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SHORT-TERM MEMORY RECOGNITION SEARCH IN APHASICS

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A nonverbal short-term memory (STM) recognition task was administered to eight matched pairs of normal and aphasic subjects. Computer-controlled apparatus presented a stimulus list of two, four, and six digits, followed by a single digit, and recorded the amount of time required for subjects to indicate whether the single digit was In or Out of the stimulus list. Response latencies were significantly slower for aphasic than for control subjects. Analysis of response latencies as a function of list length revealed that both groups displayed linear increases, suggesting a serial search process in STM. Control subjects displayed parallel increases for both In and Out functions, while aphasic subjects displayed slopes for Out functions twice the magnitude of those for In functions. This finding indicated an exhaustive search in control subjects and a self-terminating search in aphasic subjects. These qualitative and quantitative differences in STM have potential correlates with differences in language comprehension between these populations.

Contemporary psycholinguistic models of language comprehension suggest that sentences are understood by assigning appropriate deep structures to surface structures through the inverse application of the transformational rules used to generate them (Gough, 1965). If this assumption is correct, it is obvious that some type of memory system is necessary for sentences to be held long enough for comprehension.

Psychological models of memory have suggested that comprehension is accomplished by first coding and retaining a sentence in short-term memory (STM) and then subjecting it to linguistic rules stored in long-terns memory (LTM). Atkinson and Schiffrin (1965) provide a comprehensive theoretical model for viewing human memory which consists of both permanent features (including a. sensory register, STM, and LTM) and modifiable control processes (e.g., rehearsal). Evidence for dichotomization of memory is seen, for example in Milner's (1959) studies of hypocampal lesions in which breakdowns were found in retrieval and input to long-term store, while no impairment occurred in short-term store Few researchers, however, have studied the process by which linguistic comprehension is accomplished, especially the various memory-search processes which appear necessary for such a task. In view of the apparent importance of memory in sentence comprehension, it seems logical to assert that research on the processes underlying the storage of linguistic segments in. STM is mandatory for a complete theory of language decoding for normal subjects. Such research could also provide important information on aphasic language decoding. Further, as language comprehension difficulties and reduced auditory memory span are often characteristics of the aphasic disorder, it could be argued that aphasics' comprehension problems may be directly related to memory deficits.

Most of the recent psycholinguistic research on the nature of normal linguistic storage has utilized verbal learning experimental procedures (cf. Cough, 1965). It can be argued that the use of traditional verbal learning experimental procedures on aphasics is likely, by definition, to yield contaminated data. Nonverbal materials, however, do not seem to require direct utilization of mental or psychological processes which are presumably impaired in aphasics. Thus, by removing the language barrier, these materials appear to offer a logical medium through which memory can be observed validly in the aphasic population. At the same time, performance on nonverbal tasks appears to provide meaningful insights into verbal behavior. For example, Sperling (1963) and Wicklegren (1965) have shown that nonverbal visual stimuli are stored in memory in an auditory-linguistic form. Their analysis of errors on a letter recall task showed that most errors occurred in reporting a letter which sounded like the one presented, even when there was no visual resemblance. Such evidence can be interpreted to indicate presence of a type of internal verbalization on nonverbal tasks.

In a series of experiments dealing with recognition search and retrieval in STM of normal subjects, Sternberg (1963, 1966) concluded that the search process is an exhaustive (as opposed to self-terminating) serial testing procedure which occurs at the rate of 25-30 symbols per second. In an exhaustive serial testing procedure, the stimulus is compared, in turn, to all possible items in memory. By contrast, a self-terminating serial procedure compares each item, in turn, until a stimulus match is located. Swinney (1968), using a slightly different experimental design, verified these results in their essential aspects. The experimental procedure consisted of displaying a list of digits to subjects and then asking them whether a single stimulus item was or was not in the list. In these studies, Sternberg found that mean latency for recall increased linearly with the number of elements in a list. This result best supported a serial-testing process as the search utilized in STM, eliminating procedures such as stimulus-response association or parallel processing from consideration. Sternberg also found that these linear functions for both positive (In) and negative (Out) response latencies had equal slopes. Positive (In) responses consisted of the condition where the stimulus item was a member of the list. Negative (Out) responses consisted of the condition where the stimulus item was not in the list. These functions seem to eliminate the possibility of a self-terminating serial search, since to be self-terminating, the slopes for positive (In) response latencies should be, on the average, half those for the negative (Out) condition.

Since many aphasics have comprehension deficits, and STM appears to play some role in normal language decoding, a study was designed to determine how aphasic subjects process information in STM. The experimental paradigm consisted of a reaction-time study of a STM recognition search following Sternberg's (1966) procedure. If aphasics process information in memory differently from nonaphasics, then precise definitions of aphasia would have to make distinctive statements on information storage and retrieval. Indeed, Carson, Carson, and Tikofsky (1968) have suggested that aphasics process information in a manner similar to nonaphasics, the only difference being that aphasics exhibit slower information handling. Thus, an immediate goal of the study was to assess the validity of the notion that aphasic information processing differs from that of nonaphasics quantitatively but not qualitatively.

METHOD

Subjects

The subjects were eight aphasic and eight nonaphasic adults, each pair matched for age (± five years) and education. The education categories were: grade 1-3, grade 4-8, grade 9-12, 1-4 years college, and more than 4 years college. Mean ages for aphasic and normal subjects were 48.5 years and 47.13 years respectively. Modal grouping for education was the 9-12 grade category. The aphasic subjects were representative of a large range of language disorders. Their scores on the MTDDA (Minnesota Test of Differential Diagnosis of Aphasia) indicated that five subjects presented primarily expressive speech and language disorders, two presented primarily auditory and visual receptive disorders, and one demonstrated severe deficiencies in all expressive and receptive areas of language. These scores were in keeping with the judgments of language clinicians who administered language therapy to the subjects. All subjects were required to pass a Visual Numerical Discrimination Pre-Test (VNDPT).

Stimuli

Two sets of digital stimuli were utilized in the experiment. One set was for the VNDPT and the other was for the experimental task. The purpose of the VNDPT was to eliminate subjects who had difficulty distinguishing among digits. All digits were presented by way of closed circuit television and appeared as $^{3}/_{4}$" (high) x $^{11}/_{16}$" (wide).

VNDPT Stimuli. Stimuli for the VNDPT included a set of 40 digit. pairs, with each digit appearing eight times (four times on each side of the display). For half of the pairs the digits were the same and for half they differed. The latter set was constructed by arbitrarily pairing each of the digits from one to five with each of the digits from six to nine in such a way as to balance the set in the manner described above. The 40 digit pairs were placed in a single randomly ordered list.

Experimental stimuli. Stimuli for the experimental task included lists of digits which were two, four, and six items in length. Each list was paired with a test stimulus which was either a member of the list (In) or not a member of the list (Out). In lists were constructed so that the match to the test stimulus appeared equally often in all possible positions. There was an equal number of In and Out lists. Thus, a total of 24 lists comprised each set. A total of six such sets was used in the experiment, and lists were randomized within each set. Digits selected for these lists were chosen so that (1) no digit was repeated in any one list and (2) each digit appeared about an equal number of times in each set. Digits for Out test stimuli were chosen randomly from the negative subset.

Procedures and Apparatus

The subjects were seated in front of television screens placed $1^1/_2$ feet from them at eye level. Directly in front of the screens were response panels on which two buttons were placed-both easily manipulable with one hand. The buttons were labeled In and Out and were colored red and green, respectively, for the experimental task. Buttons were labeled Same or Different for the VNDPT. All stimuli were presented by means of an 1800 IBM computer controlled paper puller and closed circuit television.

VNDPT. The subjects were presented the VNDPT digit pairs and were instructed to press the Same button if the digits were identical and the Different button if they were not. Scoring was done by hand, and all the accepted subjects performed at greater than 96% accuracy.

Experimental Task. First the subjects were presented with a list of stimuli which was followed by a test stimulus. They were instructed to decide whether the test stimulus was In or Out of the list and push the appropriate button. The stimulus list was shown for 2.0 sec (approximate scanning time for a sample of aphasic adults), and, after a 0.7 sec pause, the test stimulus was shown. Upon presentation of the test stimulus, an automatic response latency timing mechanism in the computer was activated which terminated when one of the response buttons was pushed. The test stimulus remained on the screen for up to 2.0 sec (approximate maximum response time of a sample of aphasic adults in this task) or until all the subjects had responded.. There was a 4.0 sec interval between trials. The presentation timing was controlled by the computer which stored the responses and response latencies of all subjects. Scoring and analysis of the data was done by a specially constructed computer program which computed individual mean and group mean response latencies for correct responses, and individual and group error responses. The experimental session typically required 25 minutes for both aphasic and normal subjects.

RESULTS

Errors

Data concerning errors were important to this experiment for use in determining which of the subjects could be used for a study of memory search processes. Analysis of all errors indicated that, on the average, aphasic subjects had an error rate 20 times greater than that for normal subjects. Closer examination of erroneous responses revealed that two of the aphasic subjects (one classified as having primarily an expressive disorder and one with a primarily receptive disorder) performed correctly for only 27% of the trials. Since the presence of almost no measurable or observable memory eliminated the possibility of analysis of memory-search processes, these two subjects and their controls were eliminated from further analysis. Given the number of incorrect responses made by these subjects, their very few correct responses could not be attributed to any known factor in the experiment. Analysis of errors of the remaining six aphasic subjects indicated they made only three times as many errors as the normal subjects. This is clearly above-chance performance (94.6% correct) and provides sufficient behavioral data to support study of the processes used for STM search. Further, the error rate of the normal control group (1.8%) was very similar to that reported by Sternberg (1963), which was 1.3% for "experienced" subjects.

Latencies

Figure 1 displays mean latencies of correct In and Out responses as a function of list length, for both aphasic and normal subjects. The figure shows that as the list is lengthened, for any condition, latency also increases. Aphasic subjects and control subjects appear to have responded at different speeds, as shown by the gap between aphasic and control response latencies for both In and Out responses.

Latency data were analyzed using an analysis of variance in which the main effects were groups (aphasics vs controls), test condition (In vs Out) and list length (two vs four vs six). The main point to make from this analysis is that aphasic response latencies were significantly longer than normal latencies ($F = 18.82$; $df = 1,14$; $p < 0.001$). This result can be construed to indicate that aphasics search memory in a manner quantitatively different from non-aphasics.

Closer analysis of the responses of the normal control subjects in Figure 1 shows that the slopes of mean latencies of both correct In and Out responses as a function of.size of list appear to be parallel. Results of a second analysis of variance on normal subjects' latencies which had list length (two vs four vs six) and test condition (In vs Out) as main effects confirm the notion that the interaction between length and In-Out factors is not significant ($F = 0.54$; $df = 2,7$; $p > 0.10$). Since they are not significantly different, the two functions for normal subjects illustrated in Figure 1 are, in essence, congruent. This finding is similar to that reported by Sternberg (1963).

A trend analysis performed on both of the functions displayed for normal subjects in Figure 1 shows that the linear components of these functions are highly significant. In fact, almost all of the functions can be accounted for by a straight line. (For the In function, $F = 18.7$; $df = 1,10$; $p < 0.005$. For the

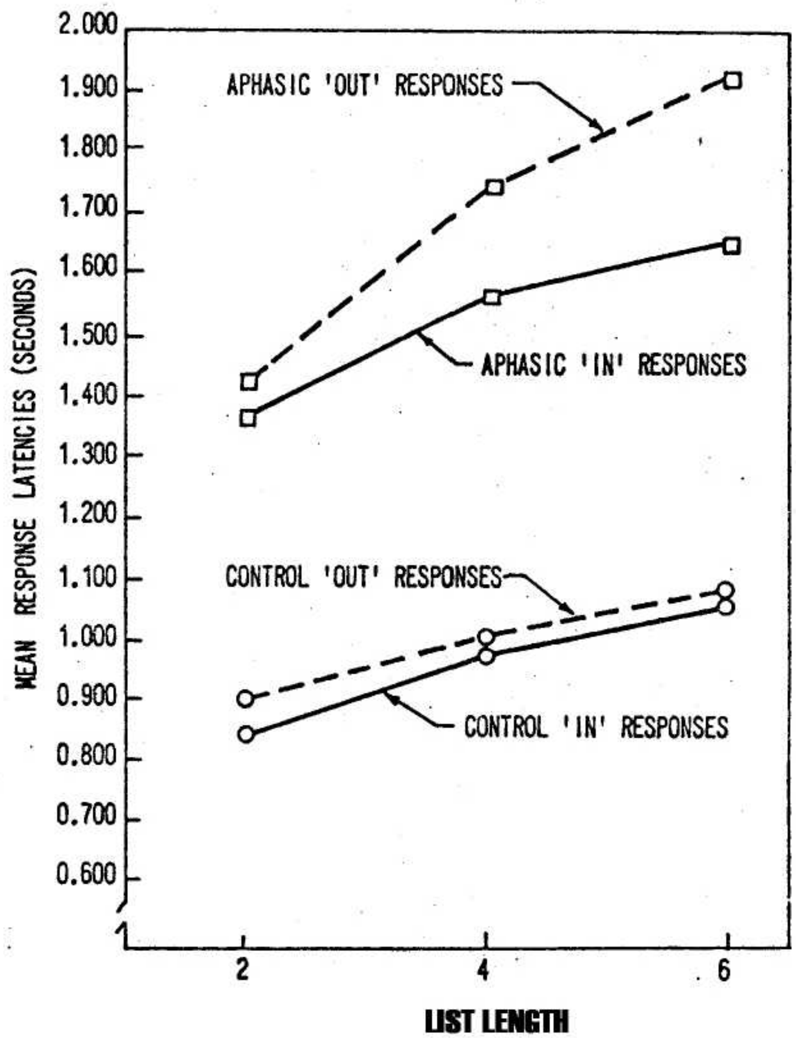

Figure 1. Illustration of the mean latency of correct In and Out responses as a function of list length (two, four, and six items) and groups (aphasic and normal).

Out function, $F = 18.2$; $df = 1,10$; $p < 0.01$.) Further, the quadratic component did not approach significance for either of these functions. It appears, therefore, that the In and Out functions for normal subjects can be considered to be linear.

Figure 1 also depicts mean latency of correct In and Out responses as a function of list size for the aphasic subjects. For this group, mean response latencies for longer lists produced a function with a steeper slope for Out responses than for In responses. The results of an analysis of variance for aphasic subjects, which had list length and test condition as main effects, show that the interaction between list length and the In-Out factor is significant ($F = 6.72$;

df = 2,14; $p < 0.01$). Thus, the In and Out functions for aphasics are, in fact, not parallel.

Trend analysis of In and Out functions for aphasic subjects indicates that the linear components of both functions are highly significant. (For the In functions, $F = 9.27$; $df = 1,10$; $p < 0.025$. For the Out function, $F = 56.98$; $df = 1, 10$; $p < 0.01$.) When the functions were analyzed for a quadratic component, significance was not approached. This finding indicates that slopes of response latencies as a function of list length increase in a linear fashion for aphasic responses.

Visual observation of the functions depicted for aphasics in Figure 1 suggested that the slope for In responses was half that for Out responses. If this were the case it would suggest a self-terminating search, as discussed earlier. In a search which stops when the desired item is reached (a self-terminating search), the In responses, on the average, will occur half the way through the list. In an exhaustive search, all items are scanned, indicating parallel slopes for both In and Out functions. A slope of the best-fitting line for each individual aphasic subject was obtained by using a least squares analysis (regression). Slopes obtained for each aphasic subject for the Out function were divided in half (by two), and this result was compared on a *t* test to slopes obtained for each aphasic subject for the In function. The results were not significant. This observation indicates that the In function slope is significantly half that of the Out function for aphasic subjects. In light of a point made previously, this fact is indicative of a self-terminating search, rather than the exhaustive search of memory found to occur in the normal control subjects.

The overall slope of decision (response) latencies as a function of list length for In and Out responses of aphasic and control subjects, and for subjects from other related experiments, is displayed in Table 1. This direct comparison of the amount of time used for scanning each item in memory reveals many of the differences and similarities between subject populations which have already been discussed.

DISCUSSION

Two major points emerge. First, some aphasics, but not others, can perform STM tasks of the type required in the present experiment. This observation leads to the suggestion that a comprehensive classification of aphasics should include consideration of the status of short-term memory. Second, and perhaps more important, aphasics who did perform in short-term memory exhibited both quantitative and qualitative memory-processing differences from normal subjects. Specifically, aphasics performed a slow, self-terminating search of memory for a recognition task, while normals performed a faster, but exhaustive, serial search of memory. Thus, an hypothesis of aphasic STM which recognizes only quantitative differences between aphasic and nonaphasic adults appears to be insufficient.

The fact that the performance of aphasics differed from that of nonaphasics both quantitatively and qualitatively deserves further discussion. The results show that normal subjects and aphasic subjects perform the same serial-type search through a list of items stored in memory. This serial search hypothesis is

TABLE 1. Comparison of search-time parameters found in the present study with previous findings in similar experiments.

Paacunetels	*Sternberg's Results (1964)* (sec)*	*Swinney's Results (1968)^ (sec)*	*Present Study* *Results-Controls (sec)*	*Results-Aphasics (sec)*
Ordinate intercept				
In	0.397	0.550	0.800	1.280
Out	0.397	0.550	0.800	1.420
Difference between In and Out functions	0.032	0.030	0.025	0.050 at ordinate to 0.300 at length-6 list
Time/item (slope)				
In	0.035	0.0375	0.043	0.087
Out	0.035	0.0375	0034.3	0.125

*Subjects were young adults, "experienced" at the task, which was a recognition search. for numbers.

^Swinney replicated the Sternberg study using young adult "naive" subjects in a recognition search for numbers as well as other items in memory. Our control subjects were 28.5 years older than Swinney's.

justified by the finding of significant linearity in all the slopes of In and Out response latencies plotted as a function of list length. That is, mean latencies of responses increased linearly with the number of elements in memory.

As shown in Table 1, the serial search rate was much slower for the aphasic subjects and only somewhat slower for the control subjects than was reported by Sternberg (1966) and Swinney (1968). Several possible factors may be related to this phenomenon. The most obvious are age differences and practice effects. Considering that our control and aphasic subjects were closely matched for age, and that they averaged 27.8 years older than Swinney's subjects, the similarity of our control search rate to Swinney's and the difference in search rate between the aphasic and the control subjects suggest that search rate differences between aphasics and nonaphasics cannot be accounted for on the basis of age alone. In considering practice effect as a possible source of the different search rates of normal and aphasic populations, it should be noted that both Sternberg and Swinney used subjects who were accustomed to participation in psychological experimentation. Experience might have aided these subjects with their task in such a way that their search rates would be more rapid than those of unpracticed subjects. This argument alone, however, will not explain why the aphasic subjects (who in this particular experimental population were more accustomed to participation in experiments than were their controls) had a slower search rate than their less test-oriented counterparts.

It is probable that both of the above factors contributed to the results to some extent, but the most important factor was probably brain injury. It was certainly a fact that aphasics scanned their memory for recognition of items at a slower serial rate than either the controls or the subjects used by Sternberg and Swinney. This observation suggests quantitative reductions of STM in aphasics. That is, the segment of the aphasic population which appears capable of functioning effectively in STM does so at an overall reduced rate.

Careful study of the data indicates that some aphasic subjects have latencies no longer than some of those of the normal subjects. While the tendency for latency overlap between aphasic and normal subjects is not significant, an interesting trend exists. Younger aphasics display relatively shorter latencies than other aphasics. At the same time, older normal subjects display longer latencies than younger normal subjects. As stated, young aphasic subjects and old normal subjects frequently have overlapping latencies. Thus, age may be a relevant variable for consideration. Many researchers. (Taylor, 1966; Doktor and Taylor, 1968; and Levy, 1968) have previously shown this apparent interaction between age and aphasic-like performance on verbal tasks. While the trend was not significant in our experiment, it suggests that the deterioration which accompanies the normal aging process affects language and language-like behavior in ways similar to those caused by brain injury, as seen, for example, in aphasia.

In general, the findings of (1) a slower search rate for aphasics, (2) a serial search pattern for both aphasic and normal subjects, and (3) overlapping of normal and aphasic latency scores as a function of age, tend to support the suggestion of Carson, Carson, and Tikofsky (1968) that aphasics differ quantitatively, but not qualitatively, from nonaphasics on information-processing tasks. On the other hand, other aspects of the data speak against this hypothesis as the following discussion demonstrates.

The slope of the search rate for normal control subjects for In stimulus items (as shown in Figure 1) is parallel with the slope of the search for Out stimulus items. This search, similar to the "exhaustive" search reported by Sternberg (1966), indicates that normal subjects search through the entire list before deciding whether they recognize an item as in or out of the list. Thus, it takes an equal amount of time, irrespective of position, to decide that an item was in the list.

Contrary to the above finding, and to the quantitative difference position, is the finding that the slope for the aphasic In search rate was half that of the aphasic Out search rate. These data best fit an hypothesis which states that aphasics search STM in a self-terminating manner. That is, if the subject stopped his search the very instant he hit the correct item while scanning memory in a serial fashion, he would stop for an In stimulus in half the time (on the average, in a balanced study) that he would for an Out item, since in the latter instance a subject must scan the entire list to discover that an item was not in his memory.

Thus, given the apparent serial exhaustive search of STM in normal subjects and the slow serial self-terminating search in aphasic subjects, serious questions must be raised concerning the validity of the hypothesis suggested by Carson, Carson, and Tikofsky (1968) that aphasics differ from nonaphasics in a quantitative, but not a qualitative manner.

Further, the differences in search suggest some relationship between search time and search process in immediate memory. Presently, there is no way of ascertaining the directionality of this possible cause-effect relationship. It might, for instance, be hypothesized that the slower aphasic search rate is a result of brain damage. Thus, aphasics may be choosing to use a more efficient scanning method for recognition search-stopping once the searched-for item has been located. For several reasons, this suggestion does not appear to be unreasonable. First, normal subjects appear to scan rapidly through the entire list of memory-stored items, set a "marker" if an item is recognized, and then, once the search is completed, determine whether a marker has been set or not. If a marker was set, the response is In. If no marker was set, the response is Out. Contrarily, the aphasic seems to operate under two possible handicaps. First, brain damage appears to force him to search memory at a slower rate. Second, he may not be able to store items in memory in the same auditory-linguistic manner as his normal counterpart. These handicaps may well have the previously mentioned cause-effect relationship with each other. Thus, when the aphasic undergoes a memory search, his inability to use subvocal linguistic cues to aid in identifying items stored in visual memory may well dictate a much slower search. Consequently, the aphasic may have enough time to decide that a marker has been set while in the process of searching, as opposed to the normal faster search time which forces decisions about markers to be delayed until the search is completed.

The fact that a self-terminating search occurs in aphasic short-term memory has implications for understanding comprehension deficits in aphasics, particularly for complex sentences. Aphasics are required to process and comprehend sentences generated by a grammar that is suited to and written by persons with different (normal) processing abilities.

At the moment, there is little knowledge about how aphasics analyze sentences which have certain meanings for those who are not aphasic. When viewed in transformational grammatical terms, our experiment indicates that certain complex linguistic structures, e.g., center-embedded sentences, might be totally confused by an aphasic. For instance, consider the following sentence: *The boy the girl saw hit the cat.* If an aphasic were to search his memory in a self-terminating manner for the verb phrase connected with *the boy* (since one supposedly looks for NP + V to make a sentence), he would stop once he hit the verb *saw* and, hence, misunderstand the sentence. An exhaustive search would have discovered the embedded nature of the verb *saw* and facilitated a correct interpretation of the meaning of the sentence. There is some preliminary evidence which shows that these sentence-types are, in fact, very difficult for aphasics to comprehend correctly.[1]

[1] *Personal communication from J. Game.*

In conclusion, the study suggests that aphasics cannot be discussed in terms of a binary categorization alone. They not only differ from normal language-speaking persons on quantitative levels, but they appear to differ on specific qualitative STM search processes, as evidenced by the self-terminating search discussed in this paper.

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