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Short-Term Memory Performance in the Absence of Phonological Coding

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These experiments examined the short-term memory performance of an aphasic patient with posterior damage who shows a selective deficit in phonological coding. In recognition memory tests, the patient relied on both visual and semantic coding, and often showed an essentially normal level of accuracy. However, for memory sets consisting of four function words, his performance was quite impaired. Also, his retention of order information was far below that of normal controls. The implications of these deficits in short-term memory for language comprehension and production are discussed.

In short-term memory tasks involving visually presented verbal items, subjects appear to rely on phonological representations of the items in order to maintain the memory trace. Several lines of evidence support this view. For example, errors in recall tend to be phonologically rather than visually similar to the target items (Conrad, 1964; Wickelgren, 1965). For memory sets consisting of phonologically similar items, recall is impaired relative to that for visually but not phonemically similar sets of items (Conrad & Hull, 1964; Baddeley, 1966; Murray, 1968). Also, studies using paired-associate learning have shown that phonological similarity affects the short-term memory component of these tasks (Dale & Baddeley, 1969).

While phonological recoding appears to be a favored strategy for maintaining verbal items in short-term memory, such coding is not essential in order to retain a short-term memory trace. Several studies have shown

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that when subjects are engaged in a secondary task that occupies their articulatory system (such as uttering "the" repeatedly, or counting one to ten), recall on a short-term memory task is impaired but does not fall to zero (Estes, 1973; Murray, 1968; Richardson & Baddeley, 1975). Such a secondary task is presumed to interfere with the subjects' ability to phonologically code and rehearse the memory set items. It might be objected that such would not necessarily be the case if phonological coding and rehearsal could be carried out internally without involving the articulatory system. Against this objection, however, it has been found that a secondary articulatory task reduces or eliminates the phonemic effects discussed above. For example, Murray (1968) found substantially smaller effects for acoustic confusability for visually presented lists when subjects were required to repeat "the" while performing the memory task.

Although employing a secondary articulatory task does eliminate phonemic effects in short-term memory tasks, the decrement in performance found on the main task could be due to having to perform two tasks at once rather than being due specifically to an inability to do phonemic coding (Richardson & Baddeley, 1975). It is possible that other forms of coding might allow for equally high levels of performance if subjects could be induced to avoid phonemic coding while not performing a secondary task. However, for normal subjects it is hard to imagine how such behavior could be induced. The sound of a visually presented word seems to come automatically to mind without any conscious effort when the phonological system is not occupied in some other task.

Another means of studying the importance of phonemic recoding, without involving a secondary task, is to look at the short-term memory performance of brain-damaged patients who have a selective impairment of phonemic coding but who retain an ability to access representations of verbal items through their visual characteristics. The advantage of such an approach is that the patient will not be involved in another task that might suppress performance apart from its interference with phonemic recoding. The disadvantage of such an approach is that any decrement that might be found might be attributed to other impairments in cognitive function caused by brain damage aside from the impairment in phonemic recoding.

In the experiments presented below, the performance of a brain-damaged patient who has a phonological deficit was examined on several short-term memory tasks relative to the performance of normal subjects in terms of type of coding and overall level of performance. Evidence is presented indicating that his deficit is a selective one of phonological processing and that other processes that might be important in short-term memory performance have been spared.

In these experiments we were interested both in this patient's short-term memory capabilities and, by comparison with the performance of normal subjects, in proposing an account of the role of phonemic coding in normal short-term memory processing.

PATIENT DESCRIPTION

J.S. is a right-handed male who was 45 at the time this study was conducted. He completed 4 years of college, but did not obtain a bachelor's degree. He was employed as an army staff sergeant prior to his cerebrovascular accident in 1979 that resulted in a left temporoparietal lesion. J.S. lives alone. His activities include watching television, listening to music, playing cards, and traveling.

J.S.'s language impairment is quite severe. He has difficulty comprehending all but the most stereotyped phrases in casual conversation. His output is fluent, but he has severe word-finding difficulties. Communication with him is facilitated by writing key words or by having him write a word or two that indicate the topic. He is usually able to write an intended word, but it is often spelled incorrectly.

CT scan reveals a large area of infarction in the superior temporal lobe, including Wernicke's area, which extends superiorly into the parietal lobe to involve the supramarginal gyrus and an area slightly superior to it. It appears that the infarcted area may involve only the anterior portion of the angular gyrus.

J.S.'s performance on a number of language-related tasks has been studied and has revealed a striking dissociation between auditory and visual processing (Caramazza, Berndt, and Basili, in preparation). In matching an orally presented syllable (e.g., "ba") to its written form, J.S. scored only 66% correct when given two written alternatives from which to choose. On an auditory lexical decision task, in which words and nonwords were pronounced aloud to J.S., he scored near chance in deciding which were words. On a visual version of the same task, however, he made only 1 error on 80 trials.

In tasks requiring the use of an internal phonological representation, his performance is quite poor. Given two pictures of objects and asked to judge whether the names for the objects rhymed, he scored 7 out of 15 correct on the rhyming trials, a chance level of performance. On another rhyming task, when given three words and asked to choose the two that rhymed he scored only 6 out of 20 correct when the visual and phonological properties of the words were in conflict (e.g., *few, sew, dough*).

On tasks requiring semantic processing of visually presented words he performs quite well. On a visual presentation of the Peabody Picture Vocabulary Test, he scored 127 out of 150 correct, which is equivalent to an IQ score of 137. On a semantic categorization task in which both words and pictures were to be placed in superordinate categories he scored 87% correct overall.

Preliminary testing of J.S.'s short-term memory ability showed a consistently high level of performance for the retention of a single visually presented item. For a single word presented visually with immediate written recall, he scored 23 out of 25 correct for the concrete nouns, and 23 out of 25 correct for the function words. On a same–different matching task with no delay between the two words or nonwords, he scored nearly 100% correct for both the words and nonwords.

From the evidence discussed above, it was concluded that the patient's visual memory for verbal items was intact. However, he appears to have a central phonological deficit that impairs his ability to comprehend auditory messages, to do grapheme-to-phoneme conversion, to use internal phonological representations, to read orally, and to produce words. His phonological deficit is still under investigation and will be presented in more detail in future work.

EXPERIMENT I

In the first experiment we examined the ability of J.S. to retain one item in memory for varying amounts of time using the procedure developed by Posner and Keele (1967). In this procedure, the subject sees one letter in either upper- or lowercase followed at various intervals by a second letter. The subject must decide if the two letters match, where a match is said to occur if the letters are physically identical or if they have the same name. Posner and Keele found that at the shortest interletter delay (500 msec) there was a substantial reaction time advantage for physical over name matches, but at about 1.5 sec this advantage had disappeared. In their discussion of this work, Posner and Keele proposed that subjects used two different codes in making their decisions—a visual code and a name code. It was suggested that the visual code was generated quickly but decayed rapidly. The name code was assumed to take longer to generate than the visual code. At the shortest interletter delay, subjects relied on the visual code when making their decisions in the physical match condition, resulting in reaction times faster for the physical match than those for the name match condition. At the longer delays, subjects relied on the name code for both the physical and name match conditions, since the visual code for the first letter was assumed to have decayed during the longer delay.

A subsequent study by Parks, Kroll, Salzberg, and Parkinson (1972) showed that if subjects were asked to shadow letters during the delay the advantage for physical matches persisted at an 8-sec delay. Thus, it appears that subjects can retain a visual code for the letter for much longer if they are motivated to do so because a secondary task inhibits verbal recoding.

Method

Subjects. Besides J.S., six normal subjects were tested in order to provide a comparison for the patient's performance. These subjects were Johns Hopkins University students who received $3.00/hr for their participation.

Stimuli. The letters A, B, F, I, J, M, N, T were presented in both upper- and lowercase form on a remote CRT controlled by a PET computer.

Procedure. Subjects initiated a trial by pressing a foot pedal after "READY" appeared on the screen. A fixation point appeared in the center of the screen for 1 sec, followed by the first letter of the letter pair. This letter remained visible for 200 msec. The second letter appeared following a stimulus onset asynchrony of 500, 1500, or 3000 msec. Following the appearance of the second letter, subjects pressed a button with either the forefinger or middle finger of the right hand (corresponding to "match" and "nonmatch" decisions, respectively). Reaction times were recorded.

Design. All four combinations of upper- and lowercase letters in first and second positions were presented for the matching trials, resulting in 32 matching trials. Of these, 16 were physical matches and 16 were name matches. For the nonmatching trials, pairs were selected such that some pairs would be visually similar, some phonemically similar, some visually similar and phonemically similar, and some unrelated in terms of visual or phonemic similarity. I and J were used as the visually but not phonemically related pair, B and T as the phonemically but not visually similar pair, M and N as the both visually and phonemically similar pair, and A and F as the unrelated pair. These pairs were presented with both members of the pair in uppercase, or both members of the pair in lowercase. Other pairs of unrelated letters were added to the nonmatching pairs that consisted of one uppercase letter and one lowercase letter. In all, 32 nonmatching pairs were used.

Subjects saw all 64 pairs in a random order in one block. Two blocks of each delay condition were presented consecutively. The order in which the subjects saw the three delay conditions was counterbalanced across subjects.

The normal subjects were tested on 1 day with the six trial blocks described above. J.S. was tested on 3 days separated from each other by approximately 1 week, completing all six trial blocks on each day. The order in which he received the delay conditions was counterbalanced across days.

Results

Reaction times for the normal subjects were averaged across the two trial blocks for each delay condition and an analysis of variance performed separately for the matching and nonmatching trials. A two-way analysis of variance was performed on the matching trials with time delay and type of match (physical or name) as factors. The only significant effect was a delay condition by type of match interaction, $F(2, 10) = 14.67$, $p < .01$. t Tests were performed on the physical versus name match reaction times for the different delay conditions, adjusting the significance level so that the overall α for the three tests would be less than .05. For the 500-msec delay, this difference was significant $t(5) = 6.18$, $p < .01$, with the physical matches having a faster mean reaction time than name matches. At the 1500-msec delay, the difference was not significant, $t(5) = 1.34$, $p > .20$. However, at the 3000-msec delay the difference was again significant, $t(5) = 2.84$, $p < .025$, but with the name matches having a faster mean reaction time than the physical matches. A plot of these results for the normal subjects is shown in the left panel of Fig. 1. Overall there was a 3.8% error rate on the matching trials with a 4.0% error rate on the name match trials and a 3.7% error rate on the physical match trials.

The results for the aphasic patient on the matching trials are shown in the right panel of Fig. 1, and provide a striking contrast with the results for the normal subjects. At all three delay conditions, the physical match pairs had faster reaction times than the name match pairs. This effect was consistent across all three testing sessions, that is, physical matches were faster than name matches for all delay conditions on all three days of testing. J.S. had a very low error rate on the matching trials, making only four errors on a total of 576 trials (0.7%). He made one error on the physical matches and three errors on the name matches. As can be seen in Fig. 1, the difference between the physical and name matches decreases over time with the reaction time for physical matches increasing with longer delays, while the time for the name matches remains constant.

A three-way analysis of variance was performed on the nonmatching trials data for the normal subjects, with delay, visual similarity, and phonemic similarity as factors. Only the reaction times for the same-case

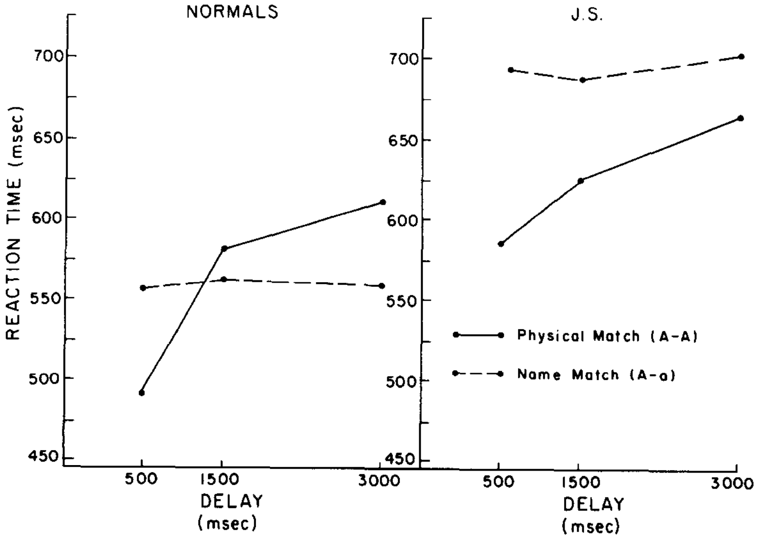

FIG. 1. Reaction times for the matching trials, Experiment I. Left panel shows the results for the normal subjects, and the right panel the results for J.S.

pairs that were selected on the basis of their visual and phonemic similarity were analyzed. Reaction times for the mixed-case nonmatching pairs were disregarded. There was a significant effect for visual similarity, $F(1, 5) = 175.6$, $p < .01$, with the visually similar pairs having longer mean reaction times than the visually dissimilar pairs at all delays. There was also a significant delay × visual similarity × phonemic similarity interaction, $F(2, 10) = 4.21$, $p < .05$. Examination of this three-way interaction revealed that within the visually similar pairs, the phonemically similar pairs (M–N) took no longer to reject than the phonemically dissimilar pairs (I–J) at any of the delays ($t(5) < 1.0$ at all three delays). However, within the visually dissimilar pairs, although there was no difference between the phonemically similar pairs (B–T) and phonemically dissimilar (A–F) pairs at the 500- and 1500-msec delays, $t(5) = .92$ and $t(5) = 1.79$, respectively, there was a significant difference at the 3000-msec delay, $t(5) = 3.69$, $p < .05$, with the phonemically similar pairs taking longer to reject. A plot of these results for the visually dissimilar pairs for the normal subjects is shown in the left plot of Fig. 2.

The overall rate on the nonmatching trials was 3.1%. By delay condition, the error rates were 1.6% for the 500-msec delay, 3.6% for the 1500-msec delay, and 4.2% for the 3000-msec delay. Within each delay condition error rates for the different distractor types were nearly equal.

As with the normal subjects, J.S. took longer to reject the visually similar pairs than the visually dissimilar pairs at all delays. Within the

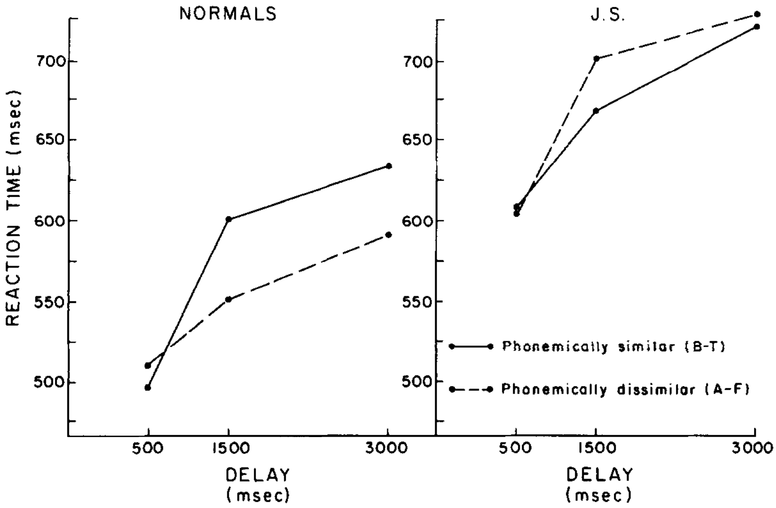

FIG. 2. Reaction times for the nonmatching trials, Experiment I. Left panel shows the results for the normal subjects, and the right panel the results for J.S.

visually dissimilar pairs, however, his pattern of results differed from that of the normals in that the effect for the phonemic similarity of the B–T pairs did not appear at the longest delay as it did for the normal subjects. At the longest delay, the mean reaction time for the B–T pairs was slightly faster than the mean reaction time for the visually and phonemically unrelated pairs (A–F). A plot of J.S.'s reaction times for the visually dissimilar pairs is shown in the right panel of Fig. 2. The error rate for J.S. on the nonmatching trials that were analyzed was 0.7% (that is, two errors out of 288 trials).

Discussion

For the normal subjects, the results for the 500 and 1500-msec delay conditions replicate what has been found previously, with faster times for the physical matches at the shortest delay and no difference at 1500 msec. The reversal at 3000 msec is, however, unexpected. Kroll and Parks (1978) suggested that the elimination of the advantage for physical matches at longer delays arises because subjects internally generate a letter opposite in case to the first one presented. This explanation would seem to imply that name matches should be faster at the longer delays than at the shorter delays, since subjects are "set" for a name match at the longer delays. While it is true that the name matches were faster than the physical matches at the 3000-msec delay, the time for the name matches remained nearly constant across the delay conditions. A similar result has been obtained by Boies (cited in Posner, 1978). Thus, it seems plausible to assume that the process by which the name matches were made remained the same throughout, while it was the physical matches that were changing. An explanation for the longer times for the physical than for name matches at the longest delay, however, awaits further investigation.

The results for the aphasic subject are similar to those found by Parks et al. (1972) with normal subjects who were engaged in a shadowing task while performing the letter-matching task. Even at the longest delay, the advantage for physical matches persisted for J.S., thus providing further evidence that a visual code can be maintained for longer than 1.5 sec when a verbal code is unavailable.

The results for the nonmatching trials also support the view that the normal subjects generated a name code at the longer delays while J.S. did not. For the normal subjects at the longest delay, the phonemically similar, visually dissimilar pairs (B–T) took longer to reject than the unrelated pairs (A–F). For J.S., this effect did not appear. Even at the longest delay, the unrelated pairs had a slightly longer reaction time than the phonemically similar, visually dissimilar pairs.

Although the effect for phonemic similarity on the nonmatching trials appeared for the normal subjects, the effect for visual similarity did not disappear at 1500 and 3000 msec, as might have been expected based on the results for the matching trials. This would suggest that even for the normal subjects the visual code persists beyond 1.5 sec, after the point at which the name code has been developed (Thorson, Hockhaus, & Stanners, 1976).

Although J.S. did not use a name code, he was able to perform the task at a high level of accuracy, having a lower error rate than the average for the normal subjects. Since he apparently does not generate the name of the item, he must at some more abstract level be able to identify that an upper- and lowercase form are representations of the same letter. However, this abstract representation is not used in short-term memory in the same manner as a name code. If it were, we would expect to see the same pattern of results for J.S. as the normals on the matching trials (although not on the nonmatching trials). At least two possible ways in which this abstract code might differ from the name code in terms of short-term memory processes are suggested by the present results. First it is possible that this code cannot be maintained in short-term memory as long as the name code, in essence implying that it fades rapidly and cannot be rehearsed. If this were true, it would suggest that J.S. performs the name match by retaining the visual code of the first item of a pair until the second appears and then checks that both have the same abstract representation. A second possibility is that this abstract code is retained in short-term memory along with the visual code, as normals retain both the name and visual codes. However, unlike the name code, comparisons based on this code do not have any advantage over comparisons based on the visual code either because it takes longer to generate the abstract code than the name code for the second letter, or because a comparison based on the abstract codes for the two letters takes longer than a comparison of name codes.

EXPERIMENT II

Although J.S.'s performance in Experiment I was similar to that of the normal subjects in terms of percentage correct, the memory set consisted of a single item. In the present experiment, the memory sets consisted of four words. With a larger memory set, visual coding might prove much less effective than phonemic coding, resulting in a decrement in performance for the aphasic patient on this task.

With words as stimuli, however, semantic coding is more possible than it is for letters. Although early researchers found evidence that semantic coding was not used in short-term memory (Baddeley, 1966), later research has shown that semantic effects can be obtained (Craik & Levy, 1970; Shulman, 1972). To investigate the role of semantic coding in this task for J.S., sets of words were used that differed in their semantic codability. Concrete nouns, abstract nouns, and function words were selected on the assumption that concrete nouns should most easily be coded semantically, abstract nouns next most easily, while function words should be most difficult to code semantically. If visual coding is sufficient for retention in such a task, then there should be no effect for semantic content on the level of performance.

Because J.S. has difficulty in both oral and written expression, a recognition probe task was used rather than a recall task. In order to study the type of coding used by J.S. and the normal subjects, negative probes were selected that were either phonemically, visually, or semantically related to a memory set item, or unrelated to all of the memory set items. For J.S. we would expect effects of the visual and semantic distractors, while for the normal subjects all types of distractors should have an effect.

Method

Subjects. Besides J.S., 18 Johns Hopkins University students, who served as controls, were tested.

Procedure. Words were presented on a remote CRT screen controlled by a PET computer. Items were presented one at a time in the center of the screen for 0.5 sec each with a 1-sec delay between items. The four memory set items were followed by two asterisks which stayed on the screen for 2 sec, followed by the probe item. The probe stayed on the screen for 2 sec. Only one probe was presented per memory set.

To initiate the presentation of a memory set, subjects pressed a start button with the left hand. Following the presentation of the probe item, subjects were required to indicate whether the probe item matched one of the memory set items. A response was made by pushing a button with either the forefinger or middle finger of the right hand, corresponding to "match" or "nonmatch" decisions, respectively. Subjects were instructed to respond as quickly as possible while keeping errors to a minimum.

Concrete nouns, abstract nouns, and function words were presented in separate blocks. Half of the trials within each block were matching trials and half were nonmatching trials. On the matching trials, probes were presented equally often that matched items located at each of the four serial positions. On the nonmatching trials, one-quarter of the probes were phonemic distractors, one-quarter visual distractors, and one-quarter semantic distractors. Examples of the different types of distractors are shown in Table 1. For each type of distractor, there were an equal number of probes related to a memory set item at each of the serial positions. The remaining one-quarter of the nonmatching probes were unrelated to any of the memory set items on any of these dimensions.

The order in which subjects saw the blocks was counterbalanced across subjects. The control subjects saw all three blocks in one testing session. J.S. was tested on 3 days, completing the three blocks on each day. The order in which he saw the blocks was counterbalanced across days.

Results

Results for the matching and nonmatching trials were analyzed separately for both the aphasic and control subjects.

A three-way analysis of variance was performed on the reaction time data for the nonmatching trials for the normal subjects with word type, distractor type, and serial position as factors. There was a significant

TABLE 1

TYPES OF DISTRACTORS USED IN MEMORY PROBE TASK (EXPERIMENT II)

	Phonemic	Visual	Semantic	Unrelated
Concrete nouns				
Memory set item	juice	head	hammer	menu
Probe word	goose	bead	wrench	window
Abstract nouns				
Memory set item	threat	record	cure	advice
Probe word	bet	resort	remedy	misery
Function Words				
Memory set item	quite	who	up	else
Probe word	might	why	down	what

effect for type of distractor, $F(3, 51) = 9.60$, $p < .01$, and a significant interaction of word type with distractor type, $F(6, 102) = 2.57$, $p < .05$. Means for the four types of negative probes for each of the word types are shown in Table 2, along with the error rate in each condition.

Because of the significant interaction of word type with type of distractor, comparisons were performed separately on the data for the three types of words, comparing each distractor type against the unrelated probes. For the concrete nouns, all three comparisons were significant: $F(1, 51) = 8.86$, $p < .01$ for the phonemic distractors, $F(1, 51) = 17.78$, $p < .01$ for the visual distractors, and $F(1, 51) = 15.2$, $p < .01$ for the semantic distractors. For the abstract words, only the visual distractors took significantly longer to reject than the unrelated probes, $F(1, 51) = 4.74$, $p < .05$. The comparisons for the phonemic and semantic distractors had F values less than 1.0. For the function words, again all

TABLE 2

REACTION TIMES FOR NORMAL CONTROLS FOR NONMATCHING TRIALS IN EXPERIMENT II[a]

($n = 18$)

	Type of distractor				
	Phonemic	Visual	Semantic	Unrelated	Mean
Concrete nouns	805	840	831	721	799
	(11)	(9)	(1)	(2)	(5.5)
Abstract nouns	803	836	747	774	790
	(3)	(9)	(1)	(3)	(4.0)
Function words	856	862	851	783	838
	(5)	(10)	(4)	(1)	(5.0)
Mean	821	846	810	759	809
	(6.0)	(9.3)	(2.0)	(2.0)	(4.8)

[a] Numbers in parentheses are error rates in percentages.

comparisons were significant: $F(1, 51) = 8.83$, $p < .01$ for the phonemic distractors, $F(1, 51) = 10.34$, $p < .01$ for the visual distractors, and $F(1, 51) = 7.66$, $p < .01$ for the semantic distractors.

On the matching trials, a two-way analysis of variance showed no effect for type of word, $F(2, 34) = .15$, no effect for serial position, $F(2, 34) = 1.33$, nor any interaction between word type and serial position, $F(2, 34) = .69$. Error rates on the matching trials were 6% for the concrete nouns, 5% for the abstract nouns, and 9% for the function words. To compare level of performance for the different word types across both matching and nonmatching trials d' values were computed. For the concrete nouns d' was 3.21, for the abstract nouns 3.39, and for the function words 2.98. Thus, although performance was worst for the function words, the d' value was not much lower than those obtained for the nouns.

The results for J.S. on the nonmatching trials are shown in Table 3. For the concrete nouns and function words, reaction times for the visual and semantic distractors were longer than those for the unrelated probes. For the concrete nouns the mean reaction time for the phonemic distractors was nearly equal to that for the unrelated probes. Although the phonemic distractors had a longer mean reaction time than the unrelated probes for the function words, the effect was much smaller than that for the other distractor types, especially the visual distractors. The results for the abstract words in terms of reaction times are somewhat curious, in that all distractor types had faster reaction times than did the unrelated probes. However, the error rate for the visual distractors was much higher than that for any of the other probes, indicating an effect for visual similarity. Since a semantic effect was not obtained for the normal subjects for the abstract words, a semantic effect was not expected for J.S.

The largest percentage of errors on the nonmatching trials for J.S. occurred for the visual distractors for all types of words considered together. However, for the function words, the semantic distractors had the most errors. Error rates are shown in Table 3.

On the matching trials, J.S. showed a serial position effect for the concrete and abstract nouns that was consistent over days showing both a primacy and a recency effect. Error rates also reflected more difficulty with the middle two positions than the two ends. For the function words, the primacy effect was not evident, although there did still appear to be a recency effect. Results for the matching trials are shown in Table 4.

In terms of overall performance, J.S. made many more errors, averaged across all word types and both matching and nonmatching trials than did the normal subjects. To compare his level of performance to that of the normals it is useful to look at d' values. For the concrete nouns d' was 2.79, for the abstract nouns 2.44, and for the function words, 1.43. Thus,

TABLE 3
REACTION TIMES FOR J.S. FOR NONMATCHING TRIALS—EXPERIMENT II[a]

	Type of distractor				
	Phonemic	Visual	Semantic	Unrelated	Mean
Concrete nouns	884	969	936	883	918
	(17)	(29)	(4)	(0)	(12.5)
Abstract nouns	906	910	854	923	898
	(0)	(19)	(6)	(0)	(6.3)
Function words	977	1210	1036	910	1033
	(12)	(19)	(56)	(25)	(28.0)
Mean	922	1030	942	905	950
	(9.7)	(22.3)	(22.0)	(8.3)	(15.6)

[a] Numbers in parentheses are error rates in percentages.

J.S.'s performance on the concrete nouns was not that different from that of the normal subjects. In fact, some of the normal subjects had error rates as high or higher than that of J.S. for the concrete nouns. For the function words, however, his performance was dramatically impaired. His performance on the abstract nouns was between these two extremes.

Discussion

For the normal subjects, the results were as expected for the concrete nouns and function words with all types of distractors affecting reaction times for the nonmatching trials. For the abstract nouns, only the visual distractors had significantly longer reaction times than the unrelated

TABLE 4
REACTION TIMES FOR J.S. FOR MATCHING TRIALS IN EXPERIMENT II[a]

	Position				
	1	2	3	4	Mean
Concrete nouns	770	842	852	783	812
	(0)	(8)	(13)	(0)	(5.2)
Abstract nouns	722	918	917	723	820
	(6)	(31)	(25)	(13)	(18.8)
Function words	832	790	922	726	818
	(6)	(31)	(31)	(31)	(24.8)
Mean	775	850	897	744	817
	(4.0)	(23.3)	(23.0)	(14.5)	(16.3)

[a] Numbers in parentheses are error rates in percentages.

probes. The lack of semantic effect for the abstract nouns may have resulted because the associations between targets and semantic distractors were not as strong for the abstract nouns as for the other word types. Looking at the examples provided in Table 1, the reader may agree that *remedy* is less likely to come to mind as an associate to *cure* than is *wrench* to *hammer* or *down* to *up*. The lack of phonemic effect for the abstract nouns may have to do with the longer average length of these words compared to the concrete nouns and function words. Baddeley, Thomson, and Buchanan (1975) have shown that there appears to be a fixed rehearsal rate for verbal items, in terms of syllables per second. The abstract nouns had an average length of 2.25 syllables, while the concrete nouns had an average length of 1.6 syllables and the function words 1.4 syllables. Subjects may not have had enough time to rehearse all of the memory set items before the probe item appeared, and thus may have been discouraged from using a rehearsal strategy.

Thus, the most interesting comparisons between the normal subjects and J.S. are for the concrete nouns and function words where phonemic effects were obtained for the normal subjects. J.S. showed no effect for the phonemic distractors for the concrete nouns; however, his performance was similar to that of the normal subjects in terms of d'. We can assume, therefore, that a reliance on the visual and semantic properties of the words was sufficient for an essentially normal performance on the recognition task for the concrete nouns. For the function words, there was a small reaction time effect for the phonemic distractors (small in terms of the size of the effect for the visual and semantic distractors for these words) for J.S. It is likely that this small difference is due to random error since the opposite effect was seen in his error rates with more errors occurring to the unrelated probes than the phonemic probes.

In terms of percentage correct, the performance of J.S. was much worse than that of the normal subjects on the function words. Thus, a reliance on visual and semantic coding for these words was not sufficient for a high level of performance. In general, function words do not have much semantic content but rather have a relational or syntactic meaning. Thus, one might not have expected the effects for the semantic distractors for the function words obtained for both J.S. and the control subjects. However, the function words for which it was possible to select semantic distractors were, of course, those functors with the most semantic content, such as *up*, *above*, and *ours*. J.S. and the normals accessed the semantic content of these words when possible, resulting in longer reaction times for the semantic distractors and a large number of errors for J.S. for the semantic distractors.

It might be argued that J.S. as an aphasic patient did more poorly on the function words not solely because he could not retain them in a phonological form, but perhaps because he cannot identify these words as words. However, J.S. does not omit function words in spontaneous speech. In a lexical decision task, J.S. showed a nearly perfect ability to discriminate function words from nonwords. While this evidence does not prove that he can comprehend function words as well as normals, it does suggest that he can at least identify them as words. It would be interesting to test normal subjects on memory for function words using a secondary articulatory task to determine if their performance would be as dramatically affected as was J.S.'s.

EXPERIMENT III

In Experiment II, J.S.'s performance for the concrete nouns was near that for the normal subjects. With both semantic and visual coding possible for these items, there was only a small decrement in recognition performance. This experiment investigates J.S.'s recall of order information as opposed to his item recognition ability for concrete nouns. Previous investigations of short-term memory that have employed a rehearsal suppression task have found that errors in recall tend to be items recalled out of order rather than intrusions of extralist items (Murray, 1968). It therefore seems plausible that a disruption of phonemic coding and rehearsal might impair recall of order information more severely than item recognition (Baddeley, 1976; Lee & Estes, 1977; Estes, 1973).

A preliminary test of J.S.'s order recall performance did show a much more impaired recall of order as opposed to item information. To circumvent J.S.'s output problems, a pointing task was used similar to that used by Goodglass, Gleason, and Hyde (1970). Sets of eight words were presented in two columns of four words typed approximately 2 in. apart on sheets of paper. J.S. was asked to read over the eight items and to familiarize himself with their locations. The sheet was then turned face down as four memory set words were presented one at a time printed on cards. The sheet was turned up and J.S. was asked to point to the items he had just seen in the correct order. Two different memory sets were used for each sheet of eight items, and nine different sheets were used. In terms of correct items, J.S. scored an average of 3.8 items correct out of four. In terms of order recall, he recalled only 5 out of the 18 sets in the correct order. Since the recall of four items in their correct order is well within the memory span of most normal subjects, J.S.'s performance for order recall is obviously impaired. However, it was felt that this task was not optimal for testing J.S.'s recall of order information since recall was dependent on a search for the memory set items through all the items on the sheet. The time involved in locating the correct items may have caused performance to be decreased beyond what it may have been if tested at a shorter delay. Also, while in the process of searching for the next item in the presentation order, it would have been possible to come across one or more of the other items in the memory set, resulting in some confusion between the input order and the order in which items were encountered during search. Thus, a second procedure was adopted that tested solely for the retention of order information and which did not involve search through a set of possible items.

Method

Subjects. Besides J.S., six normal subjects served as controls. These subjects were Johns Hopkins University students who received $3.00/hr for their participation.

Procedure. The procedure was adapted from that used by Locke and Deck (1978) for the recall of pictured objects. The memory sets consisted of three, four, five or six concrete nouns typed on 3 × 5-in. cards. The memory sets included the concrete nouns used in Experiment II, as well as additional concrete nouns of middle to high frequency. The words in a set were presented one at a time and laid face down in a row in front of the subjects. The subjects were given approximately 2 sec to view each item. Two seconds following the final word, a probe item was presented on a card. The subject had to turn over the matching item from the memory set in front of him.

There were 24 sets of three words, 24 sets of four words, 25 sets of five words, and 24 sets of six words. For each memory set, each serial position was probed equally often. All subjects saw the memory sets in order of increasing number of items per set.

Results

Performance for the normal subjects is shown in Table 5. Few errors were made on the sets of size 3 and 4, while fairly many errors were made on the sets of size 5 and 6. For the sets of size 5 and 6, a serial position effect was evident, with the first and last items having the best recall. The next to the last item appeared to be recalled the worst.

The results for J.S. in terns of percentage correct for each serial position are shown in Table 6. For memory sets of three items, J.S.'s performance was nearly perfect as he made only one error on the first 14 trials. Testing of the sets of size 3 was discontinued after this point since J.S. appeared quite bored with the task. Performance on the sets of four items showed a considerable decline as he made six errors out of the 24 trials. Performance on the sets of 5 and 6 items was worse than that on the 4's and considerably worse than that of the normal

TABLE 5
PERCENT ERRORS BY SERIAL POSITION FOR NORMAL CONTROLS, EXPERIMENT III
($n = 6$)

	Serial position						
Set size	1	2	3	4	5	6	Mean
3	0	2	0				0.7
4	3	3	6	0			3.0
5	0	13	17	17	3		10.0
6	4	13	21	29	38	4	18.2

TABLE 6
PERCENT ERRORS BY SERIAL POSITION FOR J.S., EXPERIMENT III

	Serial Position						
Set Size	1	2	3	4	5	6	Mean
3	0	0	17				5.6
4	17	33	33	17			25.0
5	0	40	40	60	20		32.0
6	0	100	0	50	50	0	33.3

subjects. For all the memory sets of size greater than 3, a serial position effect was obtained with many more errors occurring on the middle positions than on the first or last position, except for the second position for the sets of size 6. An explanation for this exception will be offered in the discussion.

Discussion

Although J.S.'s performance on the recognition task for memory sets of four concrete nouns was nearly as good as that for the normal subjects, his recall of the order of four items was quite impaired relative to that of the normal subjects. In the course of testing, J.S. made it evident that he was aware of his limitations in the recall of order information. Although he seemed to feel that the recall for the sets of three items was very easy and boring, as soon as the experimenter switched to the four item sets he said, "Now we've got trouble." Throughout the testing of the larger memory sets he attempted to indicate to the tester the type of strategy he was using to recall the items. For the sets of four items, he indicated that he tried to remember the first and last items. If the probe was not one of these items, he would select at random between the two middle items, and as he put it, his performance on the middle two items would be "50 percent." Although his performance for the center two items was not quite at chance, it was not much better. For the sets of five and six items, he again indicated he tried to remember the first and last items, but also tried to remember one of the center items. The results for the sets of size 6 support his explanation of his strategy. From the pattern of results, and from his comments, it appears that J.S. could retain two and sometimes three items in their proper order (in terms of first, last, and middle positions) without recourse to rehearsal. For the normal subjects who could augment memory with rehearsal, the order of four items was retained very well, and performance on the sets of five and six items was considerably better than that of J.S.

GENERAL DISCUSSION

These experiments examined short-term memory performance in the absence of phonemic recoding, looking at the alternate types of coding used and the overall level of performance possible with these alternate codes. As demonstrated in Experiment I, a visual code appeared to be sufficient for the retention of a single letter for up to 3 sec. Moreover, J.S. could identify two nonidentical letters as members of the same category even though he could not generate the name for these letters. Thus, he must have been able to code the letters at some more abstract level in order to perform the name match trials. For the retention of sets of four words, studied in Experiment II, it was evident that when a visual code could be supplemented by a rich semantic code, recognition performance was not impaired. However, when the words were relatively empty of semantic content, the use of a visual code was not sufficient for a high level of performance.

In Experiment III, it was found that even for items that could be coded both visually and semantically, such codes were not sufficient to retain order information for the sets of four items. Thus, it would appear that phonemic coding and rehearsal play an important role in the retention of order information. To the extent that J.S. could retain order information, it seemed that he relied on the use of a tag indicating that an item was first, last, or in the middle, rather than retaining some kind of record of the items in their proper order.

Thus, a phonemic code, though not the only type of code employed in a verbal short-term memory task appears to aid in the retention of items with minimal semantic content and in the retention of order information. These properties of a phonemic code seem relevant not only in short-term memory tasks, but also in reading comprehension and speech production. Several studies have demonstrated that one can access the semantic entry for a visually presented word visually (Kleiman, 1975; Shulman, Hornak, & Sanders, 1978; Slowiacezk & Clifton, 1980). However, comprehending an entire sentence is impaired by inhibiting phonological encoding (Kleiman, 1975). The impairment is seen most clearly in long or syntactically complex sentences (Hardyck & Petrinovich, 1970; Baddeley & Hitch, 1974). In such sentences, early items in the sentence may have to be retained briefly until later elements have been read which allow for a semantic interpretation of the early items. If the order of the words which must be retained is important and if these words include function words, then the results from the present studies would suggest that a phonemic memory code would be more advantageous than a visual code.

Although J.S.'s comprehension of single visually presented words is excellent, we do have some evidence that his reading performance may be impaired for long sentences. On a visual presentation of the Token Test (DeRenzi & Vignolo, 1962) his performance was nearly perfect for the short sentences (subtests I–III). For the long, but not syntactically complex sentences (subtest IV) and for the syntactically complex sentences (subtest V), his performance fell to below 50% correct. We are currently investigating whether his reading comprehension difficulties can be attributed to his deficit in phonological coding.

It has also been suggested that there is an equivalence between auditory–verbal short-term memory and the response buffer used for preplanning sequences of speech (Ellis, 1979). Since both auditory–verbal short-term memory and the response buffer rely on phonemic coding, a phonological deficit which impairs the retention of order information and function words might contribute to the paragrammatic speech seen in J.S. (see Caramazza et al., in preparation for further discussion of this point).

While the short-term memory deficits of J.S. can be seen as resulting from an inability to phonologically code and rehearse verbal items, it is not the case that all short-term memory deficits in aphasia result from the same impairment. Many other researchers have reported short-term memory deficits in aphasic patients, and some have ascribed these deficits to an inability to phonologically code and rehearse the items (Goodglass et al., 1970). However, other researchers have documented short-term memory deficits arising from other sources. For example, Warrington and Shallice (1969), and Caramazza, Basili, Koller, and Berndt (in press) have presented case studies of patients classified as conduction aphasics who show severely impaired short-term memory performance. However, in these patients the decrement appears to result from a capacity limitation rather than from an inability to phonologically code. Also, Locke and Deck (1978) examined a mixed group of anterior and posterior patients and found a low level of performance on memory for serial position of pictured objects even when the subjects could easily generate the name of the object. Although the ability to name objects does not necessarily imply an ability to form a smooth articulatory loop for rehearsing a set of items, their results do suggest that the memory impairment was not due to an inability to obtain a phonological representation for the items.

In order to make claims about the source of a short-term memory deficit in an aphasic patient, it would seem important to have information about the patient's performance on a number of other tasks in order that possible sources of the decrement might be elucidated. Performance could be impaired because of an inability to phonologically code, but also because of difficulty in articulation, impaired access to semantic representations, impaired visual processing of words, or a number of other factors. Having data on the patient's performance on tasks other than memory tasks would help to narrow the set of plausible causes. It is also helpful when trying to deduce the source of a memory impairment to look at memory performance in terms of the type of coding a patient might be using, as is done in Experiments I and II, to determine what resources a patient might fall back on if one type of coding has been lost.

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