achieve nearly 100 per cent correct with zero delay is consistent with his inability to repeat three words. In experiment 1 of Warrington and Shallice (1969) he was able to repeat three-word strings correctly on only 3 out of 20 trials.

With the items-correct measure there is a significant trend for longer intervals to produce lower scores (Kendall's S statistic $P < 0{\cdot}01$). If the zero delay condition is omitted, there is no longer a significant trend (Kendall's S statistic $Z = 0{\cdot}8$).

The slight trend that occurs indicates that K.F.'s STM capacity is much reduced, though not quite zero; this is consistent with the interpretation of the first experiment.

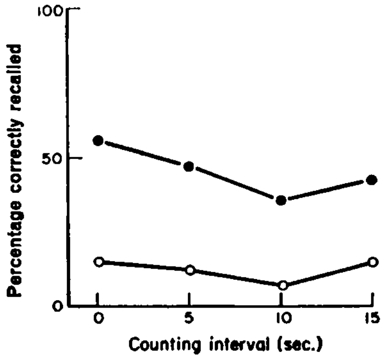

FIGURE 2. Percentage of items and trials correct as a function of the counting interval. ○, Trials correct; ●, Items correct.

Experiment III—Proactive Interference Effect

These two experiments support the view of Warrington and Shallice (1969) that K.F. has an almost complete inability to recall from STM. Yet, that study showed that K.F.'s performance on long-term memory tasks is normal, indicating that his recall from LTM is unaffected. This raises the possibility that, even in tasks normally involving short-term memory, K.F. would show characteristics typical of retrieval from LTM rather than from STM.

If a series of digit spans is presented to a normal subject, his performance typically shows a practice effect by improving over the series (Melton, 1963). By contrast, in analogous tasks using LTM, performance deteriorates over the series due to the build-up of P.I. (Underwood, 1957). Thus K.F.'s performance over a series of span tasks is of interest, since it is possible that he would show an LTM-like decline, instead of the normal improvement.

Method

Ten series, each containing ten pairs of letters, were spoken to K.F. The two letters of a pair were separated by one second and there was a maximum of 5 sec. in which to recall the two letters before the next pair was presented. There was a 1-min. gap between each series.

Results

A serial position curve can be obtained by summing scores for each serial position, shown in Table II. The declining trend over the 10 serial positions is

TABLE II

Number of digits correctly recalled for each position in a set

Position in the set	1	2	3	4	5	6	7	8	9	10
No. items correct (max. 20)	15	12	12	11	12	9	12	6	7	7

significant at the 0·002 level (Kendall's S statistic). One possible interpretation is that this decline results from fatigue. However, this is highly implausible, as K.F.'s performance had been virtually perfect in a demanding identification task in which he had to categorize 40 words spoken at a rate of 1/sec. (Warrington and Shallice, 1969). A second possible explanation of why K.F. shows this abnormal characteristic is that, in STM, P.I. operates only on the last two or three items (Wickelgren, 1965) and this makes it relatively unimportant for digit spans of the normal size but important for one of two items. However, in this case the serial position curve should reach an asymptote after the first or second position, which it does not. This finding indicates that, in digit span situations, a considerable portion of K.F.'s retrieval is from LTM.

Experiment IV—Recognition using a Probe Technique

Given that K.F.'s ability to recall from his STM is drastically reduced, it becomes relevant to ascertain whether this is due to a retrieval failure. This is of particular theoretical importance in view of his normal LTM performance. Warrington and Shallice (1969) showed that K.F.'s ability to match two strings of digits was much impaired; the probe technique allows this disability to be more accurately studied. Alternative retrieval conditions were used in order to test not only his recognition ability but also his rehearsal capacity and the effects of response interference.

Method

The experimenter spoke a string of 5 letters to K.F. at a one per second rate, a tap marking the end of the series. Three retrieval conditions were used. In condition A, the experimenter presented a probe letter to K.F., who had to say whether or not it had appeared in the string. In condition B, K.F. had to repeat the last letter of the string before being presented with the probe letter. In condition C there was a 20-sec. interval between the end of the string and the presentation of the probe letter. Sets of 8 strings were used, 4 in which the probe letter had not occurred and 4 in which each of the first 4 serial positions were probed. Before each set K.F. was told which retrieval condition was to be tested. Twenty-seven sets of each of the three conditions were presented to K.F. in a randomized design.

Results

The number of "yes" and "no" responses made in each condition and position are given in Table III. The false positive rates differ significantly between the three

TABLE III

Number of yes and no responses for each condition and serial position

Condition	Response	Position of test letter in string 1	2	3	4	Not present
A	Yes	12	22	16	26	43
	No	15	5	11	1	65
B	Yes	18	9	19	23	28
	No	9	18	8	4	80
C	Yes	13	11	15	20	24
	No	14	16	12	7	84

conditions ($\chi^2 = 8\cdot5$ $P < 0\cdot02$ at 2 *d.f.*). Consideration of the serial positions reveals no consistent trends in the proportion correct over positions 1–3. Even if the somewhat dubious procedure of summing the scores of all conditions for each serial position is used, there is no significant difference between any of the three positions: max. $(\chi^2_{12}, \chi^2_{13}, \chi^2_{23}) = \chi^2_{23} = 1\cdot6$ N.S. (1 *d.f.*); $\chi^2_{123} = 1\cdot9$ N.S. (2 *d.f.*). Therefore scores for serial positions 1–3 were combined for each condition, for subsequent analysis. In all three conditions there is a significant difference between scores on serial position 4 and on the other 3 serial positions combined: $\chi^2_A = 11\cdot6$, $P < 0\cdot001$ (1 *d.f.*): $\chi^2_B = 7\cdot1$, $P < 0\cdot01$ (1 *d.f.*); $\chi^2_C = 5\cdot5$, $P < 0\cdot02$ (1 *d.f.*). In order to allow for the significant difference in false positive rate, it seems most appropriate to transform the scores to a d' measure, (see Table IV). Three conclusions can be drawn from these findings.

(i) The recency effect is limited to two positions (the fourth and fifth) unlike that for normal subjects where either all positions or at least 6 positions, depending on list length, show a recency effect with 3-figure digits (Wickelgren and Norman, 1967). It is assumed that in condition A, the item in the fifth position is retained even though not tested since, in condition B where it is tested, a recency effect also occurs in position 4.

TABLE IV

Values of D *for each condition*

Condition	Position 1–3 (summed)	Position 4
A	0·56	2·00
B	0·82	1·68
C	0·72	1·41

(ii) Since for condition C, in which there was a 20-sec. delay before the probe, $d'_{1\text{-}3}$ is significantly less than d'_4, K.F. appears to be able to rehearse material within his short-term span. As no check was made on position 5, it is not possible to say whether he attempted to rehearse one or two items.

(iii) For normal subjects, similar values of d' are obtained with recognition and recall measures (Norman, 1966). If K.F. has a storage deficit a similar finding would be expected for him. As no probe digit experiment similar to that used by Waugh and Norman (1965) has been tried with K.F., only a rough comparison can be made between recall and recognition measures of d'. The results of position 4 in condition A and of position 2 in a 2-letter recall task (Warrington and Shallice, 1969) when transformed, give similar values of d'. This comparison is speculative because it is based on an assumption of the equal effects of stimulus and response interference, and because the d' estimate obtained from condition A is based on only one false positive response. However, it does reinforce the conclusion drawn from finding (i) that K.F.'s impairment is not limited to retrieval by recall.

Experiment V—Missing Scan

A technique which seems to test an alternative retrieval system—missing scan (Bushke, 1963)—provides further information on whether K.F.'s difficulty is one of retrieval.

Method

K.F.'s missing scan was tested for digit sets of size 3, 4 and 5. For example, for the set of size 3, two of the digits 1, 2 and 3 were presented in either order and K.F. had to respond with the digit of the set that was not presented. Two series of 10 were presented for each of the digit sets of size 3, 4 and 5. Digit strings of length 2, 3 and 4, drawn randomly from sets of size 3, 4 and 5, respectively, were also tested by recall. Each pair of series tested contained one of recall and one of missing scan. The digits were spoken at a rate of 1/sec. and K.F. was allowed to respond at his own pace.

Results

The number of correct responses (out of 20) obtained for the missing scan and the recall task for each digit set are shown in Table V. Relative to the maximum possible scores K.F.'s performance varied between a 10 and 30 per cent superiority

TABLE V

Number of items recalled with missing scan and recall

Digit set size	3	4	5
String length	2	3	4
Missing scan no. correct	15/20	12/20	9/20
Recall no. string correct	13/20	7/20	3/20

for missing scan. Bushke (1963), using various string lengths, has shown that missing scan performance is more likely to be correct than that of ordinary digit span. In his experiment the superiority of missing scan performance varied between 25 and 45 per cent for comparable success rates. Thus K.F.'s missing scan performance further supports the view that his defect is not limited to one retrieval method.

Discussion

The results reported in this paper support the hypothesis suggested by Warrington and Shallice (1969) that K.F.'s disability could be accounted for by a greatly reduced STM capacity. In both the two-component tasks, the estimate of the STM component obtained was close to zero. There was a great reduction in the recency effect in free recall and a virtual lack of decline in performance in the Peterson experiment. Furthermore, the marked and increasing effect of pro-active interference over a series of span tasks is analogous to its effect on normal subjects when LTM alone is used (Underwood, 1957). This contrasts with the pattern of results produced by normal subjects in span experiments where improvement occurs with practice (Melton, 1963), presumably because P.I. has much less effect in STM.

K.F.'s impairment on STM recall tasks can be explained by postulating a defect either of a specific retrieval mechanism or of storage capacity. If his impairment were one of retrieval by recall, tasks not requiring recall should not show a comparable deficit, yet experiments 4 and 5, using the probe and missing scan techniques, give results far below normal and comparable with his performance on recall. This finding would not be relevant if recognition and missing scan were more complex than recall, that is, if they consisted of a recall operation followed by a matching or inverting operation respectively. Introspectively this possibility seems implausible for recognition, and rather more plausible for missing scan. If recall were the least complex retrieval method, then its use in attempts to measure STM capacity should presumably result in higher values for normal subjects than those resulting from recognition or missing scan. As a rough indication, if the d' measure of STM is used for normal subjects, the value obtained from recall is approximately equal to that obtained from both recognition (Norman, 1966) and missing scan (Kaminska, personal communication). However, if the STM traces are poorly laid down or lose strength more rapidly than normal, then all three methods of retrieval should show roughly comparable poor performance, which is the case with K.F.

K.F.'s performance on three LTM tests, the Wechsler P.A. task, a 10-word learning task (Stevenson, 1968) and the Warrington and Weiskrantz (1968) incomplete-word learning task, was shown to be approximately normal (Warrington and Shallice, 1969). Thus his LTM system appears to be unaffected. The free recall results reported here also support this view, but such an interpretation would be less convincing if based on these alone. The Peterson results are not relevant to this question (see below).

Postman and Phillips (1965) found that the amount retrieved in free recall after counting backwards for 30 sec. is the same as that retrieved after immediate recall for the whole serial position curve except the last "recency effect" section (see Fig. 1); this amount can therefore be used to estimate LTM retrieval capacity. The recency effect can be used to provide an approximate estimate of STM retrieval capacity. [If one assumes retrieval from STM and LTM to operate independently, greater accuracy is obtained by the use of a probability theory correction (Waugh and Norman, 1965).] In the free recall experiment the middle 8 points can be considered as the "flat" part of K.F.'s serial position curve. Values of 3·2 and 0·5 respectively, were derived for K.F.'s LTM and STM capacity. Most comparable data for normal subjects is based on student subjects. However, Baddeley and Warrington (1970), using 6 hospital control subjects, have obtained values of 3·55 (S.D. 0·61) and 1·65 (S.D. 0·71) for LTM and STM respectively with a 3 sec. (i.e. longer) presentation rate.

One common interpretation of Peterson curves is that they arise from a declining STM and a constant LTM factor (Waugh and Norman, 1965). As no significant trend is found in K.F.'s performance on the 5-, 10- and 15-sec. intervals, these results could be used to estimate the asymptotic level of his Peterson curve and thus his LTM capacity. An 0·12 probability of recalling 3 words correctly is the estimate obtained. However, it is doubtful if this method of estimating LTM capacity is valid. Whether normal subject's curves are asymptotic is unclear; Baddeley and Warrington (1970) showed that the decline continues at least up to 60 sec. Also they found that even for the 60-sec. interval normal subjects produce the same results as amnesics, who have a defective LTM. Even if this procedure were a valid means of estimating LTM capacity, it would be difficult to use the estimate for comparison purposes as the inter-subject variance at long intervals is very large (see Murdock, 1961). In addition, the results at any interval are markedly affected by a number of factors, including inter-trial interval (Loess and Waugh, 1967), coding possibilities and skill.

The findings from these experiments indicate that K.F. has a defective STM system while his performance on LTM tasks is normal. By contrast, in the classic amnesic syndrome, the STM system has been shown to be normal with the use of very similar techniques (Wickelgren, 1968; Baddeley and Warrington, 1970). This provides strong evidence for a double dissociation of function; that is, there are at least two verbal memory stores, the STM and the LTM, which are able to operate independently.

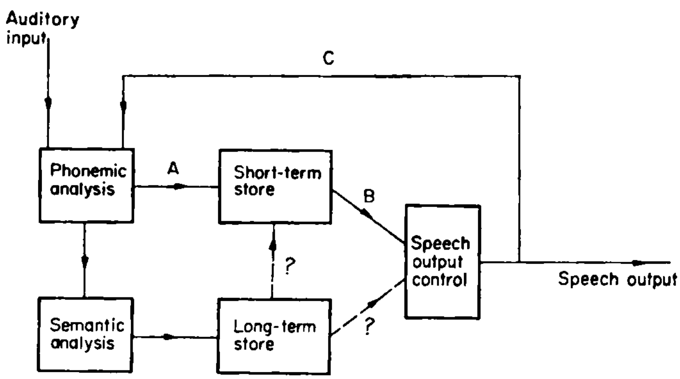

FIGURE 3. Suggested model for processing in auditory verbal memory experiments. The output connections from the L.T.M. unit are left unspecified, since these experiments provide no relevant evidence. Rehearsal is equivalent to the operation of circuit ABC, "the echo box".

More important, the results present difficulties for those theories in which STM and LTM are thought to use the same physical structures in different ways (e.g. Hebb, 1961; Norman, 1968). They also indicate that the frequently used flow-diagrams (Waugh and Norman, 1965; Atkinson and Shiffrin, 1968; Murdock, 1967; Bower, 1967) in which information must enter STM before reaching LTM, may be inappropriate. On this model, if the STM system were greatly impaired, one would expect impairment on LTM tasks, since the input to the LTM store would be reduced. To counter this argument it could be assumed, in line with one of Atkinson and Shiffrin's models, that the rate of transfer from STM to LTM is inversely proportional to the capacity of the STM. Since K.F.'s STM capacity is very low, the rate of transfer would be correspondingly high, which would explain his normal long-term memory. This is, however, a completely *ad hoc* explanation, and it is rather implausible to assume that one function of the STM system should remain totally unaffected, whilst the other function is seriously impaired.

There are two further arguments against this hypothesis. Firstly, the hypothesis provides no explanation of why STM should be subject to acoustic and LTM to semantic interference (Baddeley, 1966). Secondly, one common way of making more plausible the *ad hoc* assumption about rate of transfer is to assume that the LTM trace is laid down by means of rehearsal. This cannot be a complete explanation of the formation of LTM traces since, with techniques preventing rehearsal, an LTM component has been demonstrated (Murray, 1968).

In the light of these findings, it is suggested that a model in which the inputs to STM and LTM are in parallel rather than in series should be considered. The flow diagram shown in Figure 3 is proposed. As a theory of the relation between short-term and long-term memory, it has certain similarities to those theories suggested by Broadbent (1958) and Wickelgren (1968), though neither author is so explicit. Earlier Bühler (1908), on the basis of experiments on memory for proverbs, suggested that semantic and "sensory" memory for verbal material are mediated by independent processes. According to this model K.F. would have sustained damage to the acoustic STM store or to the pathways linking the phonemic analysis unit and short-term storage. Morton's (1969) model, which is also compatible with the results, differs by requiring the input to the STM system to be dependent on modality-free word recognition.

The idea that semantic analysis is not necessary for STM storage is supported by the observation of Geschwind (1965) that echolalia—the echoing of the doctor's speech by a patient—occurs in patients who appear not to understand the doctor. More important, in contrast to the serial model, this model has the obvious advantage of accounting for the difference in type of error found in STM and LTM, namely, acoustic and semantic, respectively. Moreover, the disparity between the anatomical correlates of the STM and LTM (Warrington and Shallice, 1969) increases the likelihood of their operating in totally different ways.

On this model, the evolutionary function of STM is not that of a unit which holds information while traces consolidate in LTM. In order to understand its operation more fully, some assessment of why the human organism should contain such a store seems appropriate. One possible function of the store is to assist in the understanding of complex sentences, since the use of the store together with rehearsal enables a person to attempt more than once to understand a sentence. Another possibility is that the store is an integral part of the speech-production system, possibly corresponding to the phonemic-representation level in Wickelgren's (1969) theory of articulation. These possibilities will be discussed in a later paper.

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