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APHASIA AND MEMORY FOR TEMPORAL ORDER

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APHASIA AND MEMORY FOR TEMPORAL ORDER

by

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Abstract

APHASIA AND MEMORY FOR TEMPORAL ORDER

by

Hannah R. Amitai

Advisor: Professor J. R. Tweedy

Aphasic adults were compared to age-matched controls and young adults on tasks of short-term order memory. Subjects were presented with four-item strings of pictures followed by immediate probed recall. Subjects responded with the ordinal position of the probe item in the preceding string. To assess the possibility of facilitation of temporal-order recall by providing concomitant spatial information, two presentation formats were employed. One provided explicit spatial cues, and one displayed each item in the string in the same position. To assess the effect of changes in the nameability of the stimulus materials, recognizable and nameable, as well as meaningless nonsense figures were used. Response distributions at each input position, reflecting accuracy and error magnitude are presented.

Results are discussed in the context of current item and order models of short-term retention.

Overall accuracy levels of aphasics were impaired relative to controls and young adults, but the aphasics' serial position functions demonstrated enhanced recency, limited to the last item in the string, where performance statistically equivalent to normals was observed. Those portions of the serial position function most dependent upon phonological coding and rehearsal, the beginning and middle portions, were depressed relative to normals. The aphasics' recall of the most recent item was apparently mediated by the application of an ordinal retrieval strategy base to an unstable visual code. There were no significant age differences between the matched controls and young adults. Patterns of information loss for all groups were consistent with those predicted by the perturbation model (Lee and Estes, 1981).

Aphasics' sensitivity to changes in the nameability of stimulus materials was reduced relative to the normal subjects tested. This sensitivity was only very weakly related to the patients' confrontation naming skill. For both the easy-to-label and difficult-to-label stimuli,

the aphasics performance was similar to that of normals under conditions of acoustic similarity.

Additional spatial information at input flattened the serial position curve for both groups but provided no overall benefit; however, error distributions at each input position revealed a slight facilitation of performance on the part of the aphasics when the easy-to-label stimuli were presented sequentially in a clockwise pattern.

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Short-term temporal order information usually cannot be acquired or maintained at normal levels in the absence of phonological coding and rehearsal (Paivio, 1971; Healy, 1974,1975; Drewnowski, 1980). Dependence upon an auditory-verbal code occurs not only for linguistic stimuli such as letters or words but extends to visual nonlinguistic stimuli such as pictures and shapes, as well as to stimuli of other input modalities. Consequently, the acquisition of short-term sequences is particularly sensitive to linguistic and attentional dysfunction.

Since most aphasics, regardless of diagnostic classification, exhibit some naming or rehearsal impairment, their performance on short-term memory paradigms is disrupted. These deficits have been interpreted in linguistic (Brewer, 1969) and attentional (Grober, 1984) terms. The combined effect of such linguistic and attentional changes disrupts the aphasic subject's acquisition of short-term order information more severely than item information (Albert, 1976; Locke & Deck, 1978; Caramazza, Basili, Koller & Berndt, 1982).

Given the fact that aphasics have limited access to the aforementioned verbal control processes, it should be possible to induce an alternate visuo-spatial strategy by the introduction of additional spatial information at input. Grober (1984) provided evidence for normal incidental recall of spatial location on the part of aphasic adults. Healy (1975) demonstrated that temporal-spatial coding is employed by normal subjects in the recall of the temporal sequences of spatial locations whenever vocalizations at input provide no useful information.

To test the possibility of spatial facilitation of temporal recall two spatial formats of presentation were used in this study. One presentation format systematically provided additional spatial information at input by presenting each of the stimuli of a trial in a different spatial location moving in a clockwise direction on the display screen. The other presentation format did not provide additional spatial information at input. Each of the stimuli was presented in the same spatial location.

For nonaphasic subjects, changes in the nameability of the stimulus material should be reflected in overall recall levels, so that sequences composed of familiar easy-to-name stimuli should result in higher levels of recall and less reliance on available spatial information. Aphasic subjects should show a reduced sensitivity to such changes and a heightened sensitivity to spatial information. To assess the effect of changes in stimulus nameability, recognizable and nameable pictures as well as meaningless nonsense figures were used.

In addition to age-matched controls, a group of young adults were tested so as to evaluate effects of age on this task. Craik and Byrd (1982) suggested that the processing inefficiencies which occur with age result in part from a diminished attentional resource. This decline in mental energy would differentially affect the more effortful memorial tasks. Though the age-matched controls in this study had a mean age of 50 years and were therefore not a geriatric group, subtle changes in their performance relative to that of the younger adults (mean age 21.5 years) might be observed on the conditions utilizing unfamiliar figures since these conditions would be the most effortful.

Memory for Order in Aphasia.

Linguistic and attentional limitations, as well as modality-specific memory impairments can disrupt the acquisition of short-term sequences. The performance of any one patient can be affected by more than one factor. Much of the evidence for impairment has been indirectly obtained from investigations focusing on other issues related to phonological coding and rehearsal function. Studies explicitly examining order memory in aphasia are few.

Most of the early work on order memory in aphasia focused on explaining the nature of the repetition impairment in conduction aphasia. For example, Tzortzis and Albert (1974) tested three conduction aphasics on a set of verbal span tasks using digits, letters and words. They observed that memory for order was disproportionately impaired when compared to memory for items, and concluded that the underlying deficit was one of ordering phonemes for output. In contrast, Strub and Gardner (1974) reported a disproportionate loss of short-term order information in the performance of the single conduction aphasic whom they studied, but they considered this to have resulted from a problem in the processing and ordering of phonemes on the input end.

Subsequently, Shallice and Warrington (1977) suggested that those conduction aphasics, whose spontaneous speech is without paraphasic errors and whose repetition of strings of frequent, familiar words is equivalent to their repetition of less-frequent multisyllabic words, actually have a defective auditory-verbal short-term memory. This subset of patients also demonstrates a deficit in the acquisition of short-term sequences (Caramazza, Basili, Koller & Berndt, 1982; Vallar & Baddeley, 1984).

Albert (1976) tested a large group of anterior and posterior aphasics on four-item lists and reported disproportionate loss of sequential information with no qualitative differences in performance between the anterior or posterior aphasics tested.

Locke and Deck (1978) reported that the use of individually-determined nameable pictures did not facilitate the acquisition of short-term order information in five aphasic adults, chosen solely on the basis of having a specific word-retrieval impairment. Results were consistent with the notion of a limited attentional capacity or a defective phonological store. They tested the aphasics on sequences of three nameable and three unnameable pictures. Pictures were presented in sequence, exposed for four seconds each, and then placed face-down in a left-to-right direction in front of the subject. The long exposure time of four seconds for each picture was equivalent to delayed recall, since increased exposure time places a burden on the subject to rehearse so as to maintain the order information. Immediately following the presentation of the third picture, the probe, a picture which matched one of the three face-down pictures, was presented. The subject had to turn over the picture which matched the probe. When pictures were nameable, the aphasics showed a primacy effect, suggesting the occurrence of rehearsal; however, middle position recall was reduced. When the pictures were unnameable, the aphasics did not show primacy, but middle position recall was increased. For the control subjects, the use of nameable pictures as stimuli potentiated recall of the first item without attenuating recall of the second. Thus, the use of nameable pictures did not facilitate the acquisition of short-term order information in these aphasic adults, thereby, demonstrating that even familiar, easy-to-name stimuli does not result in normal levels of recall of short-term sequence information in aphasic patients.

Spatial Information.

Since the acquisition of short-term sequences can be disrupted by many factors which affect phonological coding and rehearsal, it is not surprising that this deficit extends to aphasics of all classifications. Can any of these specific linguistic, attentional or memory impairments be bypassed by particular aphasic patients?

Evidence suggests that spatial information which is mediated by systems independent of those subserving phonological coding and voluntary rehearsal can be an appropriate platform for aphasics without significant right hemisphere damage. These patients are able to utilize spatial information as well as normal controls, provided effortful processing is not required (Grober, 1984). For example, if aphasics were to attempt to actively use spatial cues to maintain information while carrying-out other operations, such as temporally ordering pictures presented, performance would be disrupted. The spatial information must be incidentally acquired to be effective.

Grober (1984) found normal incidental recall of spatial location in aphasic adults, a task previously posited by Hasher and Zacks (1979) to be mediated by automatic processes. This is consistent with reports of above-chance incidental recall of the spatial locations of objects by normal adults (Mandler, Seegmiller, & Day, 1977), and by left-temporal lobectomy patients with intact right hippocampi (Smith & Milner, 1981).

Grober (1984) tested incidental memory for spatial position in ten aphasic adults. They were shown a series of ten cards with line-drawings of common objects placed in each of the four quadrants for a total of four per card. The only instructions were to remember the pictures. Following presentation of all ten cards, subjects were shown each of the forty pictures in sequence and asked to indicate in which quadrant it had originally appeared. Aphasics performed as well as normal controls on this task.

Aphasics can also substantially benefit from recurrent visuo-spatial displays provided during learning trials, apparently by constructing an internal spatial representation of the array (Cremonini, 1980; De Renzi, 1982; Smith, 1980). For example, Smith (1980) demonstrated that aphasic adults can apply temporally-ordered problem-solving procedures based on spatial relationships. Smith devised a spatial analogue to Luria's three-term series problems (e.g. "Olga is lighter than Kate, but darker than Sonia") in order to allow an independent evaluation of aphasics' logical ability which would not be confounded with elements of grammatical or linguistic competence. Under such conditions aphasic adults were able to reason inferentially by relying on spatial information with most constraints on their performance coming from limitations on memory rather than logical ability. Capacity limitations appeared to restrict an otherwise intact reasoning ability, by overtaxing the working memory system (Baddeley & Hitch 1974; Baddeley, 1976). This underscores the importance of providing aphasics with spatial information in a way that doesn't utilize attentional resources.

Item and Order Models of Short-Term Retention

Current theories of short-term retention distinguish between item and order information on the basis of several factors: (a) retention functions (b) serial position functions, and (c) the differential effects of phonemic similarity and category membership on each. Factors which affect performance include: (a) task characteristics, such as the number of items and speed of presentation; (b) subject characteristics, such as long-term knowledge, language competence, available capacity; and (c) task variables which make varying demands on memory processes. The performance of aphasics will be disrupted to the extent that normal performance depends on phonological coding, storage and retrieval of information or on the deployment of control processes such as voluntary rehearsal, since these processes utilize attentional capacity.

Perturbation model. Lee and Estes (1977, 1981) extended Estes' (1972) original synchrony model, proposing a hierarchic rather than a sequential organization for short-term memory. Both item and order errors were explained by means of a single mechanism in which item errors are subsidiary to order errors. According to this model, at input each item in a sequence becomes associated with multilevel control elements. The highest control element encodes the position of the trial within a sequence of trials, the next highest element encodes the position of the segment within the trial and the most local element encodes the position of the item within the segment.

Though trial structures varied, a typical trial consisted of input strings of twelve items composed of letters and digits divided into three segments. Some trial structures utilized digits as the intervening material between groups of letters which were to be recalled, others utilized digits as well as letters as part of the set of items to be recalled. An example of the latter type used by Lee and Estes (1981) follows: J F B K ! 9 4 1 7 ! Q S R N. Each of the items within the segments were randomly selected from a set of eight letters or digits assigned to that segment; for example, segment one above was randomly chosen from the letters B

F G H J K L M; segment two from the numbers 1 through 8; segment three from the letters N P Q R S T X Y. Subjects learned the set of items assigned to each segment before testing began. Immediately following input of the last item, subjects were cued to report one of three segments or the entire sequence of twelve items. Subjects wrote their responses on cards with twelve boxes representing the twelve input positions. A sample response to the above trial might be: JFLK QSRN 4197. The L in the first segment would be scored as an item error, the transposition of segment 2 and 3 would be scored as a position error, and the 19 in 4197 would be scored as an order error.

According to the theory, at input the representation of each item is activated in secondary memory. This activated identity information including retrieved auditory and articulatory features becomes part of the content of primary memory as does the currently encoded positional and local contextual information such as whether the item is a repetition or an end item (Drewnowski, 1980).

If no interference occurs, voluntary rehearsal processes facilitate the encoding of item and order information independent of context. When interference attenuates such processes, as would be the case in aphasia, a message from each multilevel control element encoding time and place information is sent into a delay loop, a kind of covert rehearsal process replacing voluntary rehearsal. After each cycle, reactivation takes place and bonds between control elements and items are recoded. However, inevitable timing errors or perturbations occur. The level at which the desynchronization takes place determines the kind of information lost. Item errors result from (a) perturbations at the trial level such that items are moved into a different trial context, or (b) recoding errors which result in a generally uninterpretable position code. Order errors result from perturbations at the level of the relative position of an item within a trial.

Order information is more vulnerable than item information. Order errors are evident throughout the retention interval, even at the shortest delays and for short, four-item strings. In contrast, item information is at ceiling for four-item strings at the shortest delays (Healy, 1974; Drewnowski, 1980). For example, when subjects are tested immediately on a string of four letters, they typically confuse the order of some of the letters but not the identity of the letters. Item errors occur with longer delays between presentation and test. Order information is also lost at a faster rate as string length increases. Since loss of information continues during recall, partial report techniques are best for measuring maximum acquisition. While order information is lost at a faster rate than item information in normal subjects, this effect appears potentiated in aphasia.

Obtained response distributions reveal that the input position is the modal response position and that response frequencies decline for each successively more distant serial position. During any unit of time the probability is the same that a perturbed item will be reactivated either one position earlier or one position later than the input order except for the end positions which can perturb in only one direction and are therefore half as likely to suffer the loss of order information. This accounts for the bow-shaped serial position curve seen on tasks of temporal order recall and is reflected in the more rounded response distributions for items in middle positions (Lee & Estes, 1977; Drewnowski, 1980; Healy, 1974).

Aspects of performance reflecting the putative basic mechanisms underlying order memory such as the perturbation process postulated by Lee and Estes (1981), should remain as described for aphasic as well as normal subjects, since such mechanisms are not dependent on the deployment of controls processes. For example, response distributions at each input position, depicting information retained as reflected in accuracy and error patterns, should be qualitatively similar for normals and aphasics.

<u>Rehearsal processes</u>. Cunningham, Healy and Williams (1984) compared the effect of active versus passive repetition on the acquisition of short-term order information by using a modification of Hebb's (1961) procedure. The perturbation model of Lee and Estes (1981) could be modified to account for the results by postulating two kinds of processes similar to rehearsal: (a) a delay loop or reverbatory circuit (Estes, 1972), automatic in nature, taking place out of the subject's awareness and leaving no permanent trace; and (b) the control process of voluntary rehearsal (Shiffren, 1975).

It will be recalled that Hebb (1949) had originally proposed that the neural circuits underlying short-term recall were purely reverbatory, leaving no permanent representation. To test this assertion Hebb (1961) presented subjects with 24 nine-digit numbers every third of which was identical. Subjects had to immediately report each digit in sequence. Contrary to Hebb's expectations, performance was better on the repeated string, indicating that repetition had a more than transient effect on short-term recall.

Cunningham, Healy and Williams (1984) compared the effect of active versus passive rehearsal on the repetition effect by varying subject instructions within segments of a trial. Each trial consisted of two segments, each a four-letter string. The letters were always the same, only the order varied. On any given trial one of the segments was actively and the other passively rehearsed. Passive rehearsal consisted solely of saying aloud the name of the stimulus at presentation. Active rehearsal consisted of a recall test similar to the one Hebb employed or a precue that such a test would be forthcoming.

Repetition facilitated recall only under conditions of active rehearsal. To use Lee and Estes (1981) conceptual framework, voluntary rehearsal permitted elaborative associative bonds to form within the hierarchic memory structure, thereby inhibiting further perturbations (Estes, 1972), in effect "crystallizing the memory structure" (Cunningham, Healy, & Williams, 1984). Simply saying aloud the name of the stimulus at input, resulted only in a transient reverbatory trace.

Cunningham, Healy and Williams (1984) provided supportive evidence that passive rehearsal of the kind described by Lee and Estes leaves no lasting trace and is therefore consistent with Hebb's (1949) earlier notion of short-term memory as a purely reverbatory, transient store. This pattern of performance is also expected of aphasics in short-term order tasks, due to their compromised ability to employ voluntary rehearsal.

Attribute model. At a different level of analysis, Drewnowski (1980) developed an attribute model of memory span. In this view, items in a recall list are not encoded as units, rather attributes of the items representing intra- and interlist features are encoded and stored. Intraitem features include the familiarity or accessibility of the stimulus set and their auditory properties. Interitem features include vowel transitions and repetition events. At recall, the encoded attributes are consulted as cues according to the following priority: (a) identity (b) position tags (c) auditory features, specifically distinct vowel transitions (Drewnowski & Murdock, 1980) (d) repetition events. Therefore the capacity of short-term memory as measured by memory span is not fixed in terms of items (Miller, 1956), but varies according to the outcome of these multilevel processes reflecting the encoding, storage and retrieval of specific stimulus features (Drewnowski, 1980).

Consistent with the aforementioned findings regarding the heightened vulnerability of order information, the major constraint on performance was the acquisition of order rather than item information (Brown, 1958; Drewnowski, 1980). Ordinal and repetition tags made a minor contribution to acquisition; auditory features were the essential component as they provided the most persistent and interpretable effects. Distinctive auditory properties increased capacity (Drewnowski, 1980; Sperling & Speelman, 1970). Acoustic similarity was especially detrimental to the recall of items in their correct serial positions. The disruptive effects of acoustic similarity were reflected in more rounded response distributions at each input position. Aphasics' performance should be similar to normals' under conditions of acoustic similarity due to their difficulty in applying a distinct phonemic code to incoming stimuli (Goodglass, Deanes & Calderone, 1974).

In general, the temporal-order serial position functions reflect the usual concave-upward pattern. Consistent with the work of Healy (1974), Drewnowski (1980) reported that item information was at ceiling for four-item strings. However, increased string length resulted in increased bowing of the item, and particularly the order, serial position curve, as well as a greater dependence on the auditory trace. Decreased stimulus familiarity also resulted in increased bowing of both the item and order serial position curves. Drewnowski (1980) concluded that his findings could best be accounted for by the kinds of mechanisms postulated by Lee and Estes (1977, 1981). Under conditions of visual presentation and immediate probed recall, the recency portion of the aphasics' temporal-order serial position function should be enhanced, but the beginning and middle portion should be depressed. Under such conditions, recency is least dependent on auditory-verbal coding and rehearsal. Increased bowing of the serial position curve is also expected when aphasics recall strings of difficult-to-label, unfamiliar material. As was the case for normals, the aphasics' item information should be at ceiling when recalling four-item strings (Cermak & Tarlow, 1978).

Response distributions at each input position followed the pattern reported by Healy (1974) and Lee and Estes (1977): (a) The modal response was the input position with declining response frequencies for each successively more distant serial position, and (b) end-position functions were more pointed than those of middle positions, indicating higher end-position retention levels.

Alternate Short-Term Coding Strategies

As discussed, short-term order information must be actively maintained. The preferred means to this end appears to be an auditory-verbal strategy. However, a visuo-spatial alternative can be elicited given certain subject limitations, such as deafness and aphasia, or task features, such as specific presentation and response formats which require this kind of activity.

Baddeley and Lieberman (1980) proposed a hypothetical spatial working memory, the visuo-spatial analog of the articulatory loop and as such an alternate means of actively maintaining information in short-term memory. The essential feature of this hypothesized component of working memory is spatial. The image in this instance functions as an activity-based control process. This is consistent with the neuroanatomical dissociation between pattern discrimination on the one hand and locational information on the other which has been reported in comparative (Ungerleider & Mishkin, 1982; Pandya & Yeterian, 1984) and clinical studies (cited in Newcombe, 1985).

This "visuo-spatial scratch pad" is held to underlie mnemonic techniques such as interactive imagery and the method of loci. The effectiveness of these techniques is significantly disrupted by spatial tracking of visual or auditory stimuli. Maintenance of these visuo-spatial representations utilizes capacity; therefore effective use of a strategy of this kind necessitates the use of an overlearned image.

Hermelin (1972) found that deaf and autistic children used a spatial strategy when requested to remember three digits presented sequentially in one of three positions along a horizontal line. For example, if the serial presentation of the digits was 7-8-3, but the spatial positions of these digits when presented was 8 3 7, autistic and deaf children would recall 837 and normal children would recall 783. The temporal order is preferred by normal subjects employing a verbal control process. O'Connor and Hermelin (1973) determined that the use of a spatial strategy on the part of the deaf children was elective. In addition the type of strategy adopted appeared to be influenced by input modality: a visual input was more likely to result in a spatial coding strategy while an auditory input was more likely to result in a temporal coding strategy.

Healy (1975, 1977, 1982) found evidence for temporal-spatial pattern coding in short-term memory whenever what subjects said at stimulus input contained no helpful information, and the display provided explicit spatial information. A sample of some of her procedures follows.

If subjects were presented with the following four consonants in sequence each appearing in one of four horizontally arrayed cells on the screen: _ _ B _/ _ _ _ K / P _ _ _ / _ M _ _ ; and asked to write either the temporal or spatial order of presentation on a card with four horizontally-arrayed boxes, the correct temporal sequence would be BKPM; the correct spatial sequence would be PMBK. Serial position functions for temporal and spatial positions could then be analyzed under both temporal order and spatial order recall conditions.

Healy tested subjects under conditions of temporal-order recall or of spatial-order recall, but not both. If temporal-order recall was requested, the spatial format was held constant; if spatial-order recall was requested, the temporal format was held constant. In the example, under conditions of temporal-order recall the 3412 spatial format would remain the same, only the sequence of the consonants would vary. Sets of phonemically similar and dissimilar letters were used as stimuli since phonemic confusion errors would provide evidence of phonemic coding. The retention interval was varied by presenting a range of three to eighteen digits before test. Subsequently, the distractor task was varied to include processing the spatial positions of the intervening digits.

Healy (1977) suggested a temporal-spatial pattern code as an alternative to phonemic coding on short-term order tasks on the basis of the effect of specific temporal-spatial patterns on level of performance and of the differential effect of a verbal or spatial distractor task and of phonemically similar or dissimilar stimulus sets on performance. Under conditions of spatial-order recall, there was no difference in performance when phonemically similar or dissimilar stimulus sets were used, and there was a significant disruptive effect of the spatial distractor task which required that subjects write the spatial positions of intervening digits, but not of the verbal distractor task which required that subjects read the names of the intervening digits aloud.

Temporal-spatial pattern coding was most beneficial in the recall of four-item strings. Healy described this code as analogical rather than verbal. Temporal-spatial coding occurred: (a) for the recall of spatial locations presented successively whether reported in the standard four-cell horizontal array or in a four-by-four matrix of cells (b) for temporal-order recall when explicit spatial cues were available at input and these cues had to be remembered so as to follow a spatially-defined response format, such as the use of a four by four matrix.

Under conditions of spatial-order recall and temporal-order recall, plots of spatial positions resulted in flatter serial position curves than plots of temporal positions. Under conditions of spatial-order recall, analysis of the temporal positions yielded a significant primacy but no recency effect; that is the spatial location of the first letter presented was remembered best. Retention functions for spatial order recall were flatter than those for temporal order recall. The latter were steep, indicating a rapid loss of phonemic information when rehearsal is attenuated. Overall retention levels following spatial order recall were equivalent to those of temporal order recall at the shortest retention intervals.

Therefore, for aphasics with limited access to auditory-verbal coding, explicit spatial information at input, by permitting the reconstruction of the temporal sequence by means of a visuo-spatial strategy, should significantly improve performance compared to conditions providing no systematic spatial cues. For normals explicit spatial information at input should flatten the function, but not elicit a shift of strategy.

Berch (1979) reviewed the effect of varying presentation mode and response format on spatial and temporal coding. Both presenting stimuli in sequence in one spatial location and presenting stimuli in sequence in different but randomly chosen spatial locations facilitated temporal coding, whereas presenting stimuli in sequence but moving systematically in a left-to-right direction, facilitated the encoding of spatial information which could then bolster temporal-order recall (Hitch, 1974). In addition, presentation mode interacted with response mode. Presenting stimuli in sequence in one spatial location yielded consistent results across response modes, but presenting stimuli in sequence but moving systematically in a left-to-right direction favored a partial-report response mode. However, if the starting position is always the first position, presenting stimuli in a left-to-right direction has an inherent asymmetry which accounts for the superiority of partial-report: questions regarding the temporal position of an item can be answered on the basis of absolute item-location information. To accurately assess spatial facilitation of temporal-order recall using partial report techniques and not simply be measuring levels of spatial location information, it is necessary to vary the starting point of trials, though in so doing the memory burden for the subject may be increased.

Hypotheses

The performance of aphasic adults and matched controls on tasks of short-term order memory will be assessed. Acquisition of temporal order information as reflected in serial position functions, stimulus nameability and presentation format effects will be evaluated by means of within-subjects analyses. Response distributions at each input position reflecting accuracy and error patterns will be plotted. Results will be discussed in the context of current item and order models of short-term retention.

Acquisition of temporal order information will be assessed by presenting subjects with four-item strings followed by immediate probed recall. Item information will be provided to subjects by means of the probe: Subjects will be shown the target item and will be required to decide in which ordinal position this item was presented.

To test the possibility of spatial facilitation of temporal-order recall two presentation formats will be employed, one which provides additional spatial information at input, one which does not. To assess the effect of changes in the nameability of the stimulus materials, recognizable and nameable, as well as meaningless nonsense figures, will be used.

The performance of normal subjects should demonstrate the following pattern:

1. Changes in the nameability of the stimulus material should be reflected in overall recall levels. The use of stimuli to which a distinguishing verbal label can readily be applied is expected to significantly improve accuracy. Varying the spatial format of presentation, however, is not expected to facilitate recall, since subjects with unimpaired access to auditory-verbal coding overwhelmingly adopt such a strategy when recalling temporal sequences.

2. Serial position functions should reflect the usual concave-upward pattern obtained on tasks of temporal-order recall. Increased bowing of this curve is predicted in the recall of difficult-to-name, unfamiliar material, but only when stimuli are presented successively in a single spatial location. Explicit spatial information at input should flatten the function, regardless of stimulus type.

3. Response distributions at each input position should demonstrate the following pattern: (a) The modal response should be the input position with declining response frequencies for each successively more distant serial position, (b) more information should be retained on end-position stimuli than on those of the middle positions, and (c) more information should be retained on strings of readily-nameable stimuli than on difficult-to-name stimuli.

The performance of aphasic subjects is predicted to be different from that of the controls in several ways:

1. With visually presented nonlinguistic stimuli (not letters or words) and immediate probed-recall, the serial position function of aphasics should show normal recency. In contrast, recall of temporal information on items presented early in the sequence, dependent on

reliable phonological coding and rehearsal function, should be impaired.

2. As a result of impaired naming skill, the aphasic subjects' sensitivity to changes in the nameability of materials should be reduced: Recall levels and error distributions at each input position for both pictures and Kimura figures should be more nearly equivalent.

3. The addition of spatial information at input, by permitting the reconstruction of the temporal sequence by means of a visuo-spatial strategy, should significantly improve performance over that achieved when stimuli are presented successively in one spatial location.

4. Aspects of performance reflecting the basic mechanisms posited to underlie order memory such as the perturbation process postulated by Lee and Estes (1981), should remain as described for normal subjects, since such mechanisms are not dependent on the deployment of controls processes thought to be impaired in aphasics. Response distributions at each input position reflecting both accuracy and error magnitude, should be similar in shape to those of normal subjects. Information loss will be most severe in middle-positions and errors will reflect information retained in that choices will be

temporally close to the correct response. The differences between aphasics and normal subjects will be reflected by the other factors enumerated. Response distributions at each input position for strings of distinctly-nameable stimuli will look like the distributions of normals when recalling strings of acoustically similar stimuli.

Method

Subjects. Sixteen aphasic adults, 14 males and 2 females, ranging in age from 30 to 70 years with a mean age of 57 years were recruited from local stroke clubs and from VA and other hospital speech pathology outpatient services. All had left-sided lesions, 14 of vascular origin and 2 tumors. By self-report all but one were right-handed, none were converted from left-handedness. Education level varied from 4 to 21 years with a mean of 14 years. Mean interval since onset of aphasia was 3.9 years with a range of 1 mo. to 12.8 years. Two aphasics had a visual field defect: one a right upper quadrant hemianopsia and one a right homonymous hemianopsia. None of the patients suffered neglect. For 11 of the subjects classifications of aphasia type were made on the basis of subtests of the Boston Diagnostic Aphasia Examination (BDAE) and an interview by the current investigator and the patient's speech pathologist where applicable. For the remaining 5, the Western Aphasia Battery (WAB) or The Porch Index of Communicative Ability (PICA) and a speech and language clinician's report were used. The Boston Naming Test (BNT) was given to all but one subject who received instead the visual confrontation naming subtest of the BDAE given by a psychologist working with the same patient. Classifications were made by the investigator in conjunction with a supervising psychologist or the patient's speech and language clinician. Classifications were: 2 Wernicke, 2 Conduction, 9 Broca, 1 Mixed transcortical motor, 1 Anomic and 1 fluent who does not meet more specific criteria for type. The fluent aphasic demonstrated word-finding difficulty and mild literal and semantic paraphasia in spontaneous speech, relatively preserved confrontation naming, good comprehension, and normal prosody. Table 1 and Appendices 4 and 5 present further descriptive information.

The aphasic subjects were chosen on the basis of clinical characteristics. In most cases the CT scan readings, obtained from the medical chart, were not precisely localized as to depth and extent of involvement. This may account in part for the CT readings indicating involvement of the parietal region in two of the Broca'a aphasics and the temporal-parietal region in one other.

The subject with the temporal-parietal reading underwent a left fronto-temporal craniotomy with microdissection and clipping of a giant middle cerebral artery aneurysm and hematoma evacuation. There have

Table 1

Descriptive Information for the Sixteen Aphasic Patients: Aphasic Subgroup, Severity (S), Handedness (H), Age, Education, Time post-onset, Etiology, Right hemiparesis (RHP) +, Visual field defect (VFD) ++, CT Locus

Subgroup	S	H	Age	Ed Yrs	Onset Yrs:mo	Etiology	RHP+ VFD++	Locus
Wernicke								
W1	SEV	RT	57	18	4:10	Meningioma	++	L temporal-occipital
W2	MOD	RT	47	18	12:10	CVA	+	L temporal
Anomic								
A1	MLD	RT	57	17	1:3	CVA	+	Not Available (NA)
Broca								
B1	SEV	RT	49	16	6:0	CVA	+	L inferior frontal insular operculum
B2	SEV	RT	65	17	5:9	Aneurysm	++	L temporal-parietal
B3	MOD	RT	63	16	0:1	CVA		L parietal
B4	MOD	RT	30	16	1:6	Tumor		L fronto-temporal Third frontal convolution
B5	MOD	LT	59	12	0:9	CVA		L parietal
B6	MLD	RT	54	12	3:2	CVA	+	L middle cerebral artery
B7	MOD	RT	63	11	3:3	CVA	+	L middle cerebral artery
B8	MOD	RT	70	04	7:5	CVA		Angiogram: L internal carotid artery blocked
B9	MOD	RT	68	12	10:0	CVA	+	L frontal: L middle cerebral artery
Conduction								
C1	MOD	RT	61	12	4:8	Aneurysm		L temporal
C2	SEV	RT	51	21	7:9	CVA		L temporal-parietal
Mixed transcortical motor								
MTM1	MOD	RT	52	12	0:1	CVA	+	L frontal: L anterior communicating artery
Fluent								
F1	MLD	RT	66	16	2:2	CVA		L temporal-parietal

been cases of a Broca's aphasia with only posterior damage (Marshall, 1986), though this is unusual.

Seven other patients were screened, but rejected due to marked bilateral pathology, visual impairments, fully resolved aphasia, inability to maintain concentration, or inability to understand the task despite instruction.

Sixteen control subjects matched for age and educational level were recruited from adult evening undergraduate and graduate classes. Controls subjects, (15 females and 1 male) ranged in age from 37 years to 68 years with a mean of 50 years. Sixteen young adult college students (11 females and 5 males) ranging in age from 18 years to 26 years with a mean age of 21.5 years were also recruited so as to assess any effects of age.

One forty-subject control group was originally tested, and two groups, the 16 oldest, who most closely matched the aphasic subjects in age and the 16 youngest were selected for comparison purposes. Eight subjects were not included, so that there was a ten year difference between the youngest of the age-matched control group and the oldest of the young adult group. All subjects were comparable in education level.

<u>Apparatus</u>. A Commodore 64 computer was programmed to control a Kodak carousel projector and a Lafayette

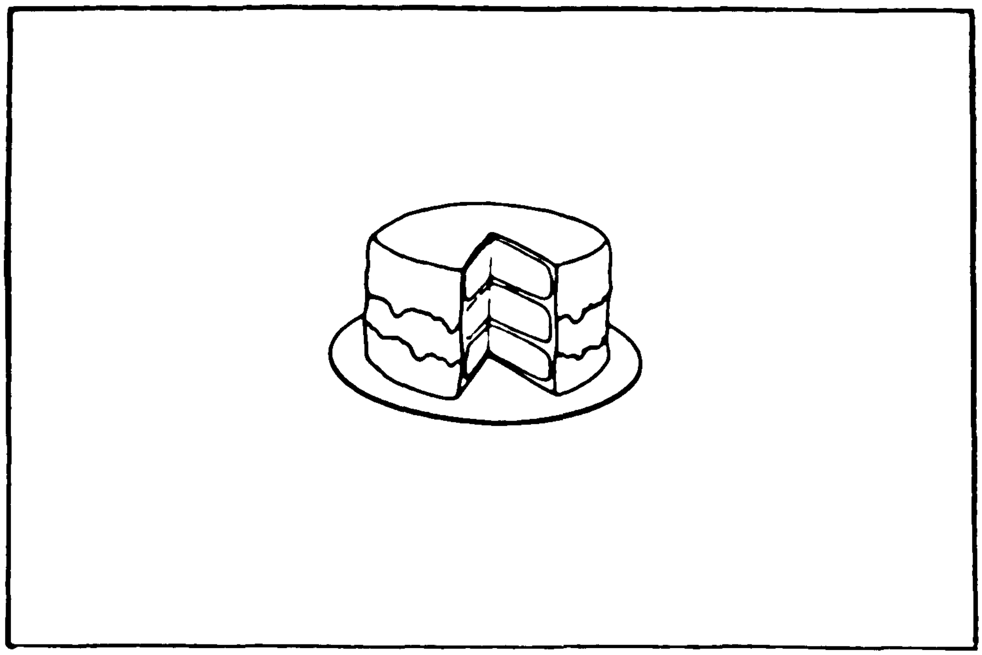
tachistoscope shutter through an electro-mechanical interface. Slides were displayed on a projection screen which was positioned approximately 1.5 meters directly in front of the subject. The illuminated portion of screen was approximately 50 cm by 40 cm, each image was approximately 12 cm in length. A response box, containing four horizontally arrayed keys centered in the middle and a fifth in the upper center was used to collect subject responses and response time, which were collected and analyzed by the computer.

Stimuli. Two kinds of stimulus materials in two kinds of presentation formats were employed. The two kinds of stimulus materials are: (a) pictures (Pic) in the form of line drawings standardized by Snodgrass and Vanderwart (1980), and (b) Kimura's recurrent figures (Kim) (1963). One-hundred-twenty-eight of the Pic stimuli were selected on the basis of factors that facilitate naming: familiarity, name agreement and image agreement. Those pictures grouped into a trial had phonemically distinct labels and spatially distinct configurations. The Kim stimuli, a set of 46 geometric and 46 nonsense figures some of which are repeated, were unfamiliar and more difficult to verbally label. All 92 originals and 36 repetitions of selected originals were used for a total of 128 figures equally divided between geometric and nonsense shapes. They were scaled with undergraduates, to determine the ease with which a distinguishing verbal label could be elicited and were grouped into trials and conditions to control for this factor. See Figure 1a for an illustration of the Pic stimuli, and Figure 1b for an illustration of the Kim geometric stimuli and Figure 2 for an illustration of the Kim nonsense stimuli.

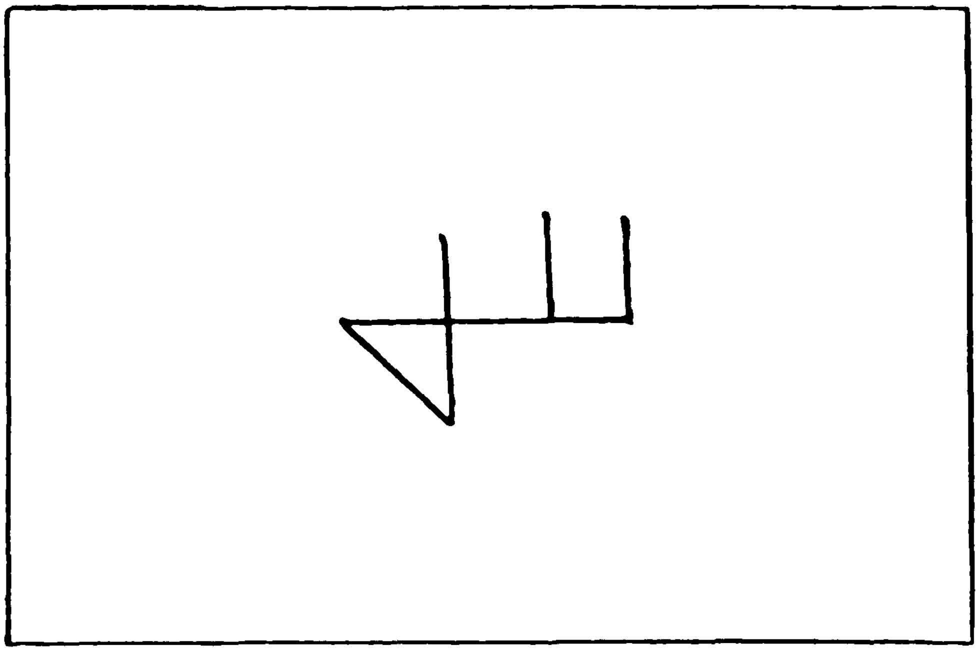
The two presentation formats were: (a) one in which the items of each trial were presented in sequence in a single spatial location or quadrant of the screen (Fix), and (b) one in which the items of each trial were presented in a clockwise sequence using each of the four quadrants (Mov). Each type of stimulus material was presented once in the Fix format and once in the Mov format for a total of four conditions: Picmov, Picfix, Kimmov, Kimfix. Figure 3 and Figure 4 illustrate the Mov and Fix presentation formats respectively.

Design. A trial consisted of a four-item string followed by the serial position probe which was always presented in the center of the screen. Each picture was presented for .5 seconds and each figure for 1 second. There was a 1 second interstimulus interval and a 1 second delay before the probe. There were 16 trials in each of 4 conditions blocked according to starting

Figure 1 An Illustration of the Pic (a) and Kim Geometric (b) Stimuli.

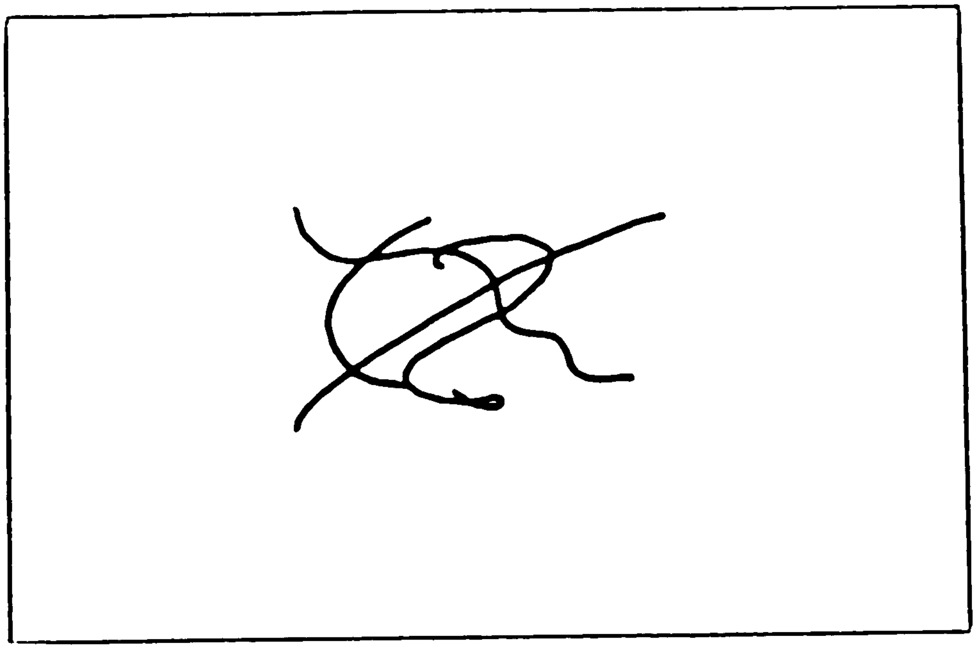


(a)

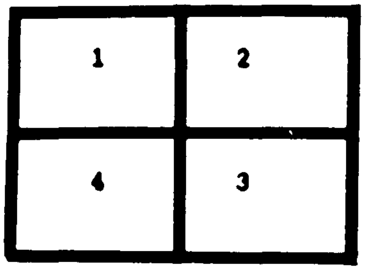


(b)

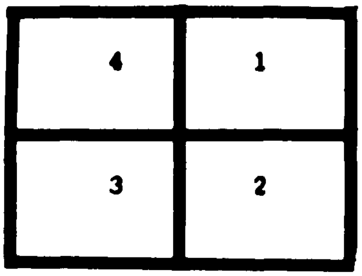
Figure 2 An illustration of the Kim Nonsense Stimuli.



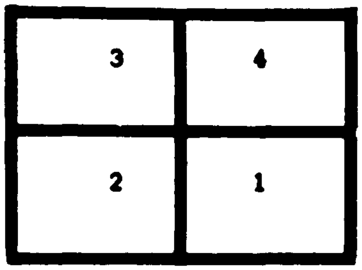
<u>Figure 3</u>. The presentation structure for each block of four trials in the Mov conditions. Numbers indicate temporal order of presentation within a trial.



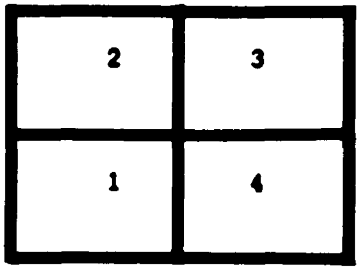
Trials 1 - 4



Trials 5 - 8

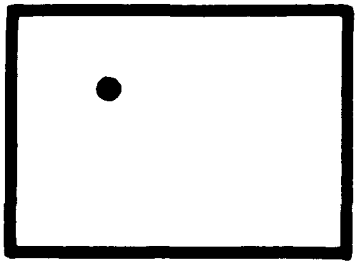


Trials 9 - 12

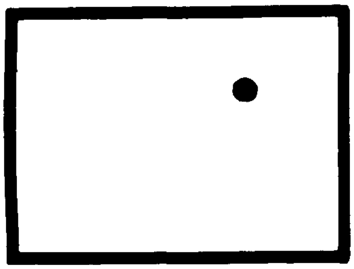


Trials 13 - 16

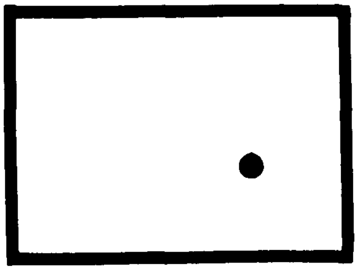
<u>Figure 4</u> The presentation structure for each block of four trials in the Fix conditions.



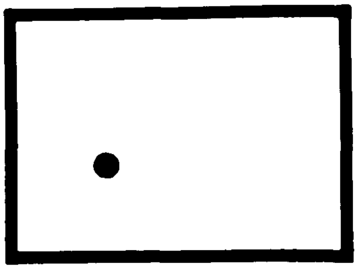
Trials 1 - 4



Trials 5 - 8



Trials 9 - 12



Trials 13 - 16

position into 4 sets of 4 trials. Starting positions rotated clockwise beginning in the upper left quadrant. For every set of 4 trials, each serial position was probed once in quasi-random order for a total of four times in each condition. There were two orders of presentation blocked according to which material is presented first, with subjects evenly divided between them.

Procedure. Each condition was preceded by 8 practice trials with feedback. Only those aphasics who were able to complete the practice trials successfully, either by responding correctly the first time or on an immediate repetition of specific practice trials were selected. When necessary, preliminary instructions were given to the aphasics using cards to demonstrate the task and provide practice; following this the 8 practice trials used for normal subjects were completed.

Subjects were tested individually. The session lasted approximately 60-75 minutes. Each subject was instructed to answer as quickly as possible without making errors. Subjects sat approximately 1.5 meters in front of the projection screen. The response box was positioned in front of them. Subjects pressed one of the four horizontally arrayed keys to indicate whether the probe item was seen first, second, third or fourth in the preceding string, and initiated the next trial by pressing the fifth button in the upper center of the response box.

Data Analysis. Three different mixed-design ANOVA were performed. Order of presentation and group were the between-subjects factors. Material (Pic or Kim), presentation format (Mov or Fix) and temporal position (1,2,3,4) were the within-subjects factors. The Greenhouse-Geisser (Winer, 1971) epsilon correction was used to obtain significance probabilities for the main effect of temporal position and for all interactions involving temporal position. All post hoc comparisons were done by means of the Newman-Kuels (Winer, 1971) procedure.

Accuracy, response time and relative deviation scores were the dependent variables. Response distributions for each input position reflecting information retained in accuracy and error patterns were plotted.

Deviation scores were obtained by tallying the deviation of each subject's responses from the correct response at each input position. For example, if the input position was the first, and the subject responded third, the deviation for that response would be two. The sum of the deviations at each input position was then divided by the sum one would expect on the basis of chance. For example, for each set of four responses at a given input position, chance responding would result in each of the four temporal positions being chosen once. This yields a chance deviation of six for the first and fourth input positions and of four for the second and third input positions.

Results

The results of three analyses are presented: (a) accuracy, (b) response time, and (c) error magnitude.

Accuracy was assessed using the number of correct responses out of a possible 16 for each of four conditions for an overall total of 64 possible correct. Response time was assessed by computing the median response time for the correct responses for each temporal position in each of the four conditions.

Deviation scores, sensitive to the amount of information retained as reflected in accuracy and error patterns, were obtained by tallying the deviation of each subject's responses at each input position from the correct response. The sum of the deviations was then divided by the sum one would expect on the basis of chance. Only the aphasics and control subjects deviation scores were analyzed, since the performance of the young adults was near ceiling.

Each temporal position was probed 4 times in each of the four conditions, when all were correct the median of these four response times was calculated. There were no speed-accuracy trade-offs for any of the groups, which indicates that subjects followed instructions which stressed maintaining a high level of accuracy.

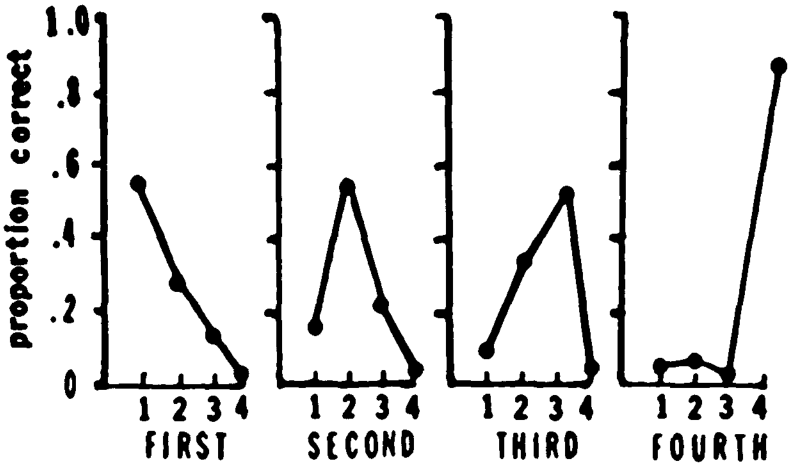
Table 2 presents the response distributions of aphasics, controls and young adults at each input position for each condition. Figures 5 through 8 plot the response distributions reflecting accuracy and error magnitude at each input position in each of the four experimental conditions for both aphasics and controls. As can be seen, when subjects made an error, they were more likely to select a response temporally close to the correct position. Sharp, steeply declining functions were associated with high levels of accuracy; the rounder, flatter pattern occurred in the recall of unfamiliar material, for the middle positions and for the aphasic subjects in most conditions of the experiment.

Table 2

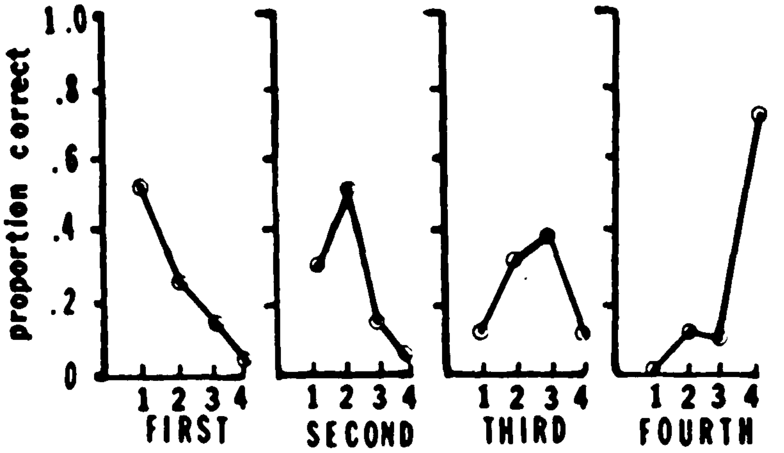
Aphasics (A), Controls (C), and Young Adults (Y) Distance Functions in terms of Percentages for each Temporal Position in the Picmov (PM), Picfix (PF), Kimmov (KM) and Kimfix (KF) Conditions

	Condition and Subject Class											
Position	PM			PF			KM			KF		
	A	C	Y	A	C	Y	A	C	Y	A	C	Y
FIRST												
1	58	92	91	50	89	95	36	70	78	48	83	80
2	27	5	6	27	9	5	36	11	14	30	9	9
3	14	3	2	17	2	0	22	19	8	13	8	6
4	1	0	1	6	0	0	6	0	0	9	0	5
SECOND												
1	17	5	0	27	6	3	20	8	5	19	27	6
2	55	84	91	53	88	94	41	67	61	50	56	74
3	22	11	3	14	6	2	36	23	33	23	12	20
4	6	0	6	6	0	1	3	2	1	8	5	0
THIRD												
1	10	5	3	13	2	1	8	10	8	13	17	13
2	34	14	10	34	15	8	28	14	3	34	22	8
3	53	80	84	39	78	89	55	70	84	39	52	73
4	3	1	3	14	5	2	9	6	5	14	9	6
FOURTH												
1	3	0	1	1	2	0	13	3	3	5	3	3
2	6	3	2	13	0	2	6	0	3	3	3	0
3	3	5	3	11	5	6	8	3	6	9	6	6
4	88	92	94	75	93	92	73	94	88	83	88	91

Figure 5. Accuracy and error magnitude functions of aphasics at each input position in the Picmov (a) and Picfix (b) conditions.

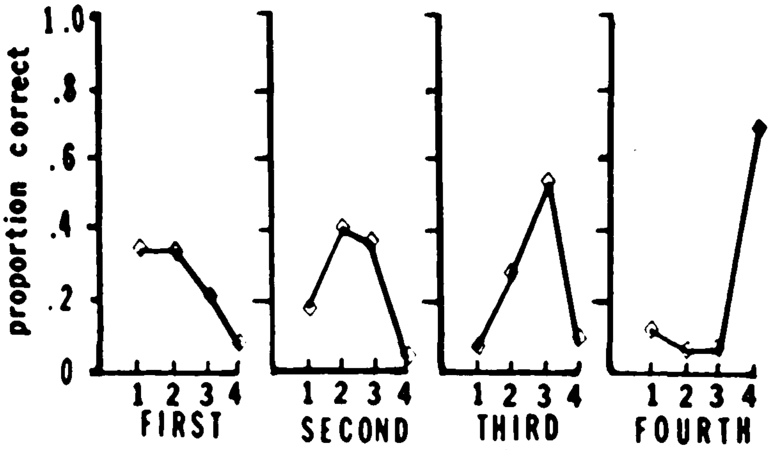

proportion correct
1.0
.8
.6
.4
.2
0
1 2 3 4
FIRST
1 2 3 4
SECOND
1 2 3 4
THIRD
1 2 3 4
FOURTH

(a)

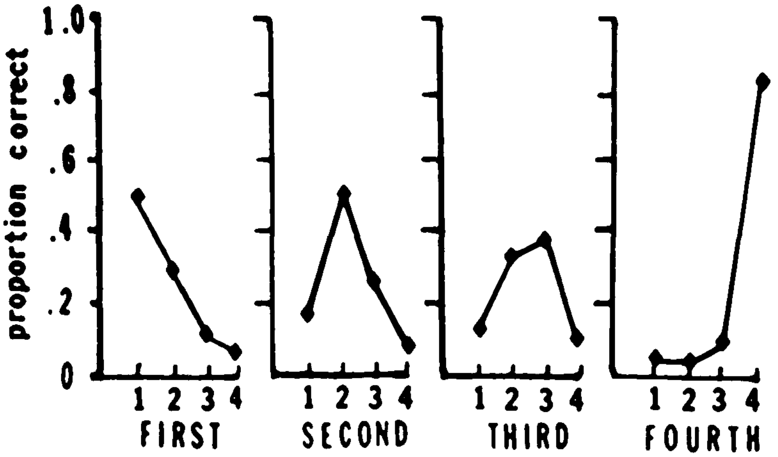

proportion correct
1.0
.8
.6
.4
.2
0
1 2 3 4
FIRST
1 2 3 4
SECOND
1 2 3 4
THIRD
1 2 3 4
FOURTH

(b)

<u>Figure 6</u>. Accuracy and error magnitude functions of aphasics at each input position in the Kimmov (a) and Kimfix (b) conditions.

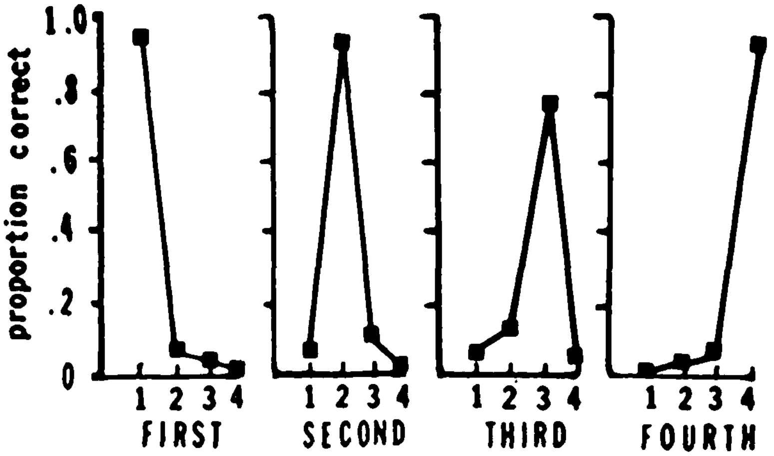

1.0
.8
.6
.4
.2
0
proportion correct
1 2 3 4
FIRST
1 2 3 4
SECOND
1 2 3 4
THIRD
1 2 3 4
FOURTH

(a)

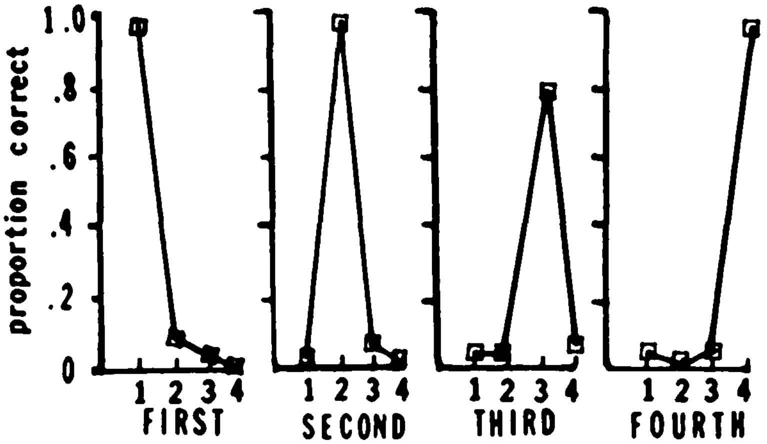

1.0
.8
.6
.4
.2
0
proportion correct
1 2 3 4
FIRST
1 2 3 4
SECOND
1 2 3 4
THIRD
1 2 3 4
FOURTH

(b)

Figure 7. Accuracy and error magnitude functions of controls at each input position in the Picmov (a) and Picfix (b) conditions.

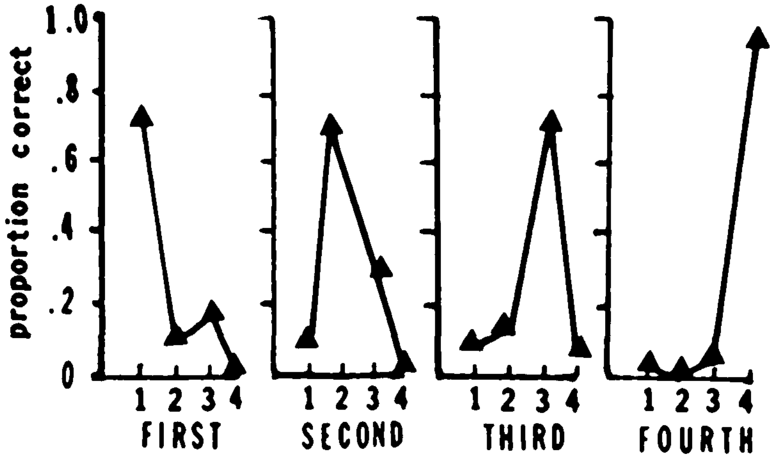

1.0
.8
.6
.4
.2
0
proportion correct
1 2 3 4
FIRST
1 2 3 4
SECOND
1 2 3 4
THIRD
1 2 3 4
FOURTH

(a)

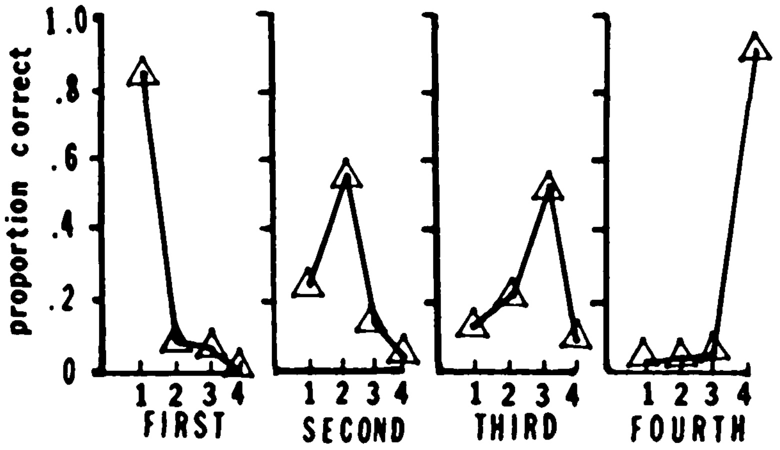

1.0
.8
.6
.4
.2
0
proportion correct
1 2 3 4
FIRST
1 2 3 4
SECOND
1 2 3 4
THIRD
1 2 3 4
FOURTH

(b)

Figure 8. Accuracy and error magnitude functions of controls at each input position in the Kimmov (a) and Kimfix (b) conditions.


proportion correct
1.0
.8
.6
.4
.2
0
1 2 3 4
FIRST
1 2 3 4
SECOND
1 2 3 4
THIRD
1 2 3 4
FOURTH

(a)


proportion correct
1.0
.8
.6
.4
.2
0
1 2 3 4
FIRST
1 2 3 4
SECOND
1 2 3 4
THIRD
1 2 3 4
FOURTH

(b)

Significant main effects. In general, the aphasics were impaired relative to controls on the accuracy, response time, and deviation score measures. The accuracy and response time scores of young adults and controls were equivalent on these overall measures as well as on all subsequent measures.

Analysis of the accuracy data yielded significant main effects for the group ($F(2,42) = 37.97$, $p < .0001$), material ($F(1,42) = 31.97$, $p < .0001$) and temporal position ($F(3,126) = 27.58$, $p < .0001$) factors. The main effect of the presentation format (Mov or Fix) was not significant nor was that of order (PK vs KP). Post hoc tests done by means of the Newman-Kuels procedure revealed that overall accuracy levels of aphasics were impaired relative to controls and young adults ($p = .01$); however, the scores of controls and young adults were equivalent both on this overall measure and on all subsequent accuracy measures. To more fully evaluate the effect of age on performance, an analysis correlating age with performance on each of the four conditions was done. No significant correlations were found ($p > .05$).

The analysis of response time data revealed main effects of group ($F(2,42) = 10.72$, $p = .0002$), and order of presentation ($F(1,42) = 4.79$, $p = .03$) that were significant, as were the material ($F(1,42) = 14.49$, $p = .0005$), and temporal position ($F(1.32,55.6) = 10.08$, $p = .001$) effects. The main effect of presentation format was not significant ($F < 1$). Post hoc tests revealed that the aphasics' response time was significantly longer than the controls or young adults ($p = .05$). As in the case of the accuracy data, the response time scores of controls and young adults did not differ from one another on this overall between-group comparison or on any subsequent comparisons.

Consistent with both the accuracy and response time results, the deviation score analysis yielded significant main effects for the group ($F(1,30) = 44.67$, $p < .0001$), material ($F(1,30) = 18.12$, $p = .0002$), and temporal position ($F(2.36,70.8) = 15.09$, $p < .0001$) factors. Post hoc tests revealed that the overall deviation scores for the Kim stimuli were higher than those for the Pic stimuli ($p = .01$), and the aphasics had higher deviation scores than controls ($p = .01$).

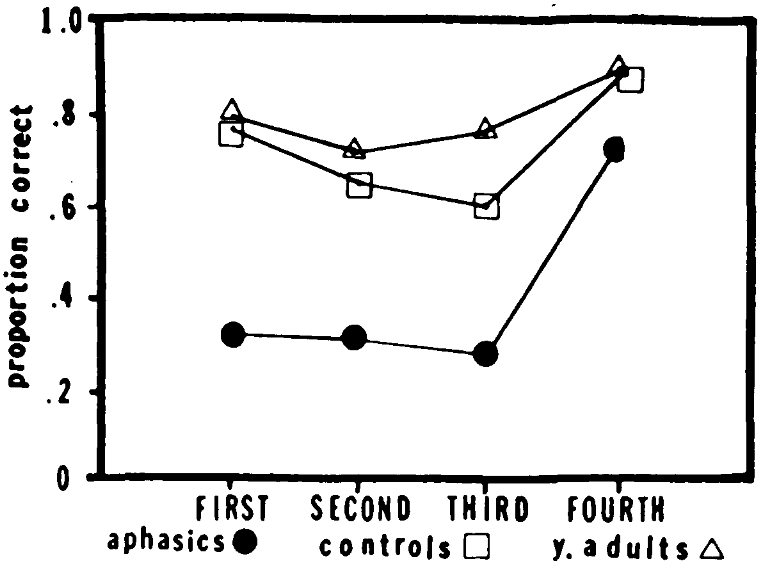
Serial position functions. The accuracy data revealed a selective sparing of performance on the most recent item for the aphasic subjects, but all other portions of the curve were depressed relative to normals. Both the response time and deviation score analyses yielded a bow-shaped curve for all groups.

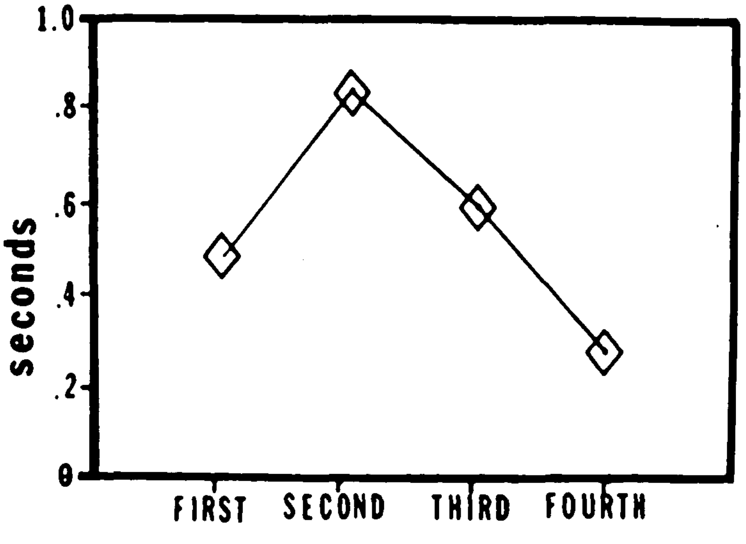
Figure 9a illustrates the significant accuracy temporal position by group interaction ($F(6,126) = 3.86$, $p = .002$). According to post hoc tests, the aphasics' serial position function demonstrated enhanced recency, so that recall of the last temporal position is statistically equivalent to that of the controls and young adults, but recall of the other portions of the curve was depressed ($p = .05$).

However, the overall response time serial position functions for aphasics, controls and young adults were similar; there was no significant interaction for group by temporal position. Figure 9b plots the response time serial position function. Unlike the accuracy analysis, the response time analysis demonstrated a primacy effect. In fact, according to post hoc tests all four serial positions were significantly different from one another ($p = .05$).

Figure 9a. Recall accuracy of temporal position judgment at each position for the three subject groups.

Figure 9b. Average median correct response time at each temporal position (collapsed over groups).


1.0
.8
.6
.4
.2
0
proportion correct
FIRST
SECOND
THIRD
FOURTH
aphasics ●
controls □
y. adults △


1.0
.8
.6
.4
.2
0
seconds
FIRST
SECOND
THIRD
FOURTH

Collapsed over order, a significant material by temporal position effect was obtained ($F(2.69,121) = 3,38$, $p = .02$). The serial position functions for both types of materials demonstrated a bow-shaped curve with significant primacy and recency effects. The separation in performance on the two types of materials was most prominent in position one, and got successively smaller with increasing recency.

As in the case of the response time results the deviation associated with each of the four temporal positions ($F(3,90) = 15.09$, $p < .0001$) followed a similar pattern in both aphasics and controls: there was no temporal position by group interaction. According to post hoc tests, the overall serial position function is symmetric and bow-shaped: The first and fourth positions were equivalent to each other and had lower deviation scores than the second and the third positions which were also equivalent to each other ($p = .05$). See Figures 5 through 8.

Consistent with the results of the deviation score analysis, a response utilization analysis, evaluating the frequency with which each of the four response alternatives was selected, demonstrated that aphasics chose the second more often than any other response overutilizing position two at the expense of position one.

Figure 10 plots the a posteriori success probability for each group at each position, corrected for nonuniform response selection (Berch, 1979). Since the young adults and controls had generally equally distributed responses, their serial position function changes little following correction; however, the aphasics' serial position function takes on the bowed shape which is consistent with the deviation score results.

Effects of stimulus nameability. The results of the accuracy and the deviation score analysis demonstrated the reduced sensitivity of aphasics to changes in the nameability of the stimulus materials. Only the performance of the controls and young adults was facilitated by the use of the Pic stimuli.

Figure 11a illustrates the material by group interaction observed in the accuracy analysis ($F(2,42) = 3.38$, $p = .04$). The material by temporal position by group interaction was not significant, but is plotted in Figure 12 to highlight the influence of material on the performance of each group. According to post hoc tests, aphasics' scores for the Pic and Kim stimuli were equivalent, while

Figure 10. Recall accuracy for the three subject groups at each temporal position corrected for nonuniform response utilization.

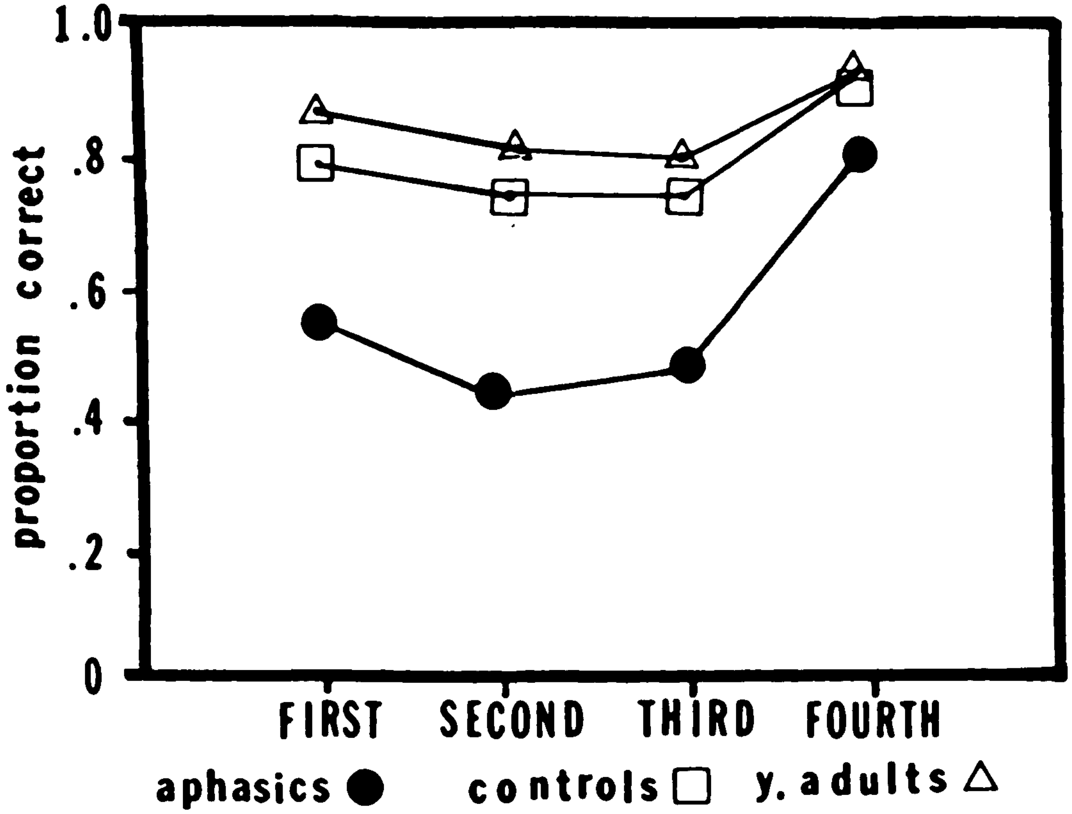
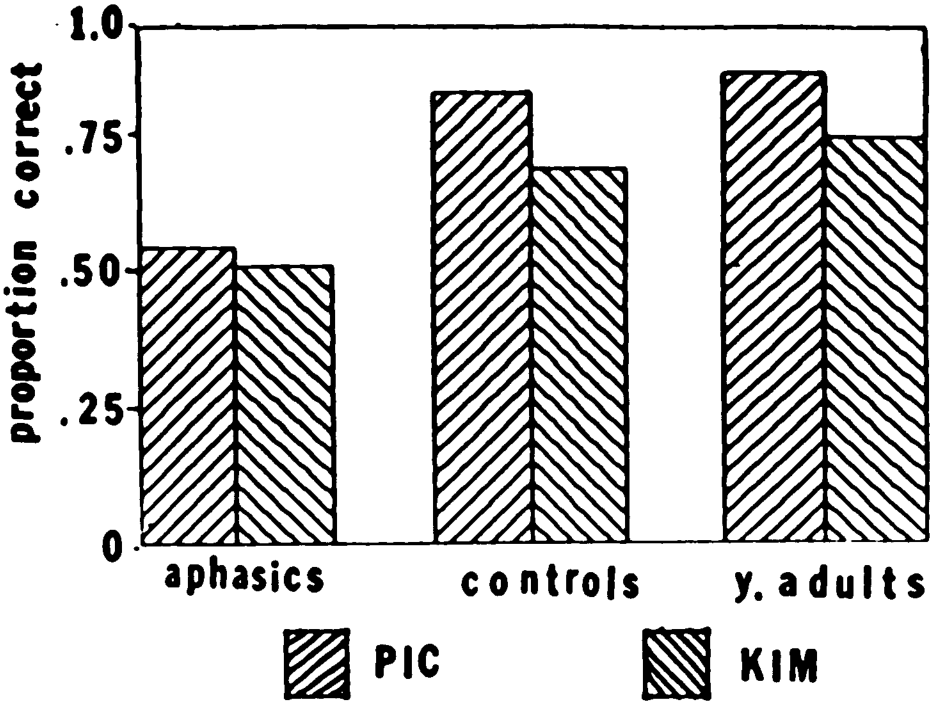
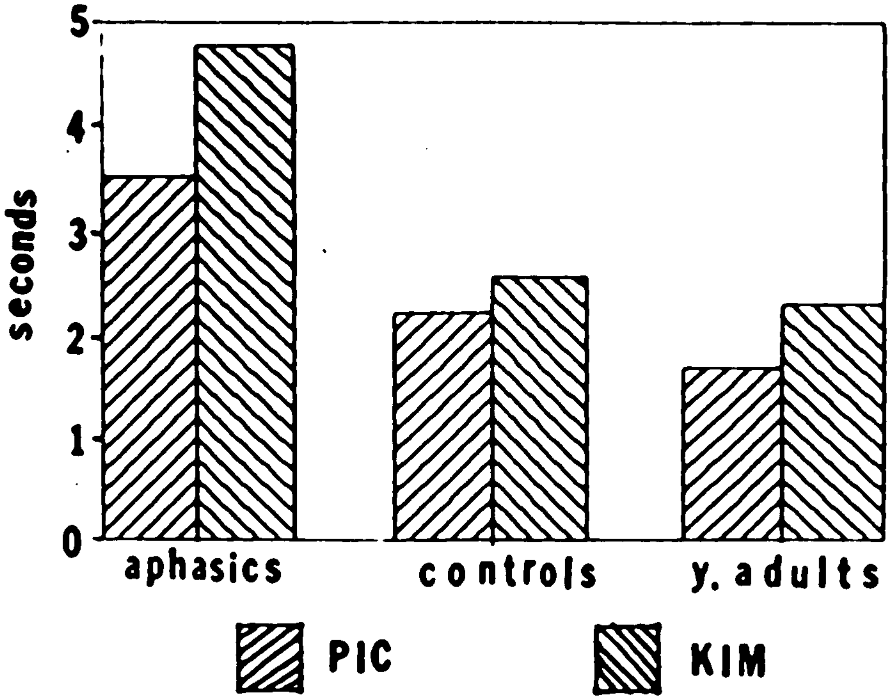

1.0
.8
.6
.4
.2
0
proportion correct
FIRST
SECOND
THIRD
FOURTH
aphasics ●
controls □
y. adults △

Figure 11. Recall accuracy (a) and average median correct response time (b) for the Pic and Kim stimuli for aphasics, controls and young adults.

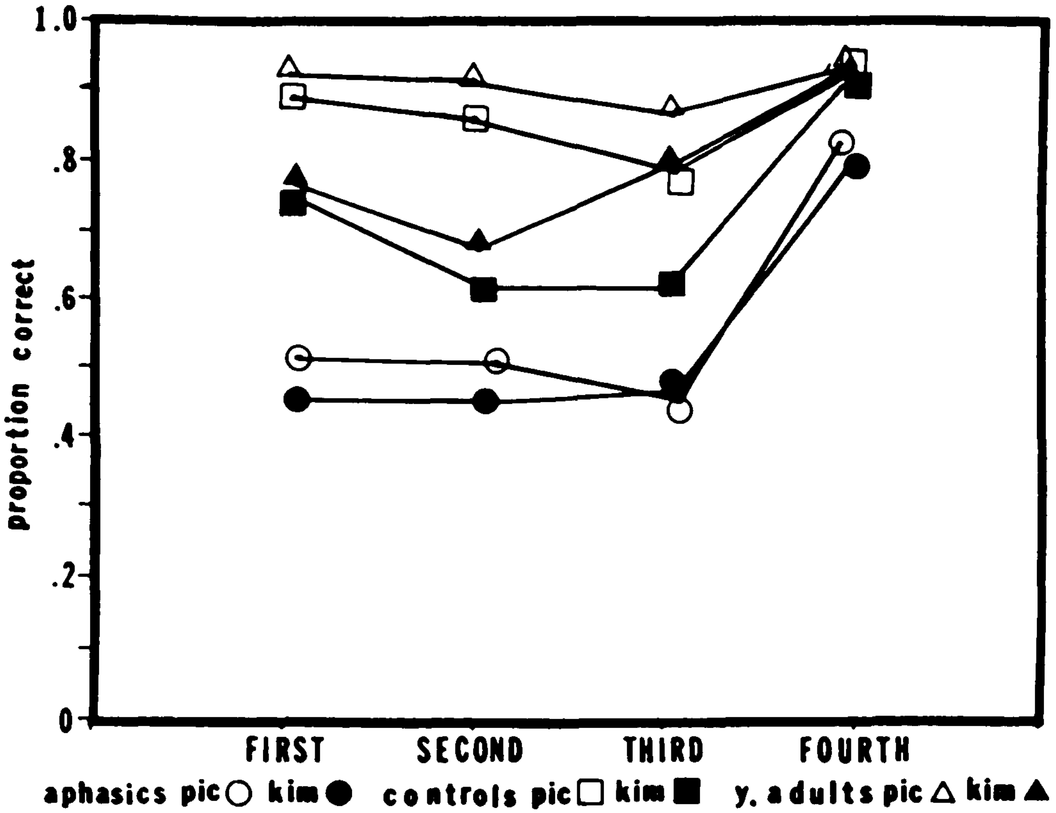

1.0
.75
.50
.25
0
proportion correct
aphasics
controls
y. adults
PIC
KIM

(a)


5
4
3
2
1
0
seconds
aphasics
controls
y. adults
PIC
KIM

(b)

Figure 12. Recall accuracy for the Pic and Kim stimuli at each temporal position for the three groups.


1.0
.8
.6
.4
.2
0
proportion correct
FIRST
SECOND
THIRD
FOURTH
aphasics pic○ kim●
controls pic□ kim■
y. adults pic△ kim▲

controls and young adults scored significantly higher on the Pic compared to the Kim stimuli (*p* = .05). Table 3 lists the percentages of correct responses.

In the deviation score analysis, the material by group interaction was significant (*F*(1,30) = 5.32, p < .03). Consistent with the accuracy results, post hoc tests demonstrated that the controls had significantly lower deviation scores for the Pic compared to Kim stimuli, but the aphasics did not show this facilitation (*p* = .05).

In the response time analysis, the material by group interaction was also significant (*F*(2,42) = 3,38, *p* = .04). See Figure 11b. According to post-hoc tests, the controls responded more quickly than the aphasics on the Pic (*p* = .05) and on the Kim stimuli (*p* = .01). In addition, both young and old controls responded faster to the Kim stimuli than the aphasics did to the Pic stimuli (*p* = .01).

Presentation format effects. The aphasics appeared to derive a slight benefit from the addition of spatial information at input, an effect not demonstrated in analyses of other dependent variables.

The deviation score analysis yielded a significant material by presentation format by group

Table 3

Aphasics, Controls, and Young Adults Percentages of Correct Responses by Condition

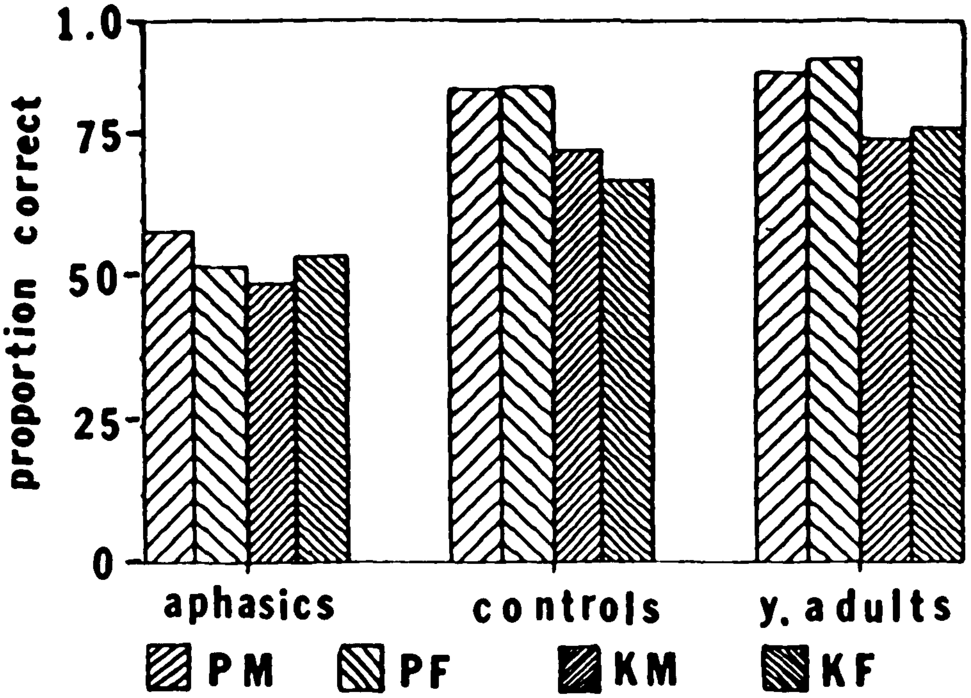
	Conditions			
Group	Picmov	Picfix	Kimmov	Kimfix
Aphasics	60	54	51	56
Controls	87	87	75	70
Young Adults	90	92	78	80

Significant differences: (Newman-Kuels, p = .05) Aphasics scores for the Pic and the Kim stimuli were equivalent. Controls and young adults scored higher on the Pic stimuli. There were no Mov or Fix presentation effects within materials. Aphasics and controls Kimfix scores were equivalent; all other scores of the aphasics were lower than those of the controls or young adults.

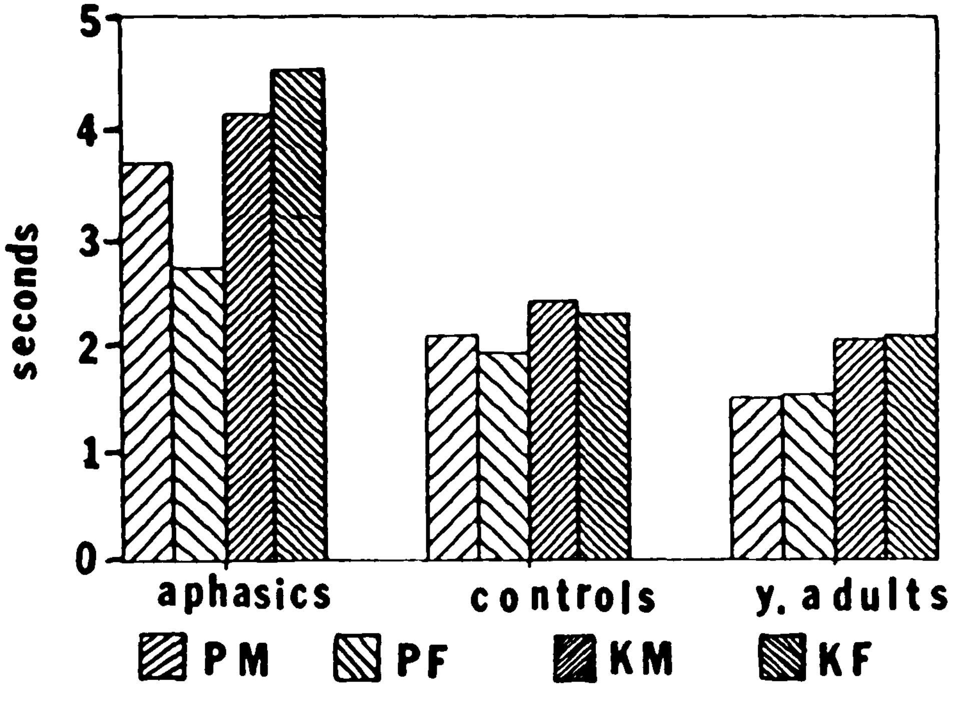
interaction ($F(1,30) = 7.71$, $p = .009$). The aphasics appeared to derive some benefit from the addition of spatial information at input. According to post hoc tests, in both Kimfix and Picfix conditions aphasics had greater deviation scores than the controls did in any of the four conditions ($p = .05$). However, post hoc tests revealed that in the Picmov condition the aphasics deviation score was statistically equivalent to that of the controls in the Kimfix and Kimmov conditions ($p = .05$). Therefore, instead of being worse than the controls on all conditions, the aphasics performance on the familiar, easy-to-name material under Mov presentation conditions approximated that of controls on the unfamiliar difficult-to-label material under both Mov and Fix presentation conditions. According to post hoc tests, and consistent with the accuracy results, the aphasics' deviation score in the Kimmov condition was greater than that of controls in the Kimmov, Picmov and Picfix conditions, but not greater than the controls deviation score in the Kimfix condition ($p = .05$).

In the accuracy analysis, inspection of the material by presentation format by group interaction ($F(2.42) = 3.23$, $p < .05$) depicted in Figure 13a also reveals a trend, though not significant, toward

Figure 13. Recall accuracy (a) and average median correct response time (b) for the Pic and Kim stimuli in the Mov (Picmov; Kimmov) and Fix (Picfix; Kimfix) presentation conditions for aphasics, controls and young adults.


1.0
75
50
25
0
proportion correct
aphasics
controls
y. adults
▨ PM
▨ PF
▨ KM
▨ KF

(a)


5
4
3
2
1
0
seconds
aphasics
controls
y. adults
▨ PM
▨ PF
▨ KM
▨ KF

(b)

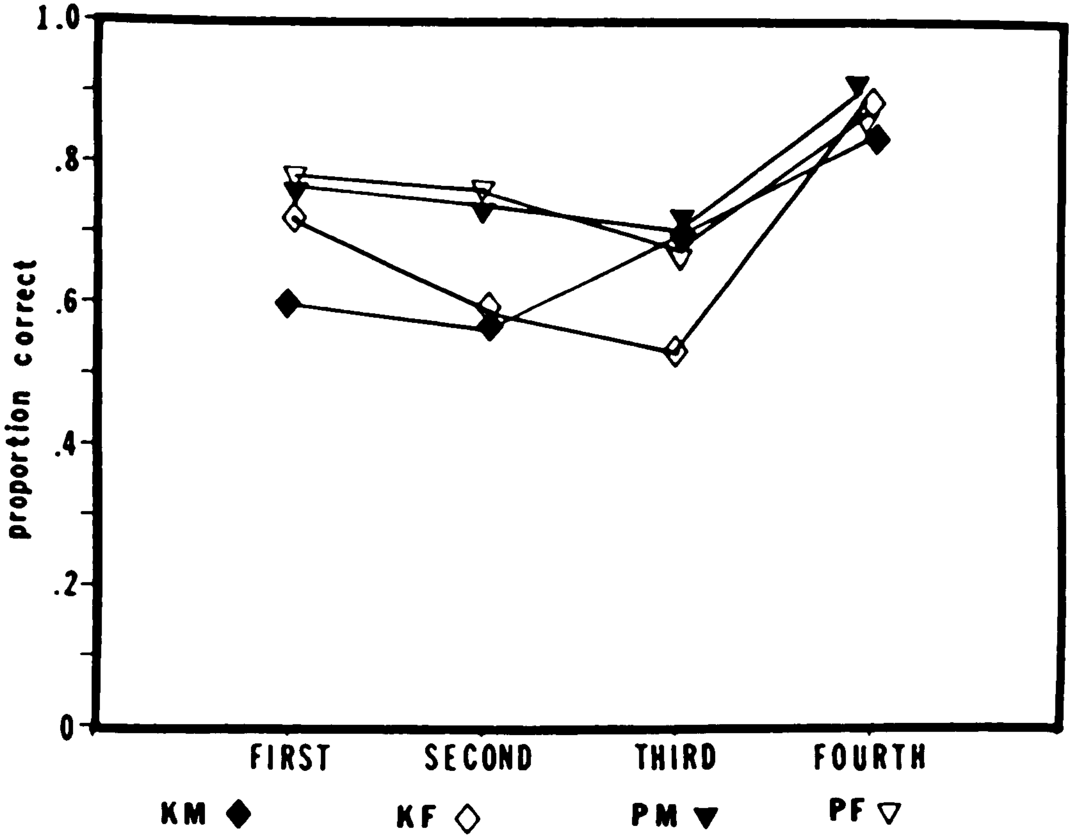
increased levels of recall in the Picmov condition on the part of the aphasics. According to post hoc tests, the control group and the aphasics had statistically equivalent accuracy levels only on the Kimfix condition ($p = .05$). All other differences remain as described for the material by group interaction.

The response time material by presentation format by group interaction ($F(2,42) = 3.65$, $p = .03$) was also significant. See Figure 13b. According to post hoc tests, in the Kimfix condition the aphasics took significantly longer to respond than in the Picfix condition ($p = .05$); also, in the Kimfix condition the aphasics' response time was significantly longer than that of the controls or young adults in any of the four conditions. In addition, post hoc tests revealed that the aphasics' response time in the Picfix condition was equivalent to that of the controls and the young adults; and that the aphasics' response time in the Picmov condition, was significantly longer than the response time of the young adults in the Picfix condition ($p = .05$); all other means were equivalent. The response time of the aphasics in the Kimmov condition was greater than that of the controls or young adults in any of the four conditions ($p = .05$), but no different than the response time of the aphasics in the Kimfix, Picmov or Picfix conditions. Since accuracy levels of aphasics were equivalent in all four conditions, the longer response times for the ordered recall of the Kim stimuli indicates the greater difficulty of such recall.

Higher-order serial position functions. For both the accuracy and the deviation analysis, all three groups followed a pattern similar to that reported for normal young adults by Drewnowski (1980) and Healy (1975, 1977, 1982): (a) increased bowing of the serial position curve for strings of unfamiliar material, and (b) a flattened serial position curve when additional spatial information was available at input, but no overall benefit to performance.

Figure 14 plots the material by presentation format by temporal position interaction ($F(3,126) = 3.68$, $p < .016$) for the accuracy data. All three groups, aphasics, controls and young adults, showed the increased bowing of the serial position curve expected in the temporally ordered recall of unfamiliar material under Fix presentation conditions (Kimfix condition), as well as a flattened serial position function when additional spatial information

Figure 14. Probed recall of temporal position collapsed over groups in the Picmov, Picfix, Kimmov and Kimfix conditions.


1.0
.8
.6
.4
.2
0
proportion correct
FIRST
SECOND
THIRD
FOURTH
KM ◆
KF ◇
PM ▼
PF ▽

was available at input (Kimmov and Picmov conditions), but according to post hoc tests this was significant only in the Kimmov condition ($p = .01$).

The controls and young adults recall of temporal position for the Pic stimuli was generally so high that the aforementioned patterns were masked. However, inspection of the serial position functions within materials reveals consistent crossovers between the functions representing performance on Kim and Pic stimuli under both Mov and Fix presentation conditions. In the Fix presentation conditions the third temporal position is the lowest, while the second is the lowest in the Mov presentation conditions. In effect the curve is shifted without any overall benefit to performance. A further illustration of this pattern is presented in Figure 15 and Figure 16 which plot the aphasics and controls serial position functions for each condition.

The pattern observed in the deviation score material by presentation format by temporal position interaction ($F(3,90) = 4.03$, $p = .01$) was also similar in both the aphasics and controls. As previously observed in the accuracy serial position functions, there was a shift in the shape of the curve when the Kim stimuli were presented in the Fix compared to the Mov presentation condition. Post hoc

Figure 15. Recall accuracy for aphasics and controls in the Picmov and Picfix conditions at each temporal position.

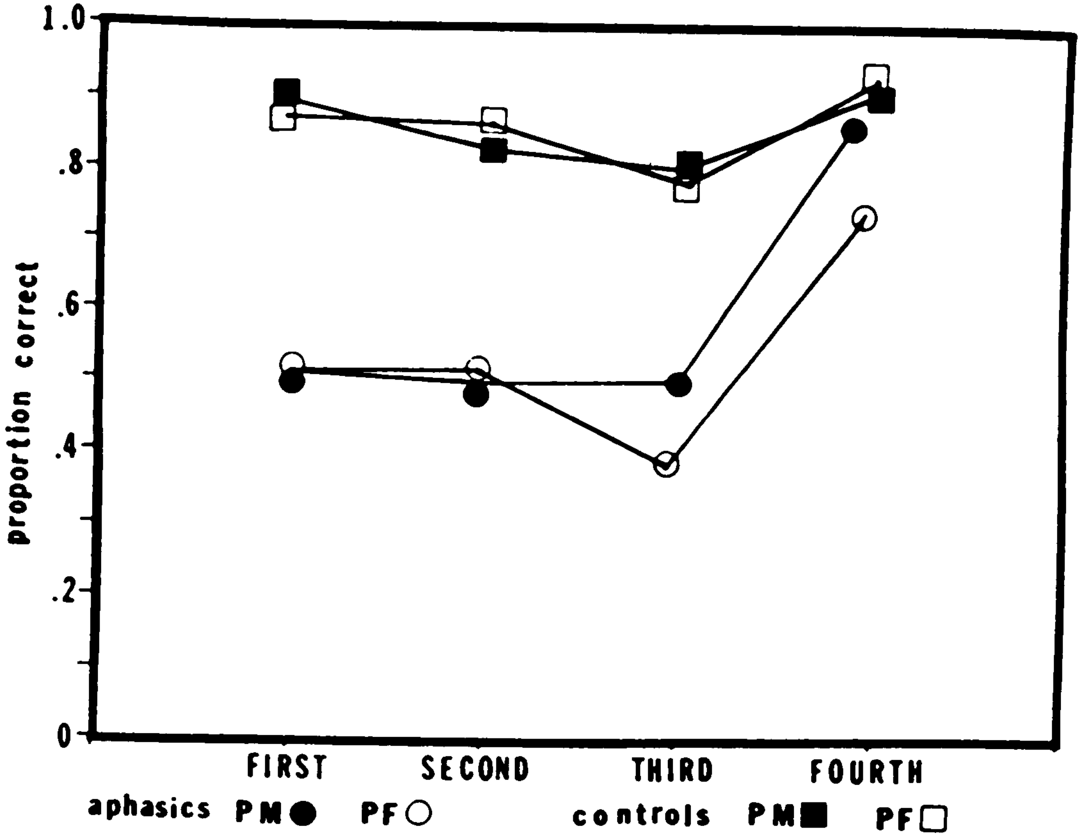
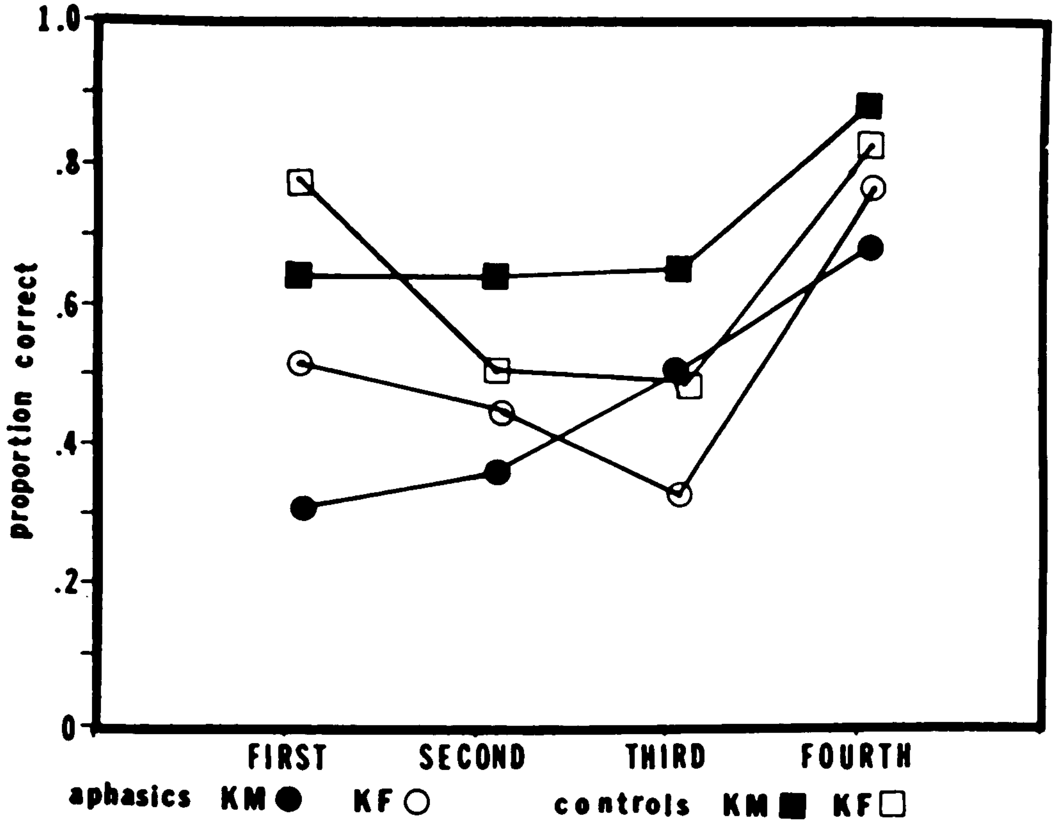

1.0
.8
.6
.4
.2
0
proportion correct
FIRST
SECOND
THIRD
FOURTH
aphasics PM ● PF ○
controls PM ■ PF □

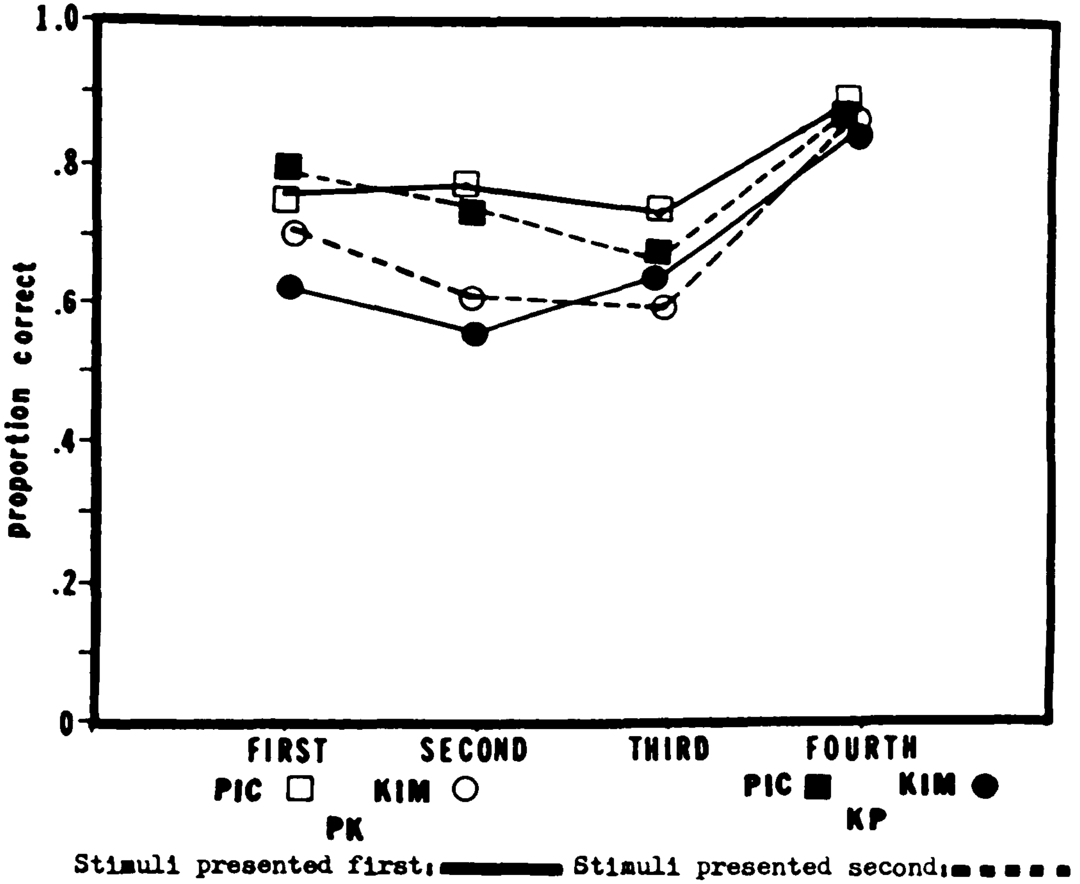
Figure 16. Probed recall of temporal position for aphasics and controls in the Kimmov and Kimfix conditions.


1.0
.8
.6
.4
.2
0
proportion correct
FIRST
SECOND
THIRD
FOURTH
aphasics KM ● KF ○
controls KM ■ KF □

tests showed the following differences: (a) In the Kimfix condition a bow-shaped pattern was seen with performance on the first and the fourth positions equivalent and significantly better than performance on the second and third positions (p = .01), (b) In the Kimmov condition the first and the second positions suffered the most information loss with performance on the third and the fourth positions equivalent to one another and significantly better than performance on the first and second (p = .01), and (c) In the conditions utilizing the Pic stimuli, all means were equivalent except the third had a higher deviation score than the fourth (p = .01).

Order effects. In the accuracy analysis, significant material by temporal position by order (PK vs KP) effect ($F(3,126) = 3.08$, $p < .04$) was obtained. Means plotted in Figure 17 reveal that ordered recall of pictures results in a more bow-shaped serial position curve for all groups when the Pic stimuli are presented after the Kim stimuli (p = .05). Though not significant, a similar trend can be observed in the ordered recall of the Kim stimuli. Such increased bowing appears to indicate the stabilization of a strategy involving the phonological coding and rehearsal pattern optimal for temporal-order recall (Healy, 1975, 1977).

Figure 17. Recall accuracy collapsed over groups for the Pic and Kim stimuli according to whether the Pic (PK) or the Kim (KP) stimuli were presented first.


1.0
.8
.6
.4
.2
0
proportion correct
FIRST
SECOND
THIRD
FOURTH
PIC □
KIM ○
PK
PIC ■
KIM ●
KP
Stimuli presented first; ▬▬▬
Stimuli presented second; ■ ■ ■ ■ ■

In the response time analysis, the material by order interaction was significant (*F*(1,42) = 5.65, *p* = .02). Post hoc tests revealed that overall response times were longer when the Kim stimuli were presented first and the Pic stimuli second (KP). However, the material by order interaction indicated that while the response times for the Pic stimuli were equivalent in both orders of presentation (PK and KP), the response time for the Kim stimuli in the KP group was longer than the response time for the Kim stimuli in the PK order. The group by material by order interaction (*F*(2,42) = 4,38, *p* = .02) was also significant. Post hoc tests showed that it is the aphasics in the KP order who responded more slowly on the Kim stimuli than the aphasics in the PK order (*p* = .01). There were no other significant differences among the means.

Examination of the aphasics' individual response times indicated that the aforementioned order effects resulted from the extremely long response times of two aphasic subjects who were both run in the KP order. These were the only two subjects with visual field defects, though it is unclear how this impairment would account for the order effect observed.

Analysis based on categorization of the aphasics scores. In order to determine the effect of naming competence on the material and temporal effects, an analysis was carried out on the accuracy data from the aphasic group collapsed over the nonsignificant main effects of order and presentation format.

The aphasics were divided into two groups on the basis of high (cutoff = 30) vs low Boston Naming Test (BNT) scores. The one anomic subject was the exception to this division. He was placed in the LN group on the basis of his speech and language clinician's estimation of his naming ability at the time he participated in this experiment. The BNT was not given at that time, although he had a BNT score of 40 nine months later, and still continued to have obvious word-finding problems in conversational speech and in picture description such as the cookie jar task of the BDAE.

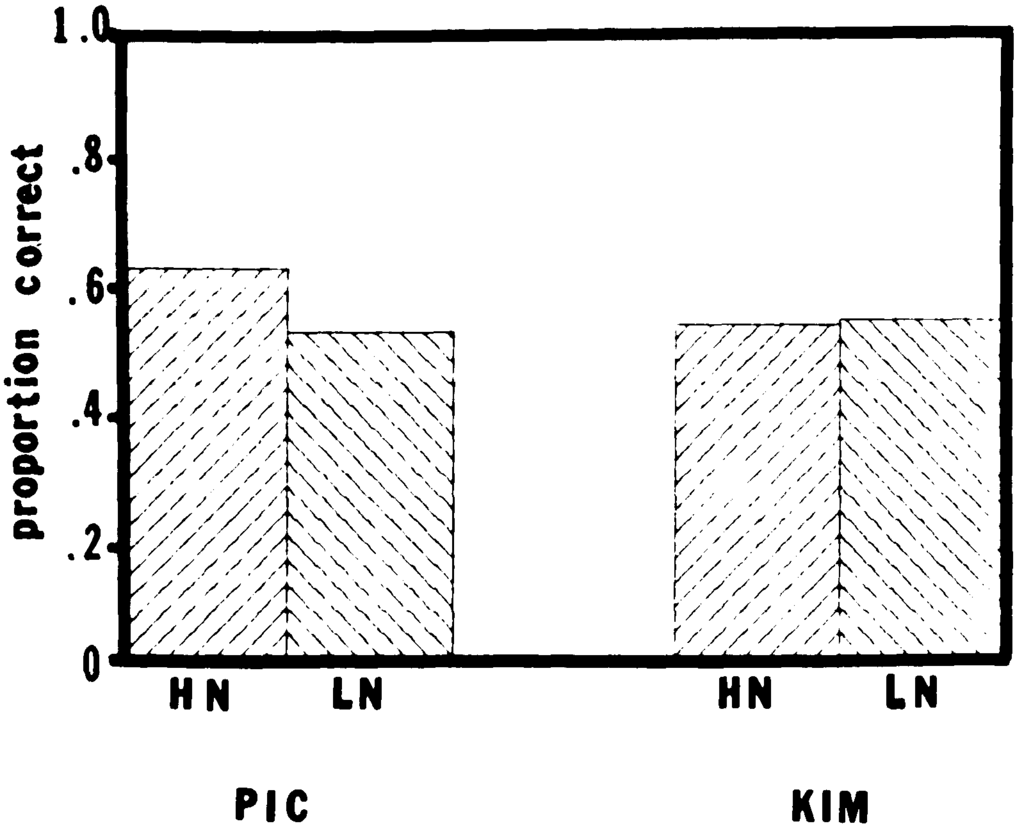
The eight aphasics in group LN had scores ranging from 2 to 26 with a median of 18; the 8 aphasics in group HN had scores ranging from 32 to 50 with a median of 39.5.

As in previous analyses, the main effect of temporal position was significant ($F(3,90) = 22.39$, $p < .0001$). The main effect of materials was not significant (_F_(1,30) = 1.71, _p_ = .20): Performance on Pic stimuli and Kim stimuli was equivalent for both the high and low naming groups.

The only other significant effect was the material by group interaction (_F_(1,30) = 4.14, _p_ = .05). Post hoc tests revealed (_p_ = .05) that the group HN's ordered recall of the Pic stimuli was significantly higher than that of group LN, but both groups had equivalent scores when recalling the Kim stimuli.

As can be observed in Figure 18, the pattern of performance observed in group HN more closely resembles the performance of normal subjects. This failure to obtain a group by materials interaction suggests that sensitivity to stimulus familiarity and ease of nameability is only very weakly related the the patient's naming competence.

Figure 18. Recall accuracy on the Pic and Kim stimuli for the aphasics in subgroups based on good (HN) and poor LN) performance on the Boston Naming Test.


proportion correct
1.0
.8
.6
.4
.2
0
HN
LN
HN
LN
PIC
KIM

Discussion

The primary purpose of this study was to investigate short-term temporal order memory in aphasia in the context of current item and order models of short-term retention. Patients with aphasia were compared to matched controls and young adults on tasks of short-term order memory employing four-item strings and immediate test. Young adults were included to evaluate effects of age on performance in this task.

To test the possibility of spatial facilitation of temporal-order recall, two presentation formats were employed, one which provided additional spatial information at input, one which did not. To assess the effect of changes in the nameability of the stimulus materials, recognizable and nameable, as well as meaningless nonsense figures were used.

In a modification of Healy's (1974) order-only design, in which subjects are provided complete item information before full report of order information is required; item information in this experiment was provided by means of probed recall: Subjects were shown the target item and were required to decide in which ordinal position this item had been presented. Healy's (1974) study demonstrated that providing item information to subjects does not influence the acquisition of order information. In addition to providing item information, a probed recall technique permitted maximum acquisition to be measured, since information loss continues during the recall period (Lee & Estes, 1977, 1981; Shiffrin & Cook, 1978).

Item information was presumed to be at ceiling, due to the use of short strings and a probed recall format. Using normal adults as subjects and Healy's item-only design (in which subjects are provided full order information so that they need only recognize the appropriate item for each temporal position from a set of foils) Healy (1974) and Drewnowski (1980) both demonstrated that item recognition is at ceiling with flat serial position curves for both familiar and unfamiliar material on short-term sequencing tasks employing four-item strings and immediate test. Since aphasic adults' recognition memory for pictures has been reported to be normal (Cermak & Tarlow, 1978), and since recognition memory for the Kimura figures following 30 to 90 second filled intervals has also been reported to be normal for left hemisphere patients (Kimura, 1963; Newcombe, 1969), aphasic subjects were presumed to follow the aforementioned normal pattern.

Consistent with previous reports (Goodglass, Deanes & Calderone, 1974) the aphasics' sensitivity to changes in the nameability of the stimulus materials was reduced, although this sensitivity appeared to be only weakly related to confrontation naming skill. Aphasics in the high-naming group performed only slightly better on the ordered recall of the pictures than did those in the low-naming group; the two subgroups were equivalent on the Kimura figures. This pattern approached that seen in the performance of control subjects. However, unlike the normals there was still no within-group improvement in the performance of either group of aphasics when pictures rather than Kimura figures were used as stimuli. Given the limited role of ordinal tagging in short-term sequencing tasks (Drewnowski, 1980; Martin & Caramazza, 1982) and the consequent dependence upon auditory-verbal mediation, this deficit in phonemic coding necessarily disrupts performance.

In the current context, the fourth item presented was the least dependent on such mediation, since it could be identified on the basis of immediate item recognition which does not necessitate labeling (Nelson, 1979). It is therefore not surprising that the aphasic subjects showed marked sparing of recall for the last item in the string where their performance was statistically equivalent to the normals. Portions of the aphasics' serial position functions more dependent on naming and rehearsal competence, the middle and beginning portions, were depressed.

The potentiated recall of the temporal position of the last item was probably due to the application of an ordinal retrieval strategy (Baddeley & Hitch, 1977) to an unstable visual code representing the fourth item (Phillips & Christie, 1977). This code was presumably more peripheral in nature and less dependent upon capacity than the phonological code (and concurrent rehearsal) required for the recall of the temporal positions of the first three items. Such a visual store would be ideal for aphasic subjects who must rely on alternate strategies to compensate for rehearsal (Rothi & Hutchinson, 1981), naming (Goodglass, Deanes & Calderone, 1974; Kohn & Goodglass, 1986; Martin & Caramazza, 1982), or capacity (Grober, 1984) limitations. In addition, a subset of aphasic subjects, unlike normal subjects (Crowder & Morton, 1969), have demonstrated enhanced recency with visual but not auditory presentation (Saffran & Marin, 1975; Warrington & Shallice, 1969).

Similarly, recency effects in the immediate free recall of word lists, though extending to more than one item, also appears to be mediated by an ordinal retrieval strategy (the last items are recalled first), and by mechanisms independent of the active memory system (the last items are maintained in a transient modality-specific store). Therefore recall of the last items presented should neither be affected by demands on capacity nor dependent upon the use a kind of modality-specific strategy. For example, recency is not reduced by a concurrent memory task, by articulatory suppression, or by an incidental as opposed to an intentional memory test (Baddeley & Hitch, 1977).

The visual serial position curve (Shiffrin, 1973) resulting from free recall or recognition of a series of complex patterns , though not bow-shaped, also has a distinct recency component, which shares some of the characteristics of recency seen in verbal free recall. For example, Phillips and Christie (1977) observed two distinct recall components resulting from a yes/no recognition task following presentation of a series of patterns. Recency was limited to the highly transient representation of the last item presented. This item had highest accuracy levels, up to 90%, and was not affected by slower rates of presentation. It reduced slowly over unfilled delays of up to 10 seconds, but was totally absent following a distraction of 3 seconds of mental arithmetic, and had response times faster than all of the other items. The presentation of even one other item wiped out this advantage. This pattern was not due to differential processing of the last item, since the length of each series varied randomly and was unknown to the subject beforehand.

The other component reported by Phillips and Christie included the representation of all but the last pattern presented. No primacy effect was observed. Accuracy here was at 60%, and improved with slower rates of presentation. Performance was not affected by unfilled delays of up to 10 seconds, or by 3 seconds of mental arithmetic and required longer response times. The flat visual serial position function reported by Shiffrin (1973) resembles this component.

In the present study, the highest accuracy levels and shortest response times also occurred in the recall of the last item, with equivalent levels of performance obtained from aphasics and normals. In addition, the overall serial position curves, collapsed over material and presentation condition, did not show a statistically significant primacy effect. A significant primacy effect was observed for all groups only with the Kimura figures presented in a single spatial location.

Primacy at this overall level was probably masked by (a) the strong performance of the normals on the middle items, especially the picture stimuli, due to opportunities for rehearsal, (b) the flattening of the curve which occurs with the Mov presentation format, to be discussed shortly, and (c) the superimposition of the aforementioned flat visual serial position curve onto the expected bow-shaped serial-order curve.

In contrast to the accuracy analysis, the response time serial position curves were bow-shaped for all groups and for both types of material. The response time for the final item was the shortest, followed by the first-position item, indicating the more ready accessibility of end-item information.

The deviation scores serial position functions, sensitive to both accuracy levels and the size of the errors committed, were also bow-shaped for all groups. Distinct primacy and recency components provided further evidence that more information was maintained on the end-position items. Consistent with accuracy and response time results, the greatest amount of information was maintained on the fourth-position item, a pattern reported by Lee and Estes (1977) for backward recall. The probed-recall response format of this study approximated backward recall conditions.

As expected, generalization gradients indicated that information was not lost in an all-or-none fashion, rather partial information was maintained. For all groups the actual input position was the modal response position, with declining response frequencies for each successively more distant serial position. The end positions maintained the most information, the distributions were more pointed and declined more steeply than those of the middle positions.

The fact that the aphasics' response distributions demonstrated the typical pattern of information loss predicted by the perturbation model suggests that the fundamental mechanisms underlying the acquisition of short-term order information (exclusive of the secondary memory components) are intact.

Lee and Estes (1981) proposed a kind of passive rehearsal process which is said to occur when the overt rehearsal of encoded information is attenuated. According to this view, when voluntary rehearsal is attenuated, information is dispatched into a delay loop or reverbatory circuit (Estes, 1972), and is automatically reactivated at periodic intervals in a kind of covert rehearsal process out of the subjects's awareness. Desynchronization in these periodic reactivations of serially encoded information is thought to result in order errors. The pattern of information loss observed in both normals and aphasics is consistent with this explanation.

Aphasics appeared to overutilize the second position response at the expense of the first position response. However, this apparent response bias probably reflects greater amounts of information loss on the initial item due to rehearsal deficiencies and the consequent response generalization from the first to the second position, as predicted by the Lee and Estes model. Consistent with this, response utilization of positions three and four showed no bias.

To the extent that phonological coding is impaired in aphasic subjects, increased use of available visual and spatial information is expected to replace the preference for phonemic coding seen in controls (Hermelin, 1972; Martin & Caramazza, 1982). Therefore, aphasic subjects were expected to demonstrate heightened sensitivity to explicit spatial information by organizing a visuo-spatial strategy around memory for spatial location (Grober, 1984). Since the retention function for spatial location information falls off gradually over several seconds (Healy, 1977), such information should persist long enough to allow a strategy of this type to succeed only in aphasic subjects without significant right hemisphere damage (Smith & Milner, 1981; Warrington & Baddeley, 1974).

While it may be difficult to evaluate the relationship between memory for an object and memory for its spatial location as a result of the fact that subjects spontaneously use spatial organizational schemes when instructed to remember a set of objects (Bower, 1970; Mandler, Seegmiller & Day, 1977), there is no question that a strong positive relationship exists between recall of an item and recall of its spatial location. Working with amnesic patients whose only cognitive complaint was that of poor memory, Hirst and Volpe (1984) reported that unless the patients could recall a specific object, they could not recall its spatial location. However, for normals, spatial location information is often above chance even if the associated item information is forgotten (Mandler, Seegmiller & Day, 1977). As previously discussed, item information in this study is presumed to be at ceiling.

Aphasic and control subjects demonstrated a similar response to presentation format variation. Explicit spatial information at input flattened the serial position function without benefit to performance. Recall of the third and fourth positions increased at the expense of recall of the first and second positions. This is in agreement with previous reports that only simultaneous not sequentially supplied spatial information at input facilitates ordered recall (Shiffrin & Cook, 1978; Von Wright, 1975).

Healy (1975, 1977) also reported a flatter serial function when subjects recalled spatial locations, however, recency not primacy was absent. This is the opposite of the results of this study in which primacy not recency was absent. Of course, subjects in the current study were never asked to recall spatial locations, only the temporal order of item presentations. In addition, the immediate, probed recall format of this study is comparable to backward recall, which as discussed yields higher recall levels and steeper distance functions for the last item. (An examination of the raw data revealed that reduced recall of the first position was not due to the fact that subjects had difficulty locating the place of initiation of the first trial of a block of four trials.)

The linear trend of the serial position functions under Mov presentation conditions could be a direct result of the salience of the spatial information for the end positions compared to that of the beginning positions. Memory for spatial location could function as an effective retrieval cue for temporal order information under these circumstances, but facilitation of overall performance would have required both the automatic encoding of spatial information, and available capacity to maintain the additional spatial information while reconstructing the temporal order from the current (but varying) location of initiation. In fact, some spatial information does appear to be encoded in secondary memory without intention at the same time that associated item information is being encoded (Grober, 1984; Mandler, Seegmiller & Day, 1977; Schulman, 1973; Zechmeister & McKillip, 1972), which is essential if aphasics with an already limited capacity (Grober, 1984) are to benefit from explicit spatial cues.

However, if attention to spatial information were required, the consequent reallocation of resources would disrupt performance, either during input or during subsequent processing. During a pilot study of this dissertation, instructions to actively use spatial information during input were disruptive to the performance of normal subjects. Schulman (1973) reported a small but similar, disruption of recognition memory for words when subjects were instructed to attend both to the word and to its spatial location.

In the current study, disruption of performance did occur, suggesting an attentional component. Under the Mov presentation condition, earlier-position items were the most sensitive to the effects of information overload, and the performance of both aphasic and normal subjects was similarly affected. This failure to find overall spatial facilitation of temporal-order recall is thus task-specific and cannot be generalized to paradigms utilizing more distinctive spatial formats. The fact that the aphasics deviation score on the familiar, easy-to-name material under Mov presentation conditions (Picmov) approximated that of controls on the unfamiliar difficult-to-label material under both Mov and Fix presentation conditions suggests the possibility of spatial facilitation.

Such a finding would be especially relevant to particular aphasic patients whose spared right hemisphere function would permit the maintenance and manipulation of information by a means of spatial strategy, thereby compensating for linguistic and attentional deficits. A larger sample of aphasic subjects would help define the characteristics of that subset of patients most likely to benefit.

Summary and conclusions

1. Overall accuracy in temporal location judgments of aphasic subjects were impaired relative to normal subjects. Age differences were not significant.

2. Aphasic subjects demonstrated relative sparing of information about the last item presented. In this position, their performance was statistically equivalent to normals, while in the middle and beginning portions, the serial position functions were depressed. Recall of the last item was probably mediated by the application of an ordinal retrieval strategy to an unstable visual code, transient in nature and less dependent upon capacity than the phonological code and concurrent rehearsal required for the recall of the first three positions.

3. Aphasic subjects' sensitivity to changes in the nameability of stimulus materials was reduced, and appeared only weakly related to their confrontation naming skill. For both the easy- and difficult-to-label material, aphasics showed the more rounded response distributions at each input position, which in normals occurs only in the recall of acoustically similar strings. This suggests an inability on the part of the aphasics to effectively retrieve and maintain a distinct phonemic code.

4. The performance of the control subjects was statistically equivalent to that of the aphasic subjects only on the Kimfix (the most effortful) condition. Craik and Byrd's (1982) suggestion of reduced attentional capacity with aging could account for this subtle impairment. There were no significant differences between the control and young adult subjects.

5. Patterns of information loss for all groups, as demonstrated by response distributions over input position, were consistent with those predicted by the perturbation model. More information was retained on end-position stimuli than on middle position stimuli for all groups. Therefore the perturbation process posited by Lee and Estes (1981) appears to be operating normally in aphasia. This is consistent with the notion that automatic encoding of order information is not involved in the aphasics' memory deficit.

6. Both normal and aphasic subjects showed the increased bowing of the serial position curve expected in the temporal-order recall of unfamiliar material presented sequentially in one spatial location. Since it is especially difficult to apply a distinct label to unfamiliar material and to maintain each during input of the remainder of the string, acquisition was disrupted for all groups tested in this condition.

7. Additional spatial information at input flattened the serial position curve for both groups but provided no overall benefit. The clockwise pattern of presentation (Mov condition) in which stimuli were displayed in the same sequence of quadrants on four successive trials did not provide adequately distinct spatial cues. Apparently, the need to remember the point of trial initiation in order to reconstruct the temporal order of presentation, overtaxed the working memory system. Therefore, results cannot be generalized to other paradigms which more successfully permit the utilization of spatial cues without draining attentional capacity.

Appendix 1

Analysis of variance summary table for the accuracy analysis

Source	SS	df	MS	F	P
Group (G)	205.60	2	102.80	37.91	0.000
Order (O)	2.75	1	2.75	1.01	0.319
GO	6.42	2	3.21	1.18	0.316
Error	113.88	42	2.71	--	--
Material (M)	31.41	1	31.41	31.41	0.000
MG	6.64	2	3.32	3.38	0.044
MO	0.05	1	0.05	0.06	0.815
MGO	0.89	2	0.44	0.45	0.639
Error	41.27	42	0.98	--	--
Presentation Format (P)	0.07	1	0.07	0.09	0.760
PG	0.92	2	0.46	0.63	0.540
PO	2.30	1	2.30	3.13	0.084
PGO	1.35	2	0.68	0.92	0.406
Error	30.84	42	0.73	--	--
MP	0.13	1	0.13	0.20	0.656
MPG	4.31	2	2.16	3.23	0.049
MPO	0.29	1	0.29	0.43	0.513
MPGO	1.17	2	0.59	0.88	0.424
Error	28.06	42	0.67	--	--
Temporal position (T)	92.36	3	30.79	27.58	0.000
TG	25.87	6	4.31	3.86	0.002
TO	0.36	3	0.12	0.11	0.945
TGO	1.86	6	0.31	0.28	0.936
Error	140.68	126	1.12	--	--
MT	8.01	3	2.67	4.55	0.007
MTG	4.86	6	0.81	1.38	0.234
MTO	5.41	3	1.80	3.08	0.036
MTGO	4.08	6	0.68	1.16	0.334
Error	73.94	126	0.59	--	--
PT	10.50	3	3.50	6.12	0.001
PTG	3.45	6	0.57	1.00	0.423
PTO	2.65	3	0.88	1.54	0.210
PTGO	2.36	6	0.39	0.69	0.652
Error	72.08	126	0.57	--	--
MPT	6.52	3	2.17	3.68	0.016
MPTG	4.45	6	0.74	1.26	0.284
MPTO	0.17	3	0.06	0.10	0.956
MPTGO	3.24	6	0.54	0.92	0.483
Error	74.30	126	0.59	--	--

Epsilon factors for degrees of freedom adjustment:

Temporal position	0.9167
MT	0.8927
PT	0.9420
MPT	0.9481

Appendix 2

Analysis of variance summary table for the response time analysis

Source	SS	df	MS	F	p
Group (G)	752.29	2	376.15	10.72	0.000
Order (O)	168.06	1	168.06	4.79	0.034
GO	180.06	2	90.03	2.57	0.089
Error	1474.14	42	35.10	--	--
Material (M)	151.68	1	151.68	14.49	0.001
MG	70.73	2	35.36	3.38	0.044
MO	59.16	1	59.16	5.65	0.022
MGO	91.66	2	45.83	4.38	0.019
Error	439.67	42	10.47	--	--
Presentation Format (P)	0.40	1	0.40	0.03	0.854
PG	8.73	2	4.36	0.37	0.691
PO	3.44	1	3.44	0.29	0.590
PGO	24.93	2	12.47	1.07	0.354
Error	491.34	42	11.70	--	--
MP	32.33	1	32.33	3.15	0.083
MPG	74.82	2	37.41	3.65	0.035
MPO	10.80	1	10.80	1.05	0.311
MPGO	69.12	2	34.56	3.37	0.044
Error	430.52	42	10.25	--	--
Temporal position (T)	288.04	3	96.019	10.08	0.001
TG	142.80	6	23.80	2.50	0.076
TO	78.57	3	26.19	2.75	0.092
TGO	125.10	6	20.85	2.19	0.107
Error	1200.06	126	9.52	--	--
MT	45.01	3	15.00	1.64	0.208
MTG	15.70	6	2.62	0.29	0.785
MTO	26.50	3	8.83	0.97	0.344
MTGO	78.16	6	13.03	1.43	0.250
Error	1150.93	126	9.13	--	--
PT	14.200	3	4.73	0.49	0.526
PTG	32.92	6	5.49	0.57	0.606
PTO	5.08	3	1.69	0.17	0.730
PTGO	48.07	6	8.01	0.83	0.465
Error	1220.40	126	9.69	--	--
MPT	32.33	3	10.78	1.25	0.280
MPTG	70.19	6	11.70	1.36	0.265
MPTO	21.53	3	7.18	0.84	0.393
MPTGO	100.78	6	16.80	1.95	0.140
Error	1082.64	126	8.59	--	--

Epsilon factors for degrees of freedom adjustment:

Temporal position	0.4416
MT	0.3889
PT	0.4110
MPT	0.4320

Appendix 3

Analysis of variance summary table for the deviation score analysis

Source	SS	df	MS	F	P
Group (G)	10.11	1	10.11	44.67	0.000
Error	6.79	30	0.23	--	--
Material (M)	1.78	1	1.78	18.12	0.002
MG	0.51	1	0.52	5.32	0.028
Error	2.95	30	0.10	--	--
Presentation Format (P)	0.14	1	0.14	2.04	0.164
PG	0.004	1	0.004	0.05	0.812
Error	2.06	30	0.69	--	--
MP	0.08	1	0.08	1.10	0.302
MPG	0.58	1	0.58	7.71	0.009
Error	2.27	30	0.08	--	--
Temporal position (T)	6.57	3	2.19	15.09	0.000
TG	0.42	3	0.14	0.97	0.398
Error	13.05	90	0.15	--	--
MT	0.38	3	0.13	1.62	0.193
MTG	0.21	3	0.07	0.92	0.433
Error	6.96	90	0.07	--	--
PT	0.730	3	0.24	3.26	0.028
PTG	0.08	3	0.03	0.35	0.773
Error	6.70	90	0.70	--	--
MPT	0.95	3	0.32	4.03	0.012
MPTG	0.15	3	0.05	0.63	0.587
Error	7.11	90	0.08	--	--

Epsilon factors for degrees of freedom adjustment:

Temporal position	0.7868
MT	0.9522
PT	0.9396
MPT	0.9280

Appendix 4

Accuracy Raw Scores for the Sixteen Aphasic Patients for each Temporal Position in each of the Four Experimental Conditions: Kimmov (KM), Kimfix (KF), Picmov (PM), Picfix (PF), Visual field defect (VFD) ++, Boston Naming Test (BNT)

Aphasic Subgroup	BNT	VFD	Experimental Conditions KM				KF				PM				PF			
			1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Wernicke																		
W1	2	++	1	2	2	1	2	1	0	3	1	3	2	3	0	2	3	2
W2	5		2	2	1	2	4	2	2	3	4	3	2	4	2	3	1	2
Anomic																		
A1	20*		0	2	2	2	3	3	0	4	0	1	1	3	2	3	1	3
Broca																		
B1	21**		4	2	4	3	2	2	3	2	3	4	3	3	2	2	2	2
B2	20	++	2	1	3	3	3	1	2	4	3	2	2	3	4	2	2	2
B3	40		1	3	1	3	3	1	1	3	1	3	2	4	3	3	1	4
B4	26		2	2	4	4	4	3	2	4	2	1	1	4	3	1	0	3
B5	50		2	0	4	4	0	2	2	4	1	1	4	4	2	2	2	3
B6	18		1	1	1	4	1	1	1	4	3	1	3	4	1	2	1	4
B7	32		2	2	3	4	4	3	0	4	4	3	1	4	3	2	2	4
B8	32		1	2	2	1	2	1	0	3	1	3	2	3	0	2	3	2
B9	38		3	1	3	2	3	3	3	3	3	2	2	4	4	3	1	2
Conduction																		
C1	49		0	2	2	4	1	1	1	3	3	3	2	4	4	1	2	4
C2	4		1	1	1	4	2	2	1	3	2	1	1	3	0	2	2	4
Mixed transcortical motor																		
MTM1	39		0	2	1	3	1	1	1	4	1	1	2	4	0	1	2	3
Fluent																		
F1	44		2	2	2	3	1	4	2	4	2	2	3	4	3	3	2	4

* Estimated by speech and language pathologist; Score was 40 nine months later.

** Estimated from the Boston Diagnostic Aphasia Examination Confrontation naming score of 38/105.

Appendix 5A

Test Information for Eleven Aphasic Patients: Boston Naming Test (BNT) Shortened Version of the Token Test (Token), Boston Diagnostic Aphasia Examination: Melodic Line (ML), Articulatory Agility (AA), Phrase Length (PL) Word Discrimination (WDIS), Body Part Identification (BPID), Commands (COM), Complex Material (CM), Repetition of: Words (RWD), High Probability Phrases (RHI), Low Probability Phrases (RLO), Automatized Sequences (AS)

Test	Aphasic Subjects										
	W1	W2	A1	B1	B2	B6	B7	B8	C1	C2	F1
BNT	02	05	20	21	20	18	32	32	49	04	44
TOKEN	9.5	NA	27	1.5	23	20	21	16	17	08	*145
ML	07	07	6.5	03	02	03	04	04	07	07	07
AA	06	07	06	03	03	02	02	04	06	07	07
PL	07	06	06	03	03	05	05	04	06	06	07
WDIS	56	ˆ10	ˆ10	53.5	69	68.5	66	72	63	63.5	72
BPID	05	NA	NA	08	19	19	18.5	16	19	16.5	20
COM	01	07	13	01	09	13	11	13	15	10	15
CM	02	02	08	04	08	08	10	09	10	05	11
RWD	08	07	10	08	07	10	09	10	07	03	09
RHI	02	00	08	03	01	08	08	07	04	00	07
RLO	00	00	05	01	01	07	07	06	00	00	07
AS	04	NA	06	03	03	06	06	08	06	02	08

*Long version of the Token Test

ˆScore on a ten-item word-picture matching task.

Appendix 5B

Test Information for Five Aphasic Patients: Western Aphasia Battery: Information (I), Fluency (F), Comprehension: Yes-No (YN), Word Discrimation (WDIS), Commands (COM); Repetition (R), Naming: Object (ON), Word Fluency (WF), Sentence Completion (SC), Responsive Speech (RS), Aphasia Quotient (AQ); Porch Index of Communicative Ability: Overall (OV), Gestural (G), Verbal (V), Graphic (GR)

Tests	Aphasic Subjects					
	B3	^^B4	B5	B9	MTM1	Clinical observations
BNT	40	26	50	38	39	^^Speech clinician's evaluation of B4: Mild comprehension deficits, marked speech formulation deficits primarily due to marked oral-facial and verbal apraxias. Patient cannot complete extended statements with specific nouns or verbs.
TOKEN	NA	NA	*121	NA	*140	
I	04	NA	04	04	08	
F	07	NA	04	06	06	
YN	27	NA	25.5	28.5	27	
WDIS	23	NA	25.5	30	29	
COM	38	NA	22	31	17	
R	37	NA	92	48	100	
ON	21	NA	33	54	52	
WF	05	NA	00	04	06	
SC	04	NA	10	08	10	
RS	08	NA	08	10	10	
AQ	55.6	NA	59.2	44.7	78.2	
OV	77	80	42	95	74	
G	94	82	22	81	39	
V	45	79	38	77	71	
GR	85	80	63	99	79	

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