A STUDY OF DIGIT SPAN CAPACITY IN DEAF AND HEARING SUBJECTS

STEPHEN SPRINGER

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Abstract

The effect of different stimulus sets (regular digits, spatial and somatic sensory digits, and the signs for the digits) on the span capacity of deaf and hearing Ss was investigated. Results were recorded for forward and reverse recall over pre and post-cued conditions for all stimulus sets. Span capacity of hearing Ss remained invariant to stimulus set. Span capacity of deaf Ss, while inferior to that of the hearing group, improved with the sign digit presentation. Serial position analyses revealed that both deaf and hearing Ss demonstrated forward/reverse effects (i.e. forward span greater than reverse span). Finally, no difference in performance was observed over pre and post-cued conditions for hearing Ss, while deaf Ss performed better on pre than post-cued conditions. Results are discussed in terms of capacity, rehearsal and coding aspects of short term memory performance.

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Early research in the area of deafness focused on determining whether the physical disability of loss of hearing had any systematic effect on the psychological functions of those disabled. At that time, researchers were interested in finding out if there was a systematic intellectual inferiority in the deaf population. Studies were designed comparing deaf _Ss_ to hearing _Ss_ on the dependent variable, intelligence.

Results were inconsistent with the hypothesis that the deaf had an overall deficit in intelligence. In standard intelligence tests involving high verbal content, deaf groups scored lower than their hearing counterparts (Pintner and Paterson 1916, 1917; Drever and Collins 1928). However, in other tests, such as the Goodenough Draw-A-Man Test (Springer 1938), tests of spatial ability (Morsh 1937), and tests of motor memory (Fuller 1959), the deaf performed as well or better than the hearing.

More recent researchers, notably Myklebust (1960), proposed a different interpretation of the question of systematic effects of deafness on psychological functions. Because the intellectual inferiority hypothesis was not supported by the evidence, it was proposed, and subsequently accepted by most researchers, that the deaf were similar to their hearing counterparts in overall intellectual competence. It was hypothesized that the differences between the deaf and hearing were qualitative in nature. By this it was meant that the intellectual potentials of the deaf group, by necessity, focused on different abilities than those necessary for the hearing group. The center of attention then shifted from the study of overall intellectual competence to the study of differences between the hearing and the deaf on ability specific tasks.

This thesis will concern itself with the study of one such ability, namely, short term memory. Short term memory as defined here refers to the description of any memory experiment that involves short term retention intervals, and not necessarily to a distinct memory process or mechanism (Waugh and Norman 1965).

There are good reasons for studying short term memory in deaf and hearing children. First, it has been shown (Blair 1957, Conrad 1971) that there is a high degree of correlation between performance in short term memory tasks and performance in important classroom behavior such as reading. The study of short term memory may then have implications for the education of deaf and hearing students. This is particularly relevant for the deaf who are found to be on the average six years behind their hearing counterparts in reading ability (Furth 1966).

Study of short term memory may provide further indications on the adaptive or functional plasticity of the central nervous system in humans. As we shall see, auditory experience appears to play an important role in short term memory processes in the hearing. The deaf are by definition without auditory experience. The study of short term memory may illuminate the types of adaptations, if any, the deaf make to compensate for their sensory deprivation.

Short Term Memory

Short term memory processes are characterized by a finite capacity, the facility and quickness with which information is retrieved, swift forgetting, and no permanent record (Craik 1971a).

In general, memory theorists conceive of the memory process as a set of successive (or simultaneous) transformations performed upon the input stimuli (Broadbent 1971). One useful tendency, introduced by Crowder and Morton (1969), is to describe the form of transferred storage as 'pre' and 'post-categorical' storage. Pre-categorical storage refers to the maintenance of the stimulus in an untransferred pre-sensory form (Sperling 1963, Posner et al. 1969). Post-categorical storage, on the other hand, refers to the storage of information after its transformation to a semantic level. Post-categorical stores may contain rehearsed material, stored in a semantic (Baddeley 1966) or phonetic (Wicklegren 1965, 1966) form, rather than sensory based forms.

Of current theoretical interest in memory research is how (i.e. using what strategies) information from the pre-categorical store is transferred to and reported from post-categorical stores. A method of investigating these strategies in the visual case is the pre/post instruction method. If the subjects show no difference with pre and post instruction, this means that they are using a stimulus directed storage strategy. They store the stimulus in a certain manner regardless of instruction. If the Ss do show a difference with pre and post instruction, this means that they are using a response directed storage strategy. They store the stimulus in a manner which is contingent on response conditions. In this way, one can highlight differences in storage strategies.

Studies of short term memory can be conveniently divided into three main types. (Craik 1971b) : those investigating the capacity of short term memory; those investigating the effects of rehearsal on short term memory; and those investigating the types of coding processes involved in short term memory.

The modality of stimulus presentation (e.g. auditory, visual, kinesthetic, etc...) and the type of response demanded (e.g. ordered recall, ordered recognition, etc...) are important elements in the short term memory paradigm. We will focus primarily on experimentation involving visual stimulus presentation and demanding ordered written recall.

Capacity:

A common method for determining the capacity in short term memory is to calculate how many stimuli can be retained over a short period of time. This capacity, called a stimulus span, is derived from the longest series of stimuli a S can recall in full in the proper order of presentation.

With the hearing, as well as with the deaf, the most frequently used stimulus material has been digits.

Studies with Hearing Subjects:

Smedely (1900-1901, as reported in Pintner and Paterson 1916) reported the following mean forward digit spans for written ordered recall for sequentially presented digits: ages 7-8, 5 digits; ages 9-11, 6 digits; ages 12-15, 7 digits; ages 16-19, 7.5 digits. Forward digit span increases developmentally.

Gates (1916) found that the mean forward digit span for written recall with college students was 7.7 digits for sequential auditory presentation and 8.2 digits for sequential visual presentation. The author noted that for both modalities, an increase in the number of digits presented beyond the subject's absolute span, tended to decrease the number of digits recalled.

In an interesting addition to the standard digit capacity short term recall paradigm, investigators began comparing recall of digits forward to recall of digits reverse. In the latter condition, the subjects were required to respond by reversing the order of the initial stimulus presentation.

Star (1923) demonstrated that for oral ordered response and sequential auditory presentation, forward span was consistently longer than reverse span for normal, retarded, sub-normal and low defective groups.

McCaulley (1928) confirmed in full the results of the Star study. Both studies demonstrated a developmental increase in both forward and reverse span. Reverse span increased more gradually than forward span across the ages, forward span being superior at all ages tested. As is frequently seen in these studies, the order of presentation of tasks was not counterbalanced, with performance on the forward recall task always demanded first. It may be that this task is susceptible to practice effects, in which case these results may reflect an underestimation of the difference between forward and reverse span, the reverse span being systematically overestimated because of practice.

For all hearing groups tested, forward span is consistently larger than reverse span. This is true for both normal intelligence and sub-normal intelligence groups.

Rate and mode of presentation of stimuli are important determinants of memory span. Conrad and Hille (1958) demonstrated better recall at fast rates for auditory presentation. At very quick rates (e.g. 10 digits per second) performance decreases rapidly (Yntema et al. 1964). Mackworth (1962, 1964) showed that a slower rate of presentation maximized recall of digits for visual stimuli. Posner (1964) showed that the rate of auditory presentation interacted with order of recall. When <u>Ss</u> were required to recall the digits in a given order, performance was better at a faster rate. Performance was better at a slow rate when the <u>Ss</u> had to recall the last four digits first and then the first four.

The serial position effect, an accompaniment of exceeding a subject's span, is an important phenomenon occurring in serial order recall paradigms. It refers to the fact that stimuli on the periphery of the span are recalled better than those in the middle. Waugh (1960) studied the interaction of primacy (mean number of items recalled correctly at the beginning of a series before a mistake) and recency (mean number of items recalled correctly at the end of a series before a mistake) effects for visual presentation of digits. In general it was found that with short stimulus spans, primacy and recency effects overlap and all items are recalled equally well. As the span length increases, exceeding the subject's absolute span, primacy and recency effects no longer overlap and items in the middle are recalled less accurately than those on the periphery of the span.

Further, Waugh demonstrated that span performance is best when a subject knows beforehand the number of stimuli to be presented. For example, providing the subject with an answer sheet indicating how many stimuli are to be presented (e.g. blanks on which the stimuli are to be recorded) improves performance.

In summary, one can determine an absolute span length in short term memory, for both forward and reverse recall. Various factors can affect the size of this span. An increase in the number of digits presented beyond subject's absolute span length decreases the total number of digits a subject can recall. Prior knowledge of the length of the stimulus presentation improves span length. A slower rate of presentation maximizes recall for visual presentation.

Forward span is greater than reverse span at all age levels. Both forward and reverse spans increase with age in early life. The fact that forward span is greater than reverse span at all age levels is not a function of intelligence.

Finally we note that at spans greater than the subject's absolute span, stimuli are recalled more accurately on the periphery of the span than in the middle. Data demonstrating serial position effects comes from studies of forward recall. Studies using reverse recall have not analyzed data for serial position effects.

<u>Studies with Deaf Subjects</u>:

McMillan and Bruner (1906) were the first to investigate immediate written recall for visual digit stimuli sets presented sequentially to deaf children (ages 8-18). They and Pintner and Paterson (1917) demonstrated that the average deaf child never reached the forward span of the average 7 year old hearing child. Pintner and Paterson attributed the poor performance of the deaf child to his lack of auditory experience. They hypothesized that after the offset of the stimulus, the deaf child had but a visual percept or image on which to depend, while the hearing child had some type of auditory image in addition to the visual one. To support this explanation, they found a positive correlation between age of onset of deafness (an index of auditory experience) and absolute span.

In a recognition task, Blair (1957) confirmed the inferiority of the deaf in short term memory for digits, while obtaining similar results for different sets of stimuli, namely pictures and dominoes.[1] Blair tested both forward and reverse recall for digits. While hearing <u>S</u>s showed

[1] The author noted that domino span was greater than digit span in the deaf.

significantly better scores on forward recognition, deaf Ss did not. No significant difference was observed between mean forward and reverse span in the deaf. In fact, mean reverse span was actually greater than the forward, although not significantly so. The author does not mention order of application of his tasks. If order was not counterbalanced, then this result may be due to a practice effect.

Fuller (1959) replicated Blair's study using digits for forward and reverse recognition. Overall results confirmed the inferior span capacity in the deaf. A developmental breakdown showed that the rate of growth of digit span forward in the deaf was virtually the same as in other studies (McMillan and Bruner 1906, Pintner and Paterson 1917), despite scoring and sample differences. Fuller also demonstrated that the rate of growth of digit span reverse was the same as that of digit span forward for the deaf.

Fuller confirmed the fact that forward span was the same as reverse span for all ages tested. A tabulation of longest complete span demonstrated that less than half of the deaf children had a longer forward span than reverse span (41.9%); most of the children had equal forward and reverse spans (47%) while a small number had a greater reverse span than forward span (8.4%). Because forward trials were always given before reverse trials, the author offered a practice effect as partial explanation for the lack of difference between forward and reverse span for digits in the deaf.

Olsson (1962) presented (both simultaneously and successively) deaf and hearing Ss (aged 12-16) with either of two sets of stimuli (digits or randomly drawn forms) for immediate recognition. After each trial, Ss were presented with an envelope containing all of the stimuli shown in that trial. Recognition consisted of a re-ordering of the stimulus material.

Both groups performed better on simultaneous than successive presentation. Recognition of digits forward confirmed the inferior performance of the deaf for both methods of presentation. With randomly drawn forms, there was no statistical difference between the groups over both conditions.

Thus far studies which have been presented have shown that the deaf have a smaller stimulus span than the hearing. This has been recorded for digits, pictures and dominoes. Further, no difference has been observed between forward and reverse span for digits in the deaf.

However, we have also noted that when the stimulus set is randomly drawn forms, the stimulus span of the deaf is the same as that of the hearing. The group of studies which follow demonstrate that the stimulus span of the deaf is greater or equal to that of the hearing for other types of stimulus sets.

Blair (1957) found deaf children (ages 7.6-12.6) superior to hearing children of the same ages in the Knox Cube Task. In this task, the subject is confronted with four blocks placed on a table. With a fifth block, the examiner taps individual blocks in increasingly difficult sequences. Recall was an ordering task. The subject was required to immediately replicate the sequence of movements in each trial.

The superior performance of the deaf child in this type of task is noteworthy. We have recorded the inferior performance of the deaf when the stimulus set is visually presented digits for immediate recall. However, when the task involves the visual presentation of ordered movements for immediate recall, the deaf are superior to the hearing. Both memory tasks involve visual presentation of stimulus material for immediate ordered recall. What varies then, is the nature of the stimulus material. This variation between stimulus sets could be attributed to either of two factors: the spatial aspects of the ordered movements; or the relative familiarity of the movements and digit set to deaf and hearing subjects.

Fuller (1959) found deaf subjects (ages 6-12) superior to hearing controls in the Van der Lugt Test of Motor Memory. In this task, the examiner blindfolds the subject and helps him trace through a raised maze with his finger. The subject, still blindfolded, must then retrace this pattern on the maze without assistance. The patterns to be traced become increasingly more difficult.

The Van der Lugt task involves the immediate ordered recall of tactual not visual information. Nevertheless, the superior memory span of the deaf for ordered recall of tactual information is noteworthy. Again we find the deaf better able to remember and make use of spatial information.

There are some studies which, although they do not involve the ordered recall of the stimulus presentation, further demonstrate the superiority or equality of the deaf when the stimulus array involves spatial information.

In a Memory for Designs task, subjects were exposed to various geometric designs presented singly for two seconds and were immediately asked to reproduce the figure with pencil and paper. Blair (1957) found the deaf superior to hearing controls in this task.

In an object location task of his own design, Morsh (1937) presented deaf and hearing subjects (ages 11-20) a vertical board with twenty compartments, each of which contained a familiar object (e.g. a pin). Subjects were permitted one minute to look at the board, after which it was removed from sight. Subjects were then placed in front of another identical, but empty board. Given an unlimited amount of time, subjects were required to reproduce the original presentation by choosing articles from a pool of forty objects and placing them in the appropriate compartments on the board. For each object in the initial display, there was a similar object placed in the pool (e.g. pin - nail) which contained the twenty correct articles and the twenty incorrect articles. Morsh reported that deaf subjects performed better than hearing controls.

Blair (1957) repeated Morsh's object location task with certain modifications. He reduced the number of target articles to fifteen and the exposure time to twenty seconds.

The replacing task, now with a time limit, was conducted with only the fifteen original objects on the board. No difference in performance was observed between deaf and hearing subjects.

In summary, the stimulus span of the deaf, relative to the hearing, varies with the type of stimulus set. With digits, pictures, and dominoes as the stimulus material, the stimulus span of the deaf is smaller than that of the hearing. With randomly drawn forms, visual and tactual movements, geometric designs, and object arrangements as the stimulus material, the stimulus span of the deaf is greater or equal to that of the hearing.

Two factors seem to emerge as important variables in the stimulus set, differentiating span capacity of deaf and hearing groups. They are the amount of spatial information in the stimulus set and the relative familiarity of the stimulus set to hearing and deaf groups.

The deaf seem better at remembering stimulus sets which contain spatial information. For unordered recall of stimulus sets with spatial information, the deaf perform comparably to the hearing in the Object location and Geometric Design tasks. For ordered recall, the superior performance of the deaf is observed on the Knox Cube task and Van der Lugt Test of Motor Memory, both of which involve dealing with spatial cues. For ordered recall of digits the deaf are consistently inferior. The domino span in the deaf is larger than the digit span. If one assumes that the domino array is remembered as digits, and not as a pattern[2], then this result is consistent with the hypothesis that the amount of spatial information in the stimulus is an important variable affecting span capacity in the deaf. Yet dominoe span in the deaf is still inferior to that in the hearing. It seems then that spatial information in the stimulus set cannot totally account for the discrepancy observed in stimulus capacity for deaf and hearing groups.

Another explanation, not mutually exclusive from the hypothesis of additional spatial cues, but nevertheless important, is the familiarity of the stimulus set. Familiarity here refers to the frequency of occurrence of the stimulus from day to day. The ordering of movements, as in the monitoring of the signs of a speaker in sign language, must be more familiar to the deaf than to the non-signing hearing subject. This would account for the superior performance of the deaf in the Knox Cube task. In tasks where the familiarity of the stimulus is minimal, as with randomly drawn forms, no difference in span capacity is observed. The superior span capacity of the hearing for digits does not, however, seem to be totally attributable to the familiarity of the stimulus. On one hand, one might argue that deaf subjects do not encounter digits as frequently as the hearing. The use of telephone numbers is an example of this. The deaf, because of the very nature of their disability, do not make use of the telephone while the hearing consistently do. However, this

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[2]This is highly probable. In Blair's sequence of tasks (1957) the dominoe task was always presented after the digit span task, thus facilitating a set to code the pattern as digits.

explanation would involve maintaining that hearing subjects in isolated areas, without telephones, and hearing groups before the advent of the telephone, had the same digit span as the deaf. One suspects that this is probably not the case. As one might expect, other factors, such as coding processes in the memory system, may further define this familiarity hypothesis.

Finally, whereas hearing subjects remember more digits forward than reverse, no such difference is reported for the deaf. However, these studies have failed to counterbalance order of presentation of forward and reverse tasks. The forward task has always been given first, the reverse last. If one assumes that a positive practice effect occurs, then these studies may have systematically overestimated the reverse span capacity.

One also wonders whether a serial position analysis of forward and reverse span at each span length might not reveal a significant difference between forward and reverse span for the deaf. This serial position analysis is more rigorous than mean span analysis, permitting the summing of observations at each span level as well as accounting for spans with incomplete recall. Mean span analysis disregards all but mean maximum span performance. An analysis of results for serial position at each span might then prove helpful in defining the parameters of this effect. For example, if forward span is indeed equal to reverse span for the deaf, then results at all span levels should indicate this.

Lack of counterbalancing and the lack of a serial position analysis then create an uncertainty in the validity of the result that there is no difference between forward and reverse recall for the deaf.

Further, for the deaf, with digits as the stimulus set, no studies have demonstrated the effect of increasing the number of digits presented beyond the subject's absolute span on the total number of digits recalled. No studies have determined whether prior knowledge of presentation length or slower rates of visual presentation maximize performance in the deaf. No studies have demonstrated serial position effects for forward and reverse recall.

Rehearsal:

The rehearsal (i.e. circulation of information) of appropriate and inappropriate information is an important variable affecting performance in short term memory. Generally, rehearsal of appropriate material (i.e. the target stimulus) aids recall while rehearsal of extraneous material has a detrimental effect on recall.

Studies with the Hearing:

Rehearsal in hearing subjects is more effective for verbal material than it is for non-verbal material (Baddeley and Paterson 1971). Studies demonstrating non-verbal rehearsal are rare in the literature. The most common technique used in the few studies available is to present information in the same modality as the target stimulus. If this shadowing, as it is called, interferes with S's performance, then it is inferred that rehearsal has been interrupted. This is consistent with the assumption that the presentation of extraneous material interferes with the rehearsal process.

Deutsch (1970) has demonstrated that memory for tonal pitch (same or different response) is disrupted by the interpolation of other tones. Gilson and Baddeley (1969) have shown that memory for tactile stimuli is affected by the interpolated activity of counting backwards. Results are inconclusive as counting backwards cannot be considered shadowing in the same modality as the presented stimuli. Therefore, one cannot conclude whether tactual rehearsal took place. In a slightly different paradigm, Kroll et al. (1970) measured recall of an oral (i.e. spoken) or visual target stimulus with vocal shadowing by the subject. Results showed better recall for intervals of 1-25 seconds for the visual target stimulus, indicating that this stimulus can be held or rehearsed in memory for 25 seconds. Unfortunately, this demonstrates rehearsal for only one visual stimulus.

Thus research demonstrating non-verbal rehearsal is inconclusive for hearing subjects. Demonstrated evidence for rehearsal of one tone or one visual stimulus is not compelling evidence for such processes in hearing subjects.

Some studies, designed to investigate the parameters involved in rehearsal of appropriate material, usually verbal in nature, have focused on the actual rehearsal strategy used by the subject.

Corballis (1966) investigated the effects on rehearsal strategies of varying inter-stimulus intervals in separate auditory and visual sequential presentations of digits. In one condition, the inter-stimulus intervals became longer as the series wore on, while in the other condition, the intervals became progressively shorter. If the Ss used a cumulative rehearsal strategy (i.e. re-rehearsed each time after each stimulus presentation) then the condition with the lengthening intervals would maximize performance. Results for visual presentation confirmed this hypothesis but results for the auditory presentation were not conclusive.

In a further study of visually presented sequential lists of digits, Corballis (1968) investigated the types of rehearsal strategies employed by recording timing of rehearsal from throat microphones. Of the ten Ss used, six demonstrated cumulative rehearsal strategies, three demonstrated grouping strategies, while the other S did not manifest any rehearsal strategy. Corballis suggested that the purpose of rehearsal strategies was to order recall information. Both the Ss who cumulatively rehearsed and the Ss who grouped performed equally well, while the S who did not rehearse performed considerably more poorly in ordered recall.

These experiments indicate that rehearsal strategies are important variables affecting short term memory performance.

Studies with the Deaf:

No studies have been directed at the description of rehearsal strategies in the deaf. No data are available demonstrating that rehearsal is more effective for certain types of stimulus material. The discussion of rehearsal in the deaf is then speculative in nature.

Informal observation in pilot study made by this author, as well as those made by Locke and Locke (1971) indicate that some deaf Ss do make use of manual rehearsal. Manual rehearsal refers to the overt rehearsing of stimuli in sign language on the hand of the S. This has been observed both together with oral rehearsal and in isolation. Given this, it seems likely that stimuli can be covertly rehearsed in the deaf in a kinesthetic-visual system as an internalization of sign language. The covert use of sign language is called dactyllic (Locke and Locke 1971). There is some evidence consistent with the notion of a dactyllic memory system in the deaf.

McGuigan (1971) replicated Max's work (1937) on thought processes in the deaf. Using more sophisticated equipment, McGuigan recorded electrical impulses (EEG) from both arms, right leg, lip muscles and the motor area of the cerebral cortex from hearing and deaf subjects. Results were consistent with Max's results with deaf subjects. Finger and arm musculature (left arm only) as well as lips functioned covertly during a silent problem solving task for the deaf, while the other EEG measures showed no significant change. Although gross EEG recordings such as these are not totally reliable, these results are consistent with the notion that a dactyllic method of rehearsal is used by deaf subjects.

If the deaf do use a kinesthetic-visual system then the rehearsal of certain items which can be easily translated or encoded to this system should be facilitated for deaf subjects compared to hearing subjects. This might account for the superior span capacity of the deaf in certain tasks such as the Knox Cube task and those making use of spatial cues.

In summary, research with hearing subjects shows that rehearsal is more effective for verbal than non-verbal material. No similar research is available for the deaf. Observation indicates that a manual rehearsal system can be used by the deaf for verbal material. Rehearsal of certain non-verbal material could be more easily adapted to a covert dactyllic system in the deaf than to the oral verbal system of the hearing.

Hearing subjects use cumulative oral rehearsal and oral grouping rehearsal for verbal material. No comparable studies have been done with the deaf. Observation indicates that deaf subjects use complex manual rehearsal strategies in isolation and/or in concordance with oral rehearsal for verbal material.

Coding:

Investigations of the type of coding processes involved in short term memory performance stem from the analysis of errors made in recall (Bartlett 1932). Recall errors of certain types (specified below) were analyzed in terms of a certain code based on similarities within a sensory system. If this code is based on a sensory system which is different from the original sensory modality of presentation, and if the errors are significant, it is assumed that the original stimuli had been recoded into the sensory system in which errors were observed. Thus, errors reflect confusion in the sensory system in which recoding occurred.

Studies with the Hearing:

In paradigms where serial order recall is demanded, one can separate four classes of errors (Conrad 1959):

(1) Transposition errors occur when adjacent stimuli are reversed in order. Transposition of two stimuli are common, and transpositions of three and four stimuli are possible. Transpositions of more than four stimuli (n+4) are difficult to identify unless the n+4 transpositions are from a field of n+4 stimuli.

(2) Omission errors occur when a subject does not make a response in a particular slot.

(3) Serial order intrusions occur when stimuli from a previously presented sequence are recalled in the correct serial position of a subsequent sequence.

(4) Substitution errors occur when a subject recalls an incorrect stimulus for a particular position. There are three possible reasons for the occurrence of a substitution error. First, the error can be random. Second, the error results because the subject guesses and has completely forgotten. Third, the error reflects a systematic substitution of one stimulus for another. It is this last possibility for this type of error which has been the focal point of much interest in recent years.

The interest stems from studies (Conrad 1962, 1964, 1965) which demonstrate that for visual presentation of stimuli (usually letters of the alphabet) the code analyzable from this type of substitution error is acoustic in nature. Thus for visual presentations the subject would confuse 'c' for 'd' because they 'sound alike' rather than 'c' for 'o' because they 'look alike'. Others, notably Wicklegren (1965, 1966), have since argued that the nature of these confusions is really articulatory and not acoustic. It will suffice for the purposes of this consideration to call this type of error auditory, whether it be acoustic or articulatory.

Studies with the Deaf:

Research into coding processes in the deaf followed naturally from the question: What type of code do those who have no auditory experience use?

Conrad and Rush (1965) studied immediate written recall of simultaneously presented letters of the alphabet in deaf subjects (ages 13-20). The authors, arguing that the auditory errors reflected an important auditory component in their memory processes, hypothesized a similar visual error in the deaf. Their rationale for this hypothesis came mainly from results of the digit span studies (Blair 1957, Fuller 1959) with the deaf which indicated that forward span was the same as reverse span. Conrad and Rush interpreted this as evidence for the fact that the deaf used a primarily visual coding system. Forward span being the same as reverse span was evidence for the fact that they could 'read off' the rehearsed stimuli with equal facility in either direction.

We have noted before that there is reason to doubt the fact that forward recall is the same as reverse recall in the deaf. Also, this hypothesis, based on the deaf S's rehearsal of digits, fails to take into account the inferior performance of the deaf to the hearing. It is not surprising then that Conrad and Rush were unable to find any evidence for their hypothesis. Errors made by the deaf were not consistent with either auditory or stimulus shape (i.e. visual) cues. Discussions of manual rehearsal systems and dactyllic codes in the deaf, although speculative in nature, would suggest that even if one ignores the inferior span capacity of the deaf a most obvious code of analysis should be a dactyllic one. This type of analysis was not performed.

Conrad (1970) reported a similar study with a highly select sample (i.e. high standard of educability) of deaf students, aged 12-17. Presenting letters of the alphabet successively for immediate written recall, Conrad was able to divide the sample into two groups on the basis of error analysis. One group of deaf students (Group A) showed error matrices consistent with articulatory confusions, however these types of deaf Ss comprise only a small minority of all deaf Ss. The second group of deaf students (Group B) had error matrices with no consistently analyzable confusions. Error analysis of dactyllic coding was not used.

In a test of reliability of this classification, both groups silently read two lists of words for immediate recall. One list of words consisted of five pairs of common homophones (words which sound alike but look different), while the other list consisted of five pairs of common homographs (words which look the same but sound different). Group A recalled significantly more homophones while Group B recalled both lists equally well. This result confirmed the faciliatory use of articulatory cues by Group A.

Conrad (1971) following up the above study with the same subjects, reported that in a test of reading comprehension, Group A retained more material when reading aloud than did Group B. When reading silently, both groups retained the same amount of material. This result is difficult to interpret. It is a moot point whether speaking out loud facilitated the performance of Group A or inhibited the performance of Group B.

Although it does seem to be accepted that reading out loud does have a faciliatory effect on the performance of the hearing (Murray 1965, Conrad and Hull 1968, Murdock and Walker 1969), it is not clear whether this fact is true of the deaf, given the little that is known of their coding strategies. The results do, however, confirm the use of articulatory cues by a small minority of the deaf population.

Another type of research relevant to the eludication of coding strategies in the deaf is found in the work of Allen (1969). In her studies, paired associate tasks were given to deaf, hard of hearing and hearing subjects. The lists varied in structure. In the first study, two lists were given, a list of homographs and a list of homophones. The results revealed an interaction between hearing ability and list type. The hearing group took fewer mean trials to criterion on the homophone list but more trials than both hearing deficient groups on the homograph list. In general, both hearing deficient and deaf groups performed alike. In a second experiment, the lists were set up to produce inhibitory rather than faciliatory effects. For example, the homophonic inhibiting lists had homophonal relationships between response words and not between stimulus and response words (e.g. door - sigh, more - lie). Similarly, the homographic inhibiting lists wet up homographic relationships between response words (e.g. done - rush, gone - push). In this way homophonic and homographic cues were interferring rather than helpful. Results were consistent with those in the first experiment. Deaf groups now took more mean trials to criterion with the homographic confusing list, while the opposite was found for the hearing group.

The author concluded that the interaction of list type with hearing ability reflected differences in strategies in coding processes in the two groups, for verbal material. That the deaf group took advantage of visual cues in these specific tasks does not, however, demonstrate what strategies or modalities are determined by their memory processes for verbal material, but rather what modalities can affect their performance. For example, the fact that the deaf group used visual cues does not preclude the hypothesis that they use a dactyllic system. Results from another study indicate that this may be so.

Locke and Locke (1971) suggest that some deaf subjects can use dactyllic cues to aid their performance in visual paired associate tasks. Three lists of letters of the alphabet, a list of paired phonetically similar letters, a list of paired visually similar letters, and a list of paired dactyllically similar letters were presented to hearing, orally proficient deaf subjects and non-orally proficient deaf subjects for immediate written recall. It was hypothesized that items would be easier to recall if they shared a feature in common (Jenkins et al. 1968, Underwood et al. 1959). If the items sharing this feature were relevant to the coding strategy of the subject, then they would be recalled more accurately.

Results showed that hearing loss interacted with list type. Non-oral deaf subjects recalled more dactyllically similar pairs than both other groups, there being no difference in performance between orally proficient deaf and hearing subjects. This suggests that some deaf subjects can make use of dactyllic cues.

Hearing subjects recalled more phonetically similar and visually similar letters than either of the deaf groups, there being no difference in performance between the two deaf groups for these list types. This suggests that hearing subjects profit more from the use of phonetic and visual cues.

That hearing subjects can better use phonetic cues is consistent with previous findings (Conrad 1962, 1964, 1965). That some deaf subjects can better use dactyllic cues is consistent with observations of rehearsal strategies in the deaf. Indeed, Locke and Locke's own observations corroborate this fact. Two results are not consistent with previous findings. First, that orally proficient deaf subjects were not better able to use phonetic cues than non-orally proficient deaf subjects is not consistent with the findings of Conrad (1970). Most likely this means that Conrad's 'articulators' were a highly select group of deaf subjects, as Conrad himself suggested. Second, that hearing subjects made more use of visual cues is not consistent with the findings of Allen (1969) who found that deaf subjects were better able to use homographic cues in paired associate tasks. The authors can offer no explanation for this apparent discrepancy.

That deaf subjects can profit from dactyllic cues does not demonstrate directly, however, that this is their primary modality of coding for verbal material.

In summary, it has been demonstrated that auditory coding is an important factor in the short term memory performance of hearing subjects. Comparable studies have failed to identify a similar code for the majority of the deaf subjects. A small group of highly select deaf subjects can use articulatory coding. However, data from most studies have not been analyzed to determine whether a dactyllic code had been used by deaf subjects. Results from paired associate studies indicate that deaf subjects can profit from the use of dactyllic cues as well as visual cues.

Experiment 1:

The purpose of this experiment was to assess the relative ability of deaf and hearing Ss in the recall of visually presented series of digits. Since previous studies have failed to counterbalance forward and reverse recall, that was done. Also, because the effects of pre and post-cueing have not been looked at in the deaf, that variable was included. The effects of pre and post-cueing are thought to be important in revealing short term memory strategies in deaf and hearing Ss.

On the basis of previous studies, it was hypothesized that the deaf would show an overall capacity deficit in serial recall ability compared with hearing Ss. Further it was expected that both deaf and hearing Ss would show better forward recall than reverse recall (a forward/reverse effect). It was expected that this effect would be more pronounced in hearing Ss.

Subjects:

Forty deaf subjects from the Newfoundland School for the Deaf (St. John's) and forty hearing subjects from Roncalli School (St. John's) were used. All subjects (24 females and 16 males in each group) were between the ages of 12 and 17. Hearing Ss were drawn to match deaf Ss on age and sex. As there exists no fair way of assessing the IQ of deaf Ss in this age range (Furth 1966), it was not possible to match Ss on IQ criterion. Objections to matching deaf and hearing Ss on only age and sex can be partly met by the lack of reliable intellectual criteria and also by the fact that performance on the digit span is not strongly related to intelligence. For example, the Digit Span subtest of the Wechsler Intelligence Scale for Children has a low correlation with other subtests. In fact, for that reason, Wechsler omitted Digit Span from the calculation of IQ (Wechsler, 1949, p. 6).

The Newfoundland School for the Deaf is a residential school for deaf children from all over the province of Newfoundland. Of the 135 children who attend this school, 35 children are from St. John's and live at home. The rest of the children live in a residence adjacent to the school.

The school is of the oral philosophy of deaf education. This means that the children are given intensive oral training. All communication in the classroom is done orally and all the students are encouraged to wear hearing aids. Sign language is not permitted in the classroom.

In practice, most deaf Ss use sign language to communicate among themselves and with teachers who know sign language. However, the deaf children vary considerably in their sign language and oral skills. There was, unfortunately, no reliable method of assessing the diversity in oral and manual skills of the deaf Ss in this study. Further, as the school does not have any records of the etiology of deafness for its pupils, there was no reliable method available to assess the differential performance of congenitally and adventitiously deaf Ss. Criterion of admission to the school was a hearing loss of 75 DB or more in the better ear over the speech range of frequencies.

Roncalli is a school just outside the city of St. John's, with students from the city and a nearby town, Portugal Cove.

All Ss had normal or corrected vision. No S had serious visual defects.

Materials:

The stimuli consisted of single black Lettraset 42 points Hellvetica medium digits applied directly to the surface of 2" x 2" electrographic slides. Only the digits 1 through 9 were used. A Carousel 850 Slide Projector was used to project a one and one-half foot square image on the wall approximately ten feet in front of the S. Timing was controlled by an electric Digibit timer assembled specifically for the study.

Procedure:

Digits were presented singly in sequence in ascending spans starting with a three digit series. Span lengths were increased by one digit on each new trial until the maximum of a nine digit series was reached. No digit appeared twice in the same span.

Each S was given a special booklet in which to write his responses and was instructed to write the digits in the indicated order. One page in the booklet was used for each trial. Each page contained as many empty spaces as there were digits in the span to be presented.

Verbal instructions were given to hearing Ss. They were told that they would see digits in succession. They were told to wait for an arrow to appear before writing down the numbers they saw in the same order presented (for forward recall) and in the reverse order presented (for reverse recall). For the deaf Ss, identical instructions were given simultaneously in oral and sign language.

All testing was done individually in two sittings (one week apart) lasting about one-half hour each. Each S did the pre-cued condition in the first sitting and the post-cued condition in the next sitting. Before each session, all Ss received practice on two and three digit series. Practice criteria were correct responses to two two-digit series in a row.

An arrow was used to cue recall and its direction cued direction of recall. An arrow pointing to the right cued forward recall. An arrow pointing to the left cued reverse recall. This directional cueing was used consistently through all trials, regardless of pre and post-cued conditions. In the pre-cued condition, the directional cueing was, of course, redundant. In the post-cued condition, the arrow was the S's sole cue to recall the digits in the order given or in reverse order.

In the pre-cued condition each S knew beforehand what the direction of recall would be. Half the Ss did a complete forward span series first (a three digit to a nine digit series) and a complete reverse span series next (three digit series to a nine digit series). The other half of the Ss did the reverse span series first and the forward span series last. The Ss were randomly assigned to the two categories.

In the post-cued condition, no subject knew beforehand what the direction of recall would be. As in the pre-cued condition, two sets of stimuli consisting of a three digit to a nine digit series, were presented. However, forward and reverse recall (now critically dependent on the directional cueing) were required in a random order within each set. Two sets of stimuli were necessary, therefore, in order to obtain a forward and reverse measure at each span. The order of presentation of these two sets of stimuli was counterbalanced.

The experiment, therefore, provided two measures of forward and reverse recall for pre and post-cued conditions over seven span lengths (three digits through nine digits) for each subject tested.

A standard stimulus onset period of one second as in Olsson (1960) and Conrad (1970) was used. The inter-stimulus interval was two seconds. Thus, one digit was presented every three seconds. (For example a five digit series would take approximately 15 seconds from onset of first digit to recall). This may be considered slow, but Mackworth (1962) has shown that slower visual presentation rates maximized performance for hearing Ss. This slow interval also allows for cumulative rehearsal for longer spans.

Scoring:

Two methods of scoring were used, ordered recall (OR) and unordered (UOR). In OR, the number of digits correct with regard to serial position was totalled for each trial.

For example, if the <u>S</u> had five digits in the correct positions in a nine span, he was given a score of five. In UOR, the number of digits correct without regard to serial position was totalled for each trial. For example, in the nine span of the <u>S</u> above, if the other four digits, wrong with respect to order, did appear in the <u>S</u>'s response series, he would receive a score of nine.

<u>Design</u>:

A four way analysis of variance with repeated measures on three factors was used for both OR and UOR. The between subject variable was Deafness (D), with two levels, hearing and deaf. There were three within subject factors: Cueing (C), with two levels, pre-cueing and post-cueing; Forward/Reverse (F), with two levels, forward recall and reverse recall; Series Length (S), with seven levels, one for each of the spans presented (i.e. a three digit through a nine digit series). There were forty observations per cell.

<u>Results</u>:

The results of the analyses of variance are shown in Table 1. There was a significant deafness (D) effect in both OR and UOR analyses. Hearing <u>Ss</u> recalled more digits ($\overline{X}_{OR}$= 3.73, $\overline{X}_{UOR}$=5.38) than deaf <u>Ss</u> ($\overline{X}_{OR}$=2.12, $\overline{X}_{UOR}$=4.13).

Overall, subjects of both deaf and hearing groups recalled more digits in the forward spans ($\overline{X}_{OR}$=3.25, $\overline{X}_{UOR}$=4.85) than in the reverse spans ($\overline{X}_{OR}$=2.60, $\overline{X}_{UOR}$=4.67).

The significant deafness by forward/reverse interaction (DF) for both OR and UOR is shown in Table 2. The deaf <u>Ss</u>

TABLE 1

Experiment 1

Analysis of Variance

Source	DF	Ordered MS	Ordered F	Unordered MS	Unordered F
Between					
Deafness (D)	1	1451.53	117.54**	876.25	67.47**
Subject within groups (R)	78	12.35		12.99	
Within					
For/Rev (F)	1	241.17	55.93**	17.33	12.85**
DF	1	121.18	28.10**	29.95	22.21**
RF	78	4.31		1.35	
Cuing (pre-post) (C)	1	44.30	16.47**	.49	.27
DC	1	10.18	3.79	2.25	1.26
RC	78	2.69		1.79	
Series Length (S)	6	37.98	15.14**	451.86	184.69**
DS	6	35.00	14.07**	50.13	20.95**
RS	468	2.51		2.39	
CF	1	3.23	1.60	2.38	1.75
DCF	1	3.54	1.75	1.66	1.22
RCF	78	2.02		1.36	
CS	6	4.73	2.38*	1.09	1.05
DCS	6	2.59	1.31	.43	.41
RCS	468	1.99		1.04	
FS	6	9.09	4.59**	4.35	3.75**
DFS	6	17.83	9.00**	2.59	2.23**
RFS	468	1.98		1.16	
CFS	6	2.75	1.61	2.32	1.97
DCFS	6	1.66	.97	.26	.22
RCFS	468	1.70		1.18	

p<.05*
p<.01**

TABLE 2

Experiment 1

DF Interaction

		OR	UOR
Deaf	Forward	2.21	4.11
	Reverse	2.02	4.16
Hearing	Forward	4.29	5.59
	Reverse	3.18	5.18

showed no differences between forward and reverse recall on either of the scoring methods, while in the hearing case, forward recall was greater than reverse recall in both methods of scoring ($F_{OR}=82.02$, $p<.01$; $F_{UOR}=34.52$, $p<.01$).

There was a significant deafness by series length interaction (DS) with both methods of scoring (see Figure 1). Hearing Ss recalled significantly more digits than the deaf Ss at the 4, 5, 6, 7, 8 and 9 spans in OR (for these and other significant multiple comparison tests, see Appendix 1) and at the 5, 6, 7, 8 and 9 spans in UOR.

The significant deafness by forward/reverse by series length interaction (DFS) (see Figures 2 and 3) showed that deaf Ss gave significantly better recall for forward series for both the 4 and 5 spans in OR, but no forward/reverse differences in UOR. Hearing Ss showed better forward recall than reverse recall at the 5 through 9 spans in OR and at the 7, 8 and 9 spans in UOR.

The significant main effect cueing (C) in OR showed that, over both deaf and hearing groups, pre-cueing ($\bar{X}=3.06$) produced better performance than did post-cueing ($\bar{X}=2.78$).

All other interactions are outlined in Appendix 1.

Discussion:

The overall inferiority of deaf to hearing Ss in short term memory for visual presentation of digits as reported in previous studies (Blair 1957, Fuller 1959) is confirmed here. For both ordered and unordered measures of recall, deaf Ss did not recall as many digits as their hearing counterparts.

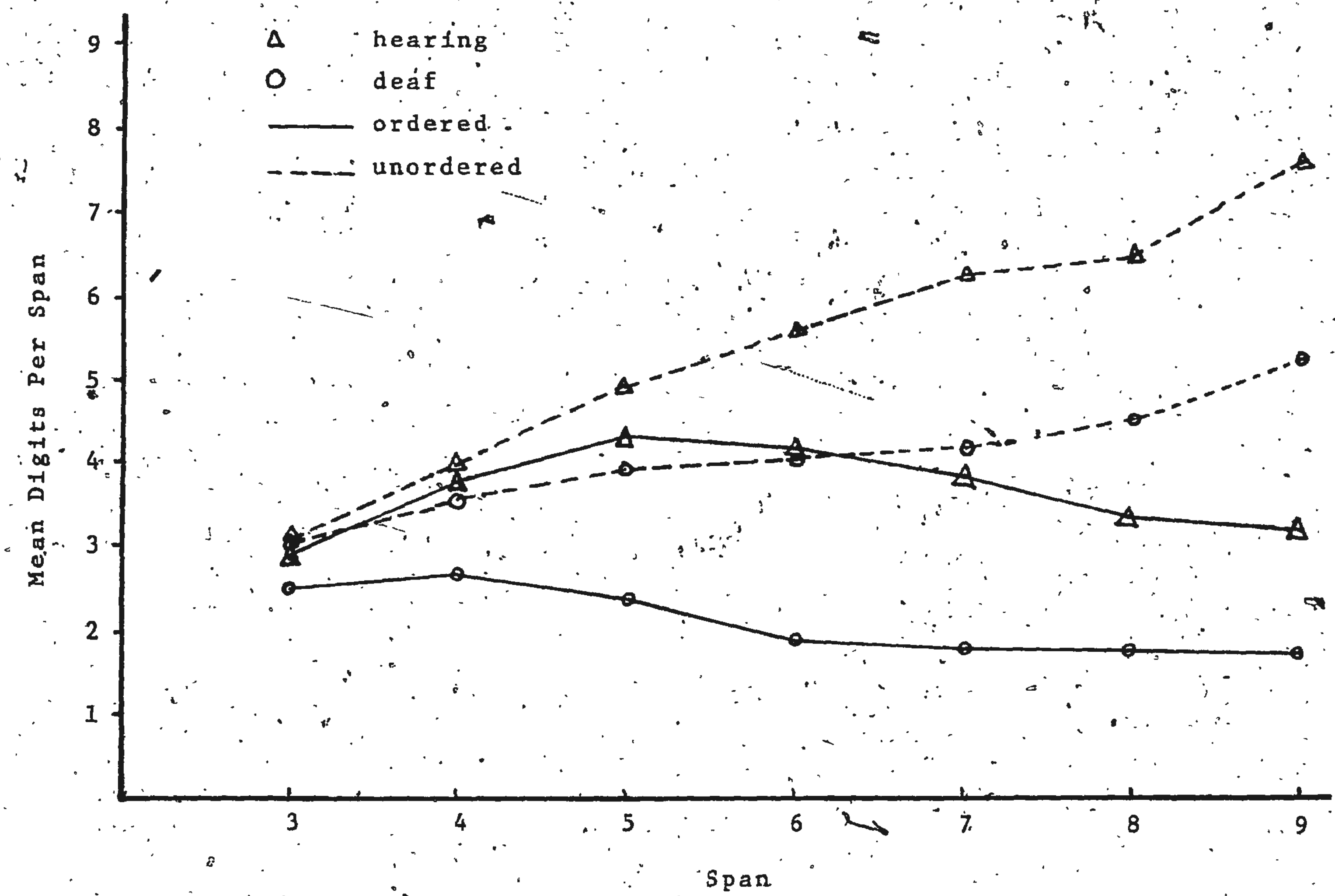

FIGURE 1. DS Interaction
Experiment 1

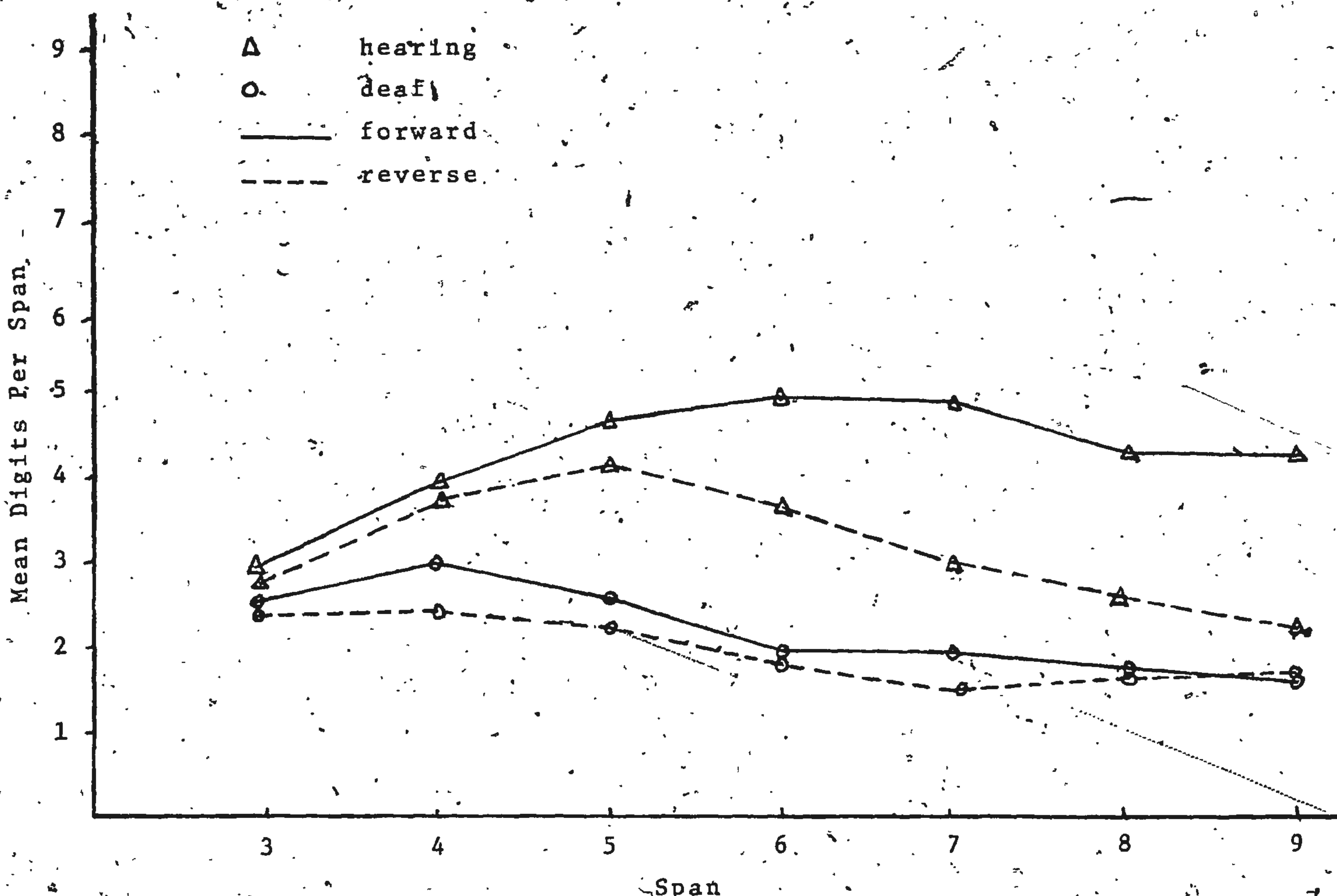

FIGURE 2. DFS Interaction: Ordered Recall
Experiment 1

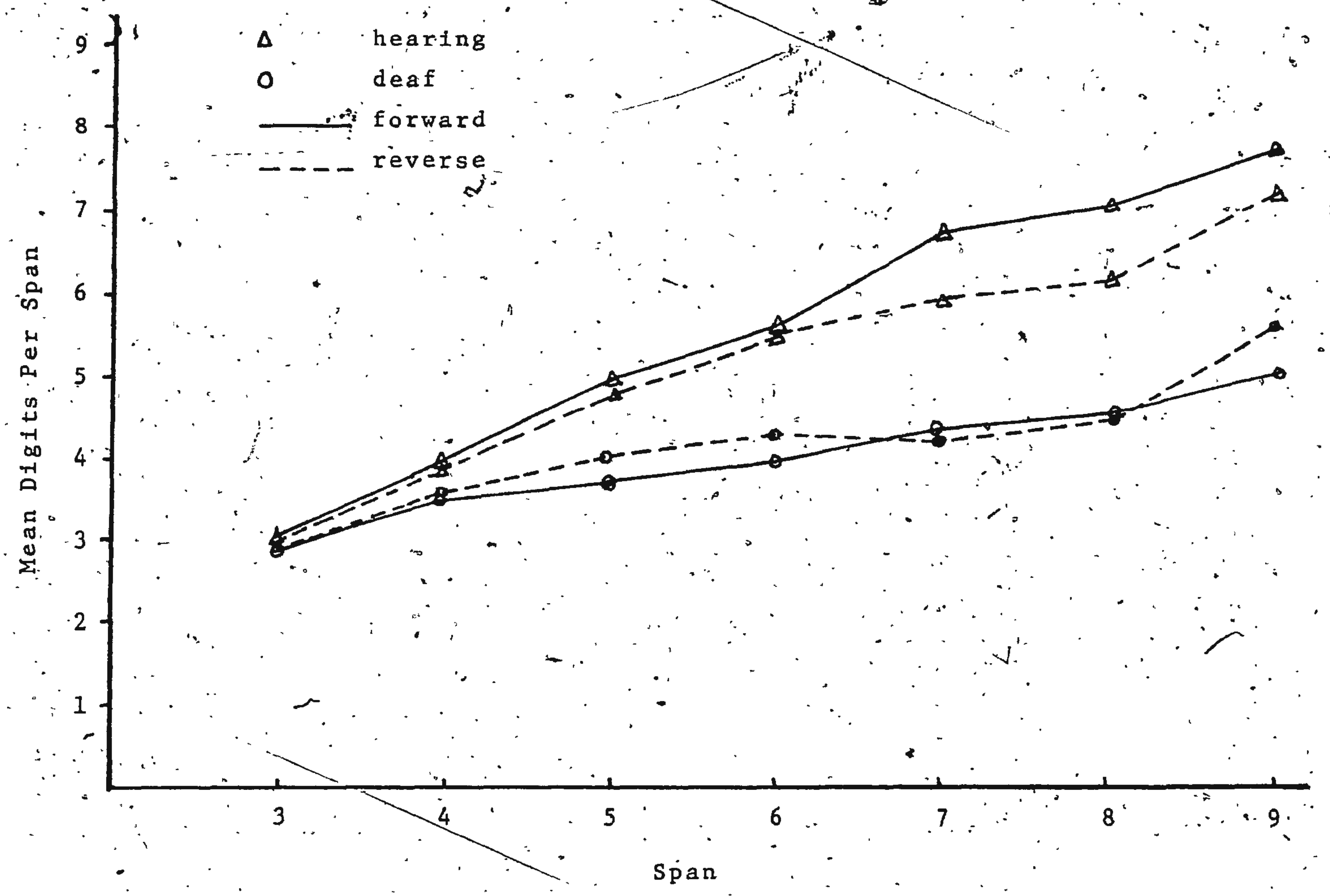

FIGURE 3. DFS Interaction: Unordered Recall
Experiment 1

Examination of this result reveals that the lower performance of deaf Ss was more pronounced in ordered recall, the deaf being inferior to the hearing at all but the three span. In unordered recall, deaf Ss were inferior to hearing Ss at all but the three and four spans. In other words, at the three span, deaf Ss recalled as many digits as the hearing Ss for both measures of recall, while at the four span, deaf Ss were inferior in OR, but recalled as many digits as the hearing in UOR. This suggests that capacity deficits here are due to an inferiority in ordering. Deaf Ss were inferior at the five to nine spans for both measures of recall.

The striking differences between the deaf and hearing in UOR suggests a content deficiency in the deaf. Examination of the performance of the deaf in UOR shows that deaf Ss did not have available as many correct stimuli for ordered recall. While hearing Ss consistently retained close to the maximum number of correct digits, deaf Ss performed well below this level. That these digits were not available to the deaf for ordered recall suggests that the overall capacity deficit in the deaf can, in part, be traced to input factors. That few correct digits were present means that either the information did not enter the system or was lost very quickly.

Several possibilities exist to explain this fact. These include memory processing factors such as inferior coding mechanisms, inferior rehearsal strategies and even the possibility that the recall of the digits themselves is interfering. There also exists the possibility that aspects of the stimulus such as inadequate spatial cues or a lack of familiarity, are important.

While hearing Ss showed overall superior forward recall for both OR and UOR, deaf Ss showed no overall differences on both measures. Deaf Ss did, however, show better forward than reverse recall in OR at the four and five spans, while hearing Ss showed better forward recall at the five through nine spans. In UOR, the deaf showed no difference between forward and reverse recall at any span, while the hearing showed better forward recall at the seven through nine spans.

For hearing Ss, these results in OR are consistent with previous studies (Star 1923, McCaulley 1928) which indicated that performance is better for forward than reverse recall. This experiment reveals a similar result for UOR, a measure not previously used.

For deaf Ss the overall result that no difference exists between forward and reverse recall in OR is consistent with previous studies (Blair 1957, Fuller 1959). However, examination of the relative strengths of forward and reverse recall across the spans indicates that this overall result did not hold true at all spans. In OR, forward recall was greater than reverse recall at the four and five spans. In UOR, there was no difference between forward and reverse recall.

Although the cueing (C) factor was significant, it did not differentiate between deaf and hearing groups. The deafness by cueing interaction (DC) in OR, however, did approach significance. The direction indicated is that while hearing Ss remained unaffected by pre and post-cueing conditions, deaf Ss performed better with pre-cued instructions.

Experiment 2:

In Experiment 1, it was found that deaf Ss did not have as many correct digits available for ordering as hearing Ss. It has been noted that the span capacity of deaf Ss varies with the type of stimulus presented. The purpose here then, was to increase the digit span capacity of deaf Ss by adding cues to the stimulus. Spatial and/or somatic sensory information was added to the stimulus set as described below. As in the previous experiment, forward and reverse recall in pre and post-cued conditions were examined.

Consistent with the notion that deaf Ss profit more from added spatial information than hearing Ss, it was hypothesized that added spatial cues in the digit stimulus set would improve the recall of deaf Ss relative to hearing Ss. Also, since deaf Ss are more sensitive to kinesthetic and somatic sensory information (in that they use hand and body gestures to communicate), it was hypothesized that added somatic sensory information in the digit stimulus set would improve the span capacity of deaf Ss relative to the hearing.

Subjects:

The forty deaf and hearing Ss from Experiment 1 were used. Each of the deaf and hearing groups was divided in two, with the Ss in each half matched on their performance in Experiment 1.

Materials:

Digits were applied singly to 2x2 slides as in Experiment 1 except that different digits always appeared in a fixed location on the slides (see Figure 4). Therefore, the individual digits were discriminable not only in terms of their form, but also in terms of their spatial location on the screen.

Added somatic sensory information was provided by E gently tapping the S's back in a location equivalent to the location of the digit on the screen. That is, S's back was divided into nine locations just as the slides (see Figure 5). For example, if 1 was presented on the screen, the upper left shoulder blade was tapped. The hypothetical 3x3 matrix on the back of the S mirrored in orientation the 3x3 matrix of the visual display.

The equipment used in this experiment was identical to that used in Experiment 1.

Procedure:

Half the deaf Ss and half the hearing Ss were assigned to the spatial condition while the other subgroups were assigned to the spatial and somatic sensory condition. The procedure used in this experiment for those Ss who received only additional spatial information in the stimulus set was identical to that used in Experiment 1. Those Ss who, along with the added spatial information, received additional somatic sensory information, also received practice on somatic sensory stimulation alone. E explained (orally for the hearing and in sign language for the deaf), using an appropriately marked visual aid, that their back was to be 'broken up' into the nine digits. When a digit was shown on

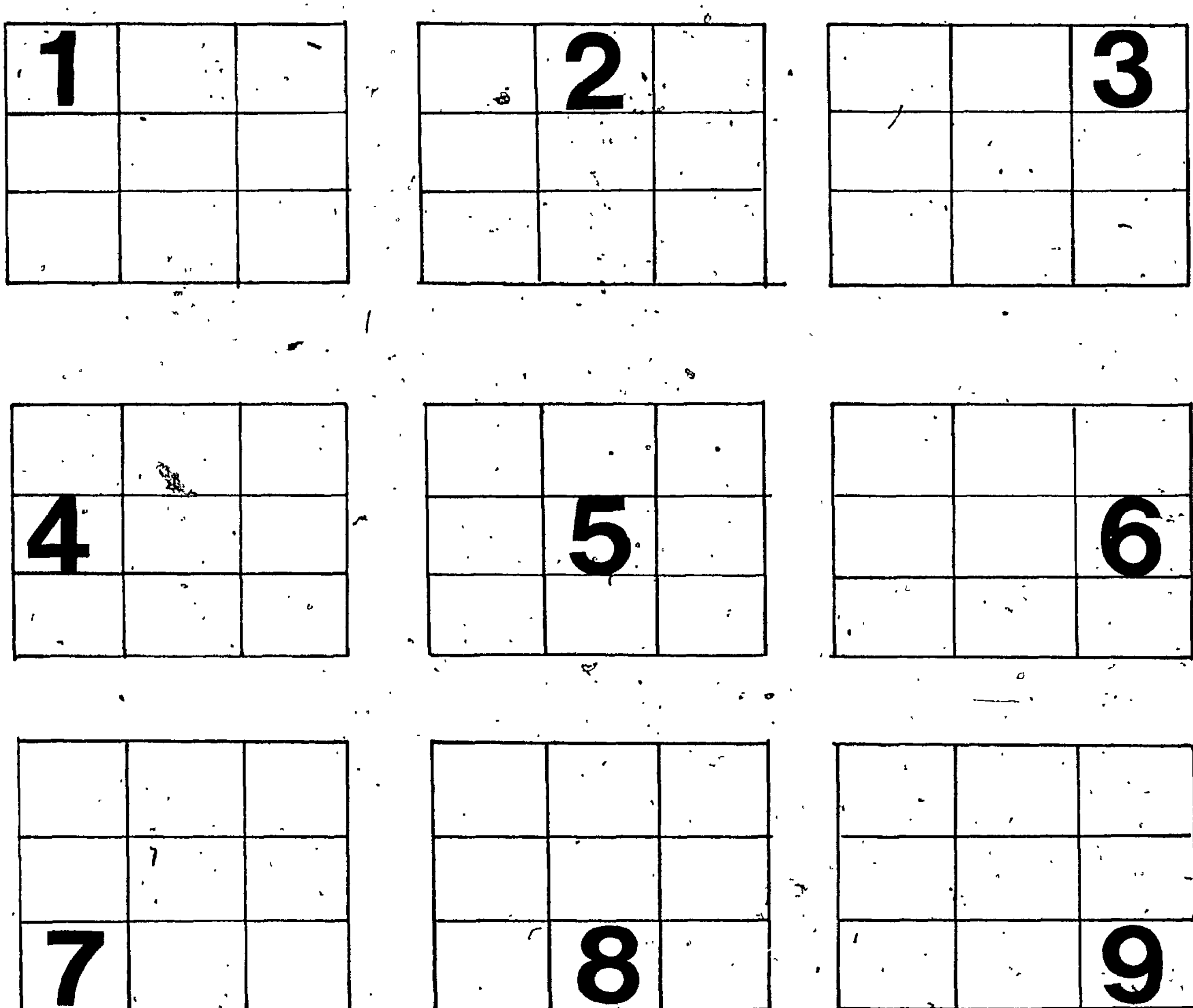

FIGURE 4. Spatial Digits
Experiment 2

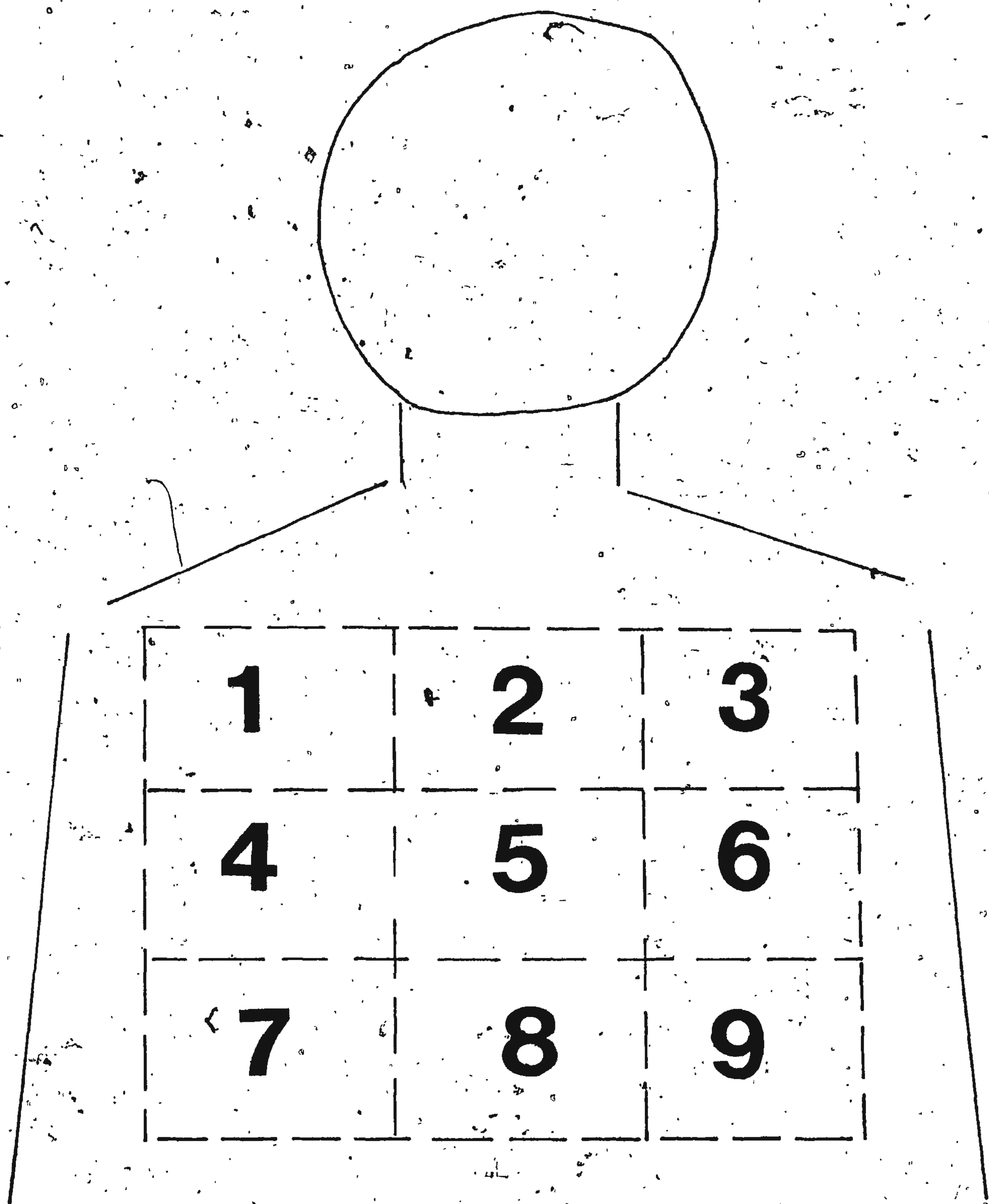

FIGURE 5. Somatic Sensory Digits
Experiment 2

the screen, E would simultaneously tap the appropriate place for that digit on the back of the S. E sat directly behind all Ss who received this 'backtapping'. Criteria for completion of practice for this condition was the correct identification of all nine digits, tapped in random order.

Different random orders of digits were again chosen for presentation, but in all other respects, this experiment was performed like Experiment 1.

Design:

A five way analysis of variance with repeated measures on three factors was used for both OR and UOR. There were two between subject factors: Deafness (D), with two levels, deaf and hearing; Backtapping (B), with two levels, those who received added somatic sensory information and those who did not. There were three within subject factors: Cueing (C), with two levels, pre-cueing and post-cueing; Forward/Reverse (F), with two levels, forward recall and reverse recall; Series Length (S), with seven levels, one for each of the spans presented (i.e. a three digit series through a nine digit series). There were twenty observations per cell.

Results:

The results of the analyses of variance are shown in Table 3. There was a significant deafness (D) effect in both OR and UOR analyses. Hearing Ss recalled more digits ($\overline{X}_{OR}$= 3.91, $\overline{X}_{UOR}$=5.60) than deaf Ss ($\overline{X}_{OR}$=2.33, $\overline{X}_{UOR}$=4.37).

There was no significant backtapping (B) effect.

TABLE 3

Experiment 2

Analysis of Variance

Source	DF	Ordered MS	Ordered F	Unordered MS	Unordered F
Between					
Deafness (D)	1	1395.46	92.01**	855.11	66.77**
Backtapping (B)	1	1.03	.07	6.86	.54
DB	1	25.29	1.67	1.21	.09
Subjects within Groups R	76	15.17		12.81	
Within					
For/Rev)F)	1	275.80	61.40**	9.00	9.92**
DF	1	83.31	18.55**	1.50	1.66
BF	1	4.83	1.07	.22	.24
DBF	1	7.01	1.58	.79	.87
RF	76	4.49		.91	
Cuing (C)	1	45.71	20.18**	5.66	7.31**
DC	1	16.80	7.42**	1.21	1.58
BC	1	4.29	1.89	.71	.93
DBC	1	.11	.001	.46	.46
RC	76	2.27		.77	
Series Length (S)	6	21.94	8.93**	608.35	264.22**
DS	6	43.42	17.68**	53.0	23.02**
BS	6	2.37	.97	3.44	1.49
DBS	6	2.80	1.14	3.09	1.34
RS	456	2.46		.30	
CF	1	4.83	1.96	3.62	5.10*
DCF	1	8.50	3.46	4.29	6.05*
BCF	1	.88	.04	.22	.31
DBCF	1	1.83	.74	.15	.02
RCF	76	2.40		.71	
CF	1	4.83	1.96	3.62	5.10*
DCF	1	8.50	3.46	4.29	6.05*
BCF	1	.88	.04	.22	.31
DBCF	1	1.83	.74	.15	.02
RCF	76	2.40		.71	
CS	6	1.12	.48	.26	.37
DCS	6	1.11	.47	.78	1.11
BCS	6	3.39	1.14	.80	1.13
DBCS	6	2.61	1.11	1.42	2.01
RCS	456	2.35		.71	

TABLE 3 (cont'd.)

Source	DF	Ordered MS	Ordered F	Unordered MS	Unordered F
FS	6	7.12	3.45**	.79	1.16
DFS	6	22.01	10.70**	.84	1.23
BFS	6	1.08	.52	.72	1.05
DBFS	6	1.31	.63	.44	.65
RFS (DB)	456	2.06		.69	
CFS	6	4.71	2.46*	1.78	2.75*
DCFS	6	1.86	.97	.86	1.33
BCFS	6	1.10	.58	1.09	1.68
DBCFS	6	1.55	.81	.41	.63
RCFS (DB)	456	1.92		.65	

*$p<.05$
**$p<.01$

Overall, Ss of both hearing and deaf groups recalled more digits in the forward spans ($\bar{X}_{OR}$=3.47, $\bar{X}_{UOR}$=5.05) than in the reverse spans ($\bar{X}_{OR}$=2.77, $\bar{X}_{UOR}$=4.92).

The significant deafness by forward/reverse interaction (DF) in OR is shown in Table 4. Both deaf and hearing groups recalled more digits in forward than reverse spans. However, the forward/reverse effect shown by hearing Ss (F=73.82, $p<.01$) was more pronounced than that shown by deaf Ss (F=6.19, $p<.05$). This interaction was not significant in UOR.

There was a significant deafness by series length interaction (DS) with both methods of scoring (see Figure 6). Hearing Ss recalled significantly more digits than deaf Ss at all spans in OR (for these and other significant multiple comparison tests, see Appendix 2) and at the 5 through 9 spans in UOR.

The significant deafness by forward/reverse by series length interaction (DFS) in OR (see Figure 7) showed that while hearing Ss showed better forward than reverse recall at the 4 through 9 spans, deaf Ss showed better forward than reverse recall at the 3, 4 and 5 spans. This interaction was not significant in UOR.

The significant main effect cueing (C) in OR and UOR showed that over both deaf and hearing groups, pre-cueing ($\bar{X}_{OR}$=3.26, $\bar{X}_{UOR}$=5.03) produced better performance than post-cueing ($\bar{X}_{OR}$=2.98, $\bar{X}_{UOR}$=4.93).

The significant deafness by cueing interaction (DC) in OR is shown in Table 5. Deaf Ss recalled significantly more digits in the pre-cued condition than in the post-cued

TABLE 4

Experiment 2

DF Interaction: OR

	FORWARD	REVERSE
DEAF	2.49	2.18
HEARING	4.46	3.38

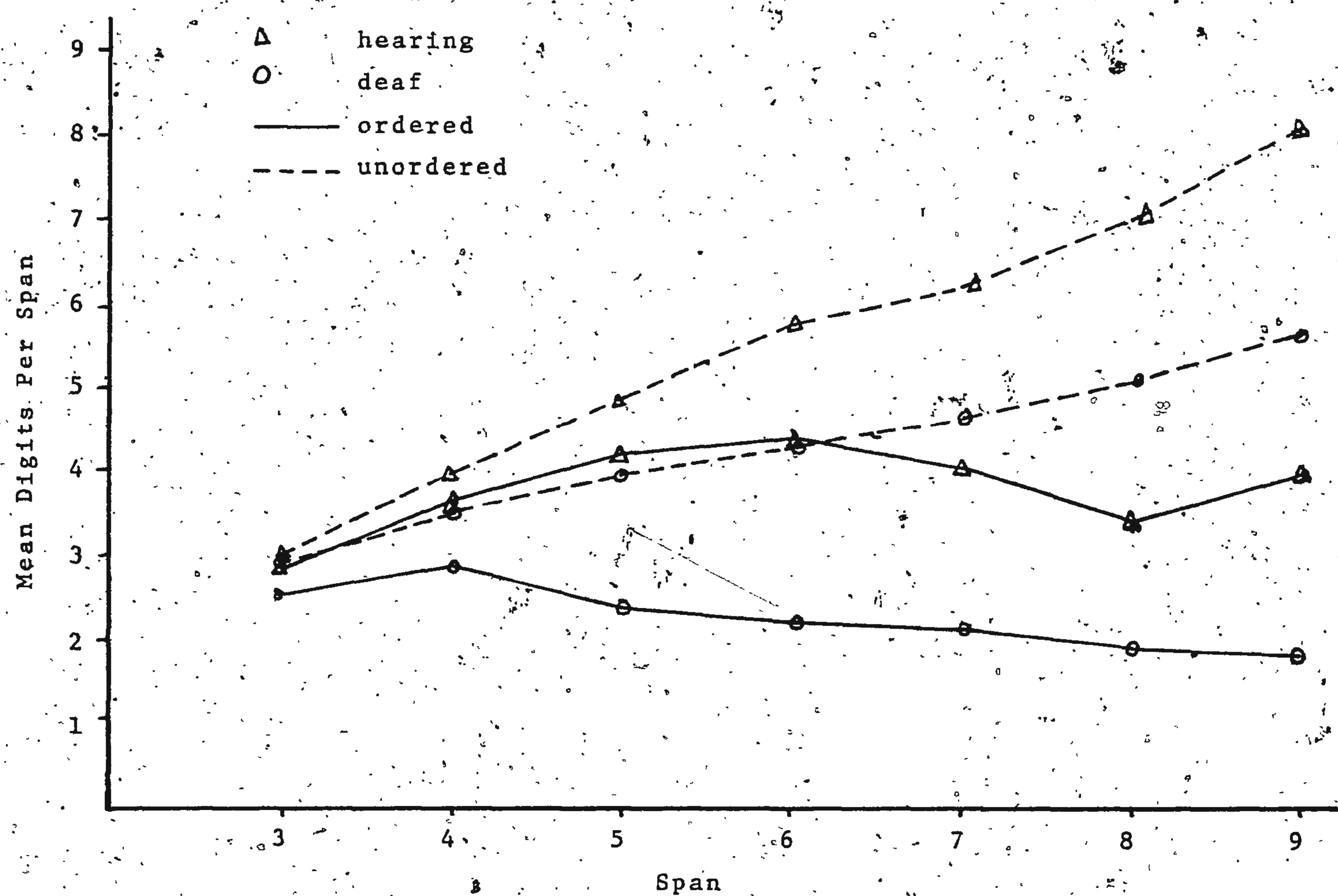

FIGURE 6. DS Interaction
Experiment 2

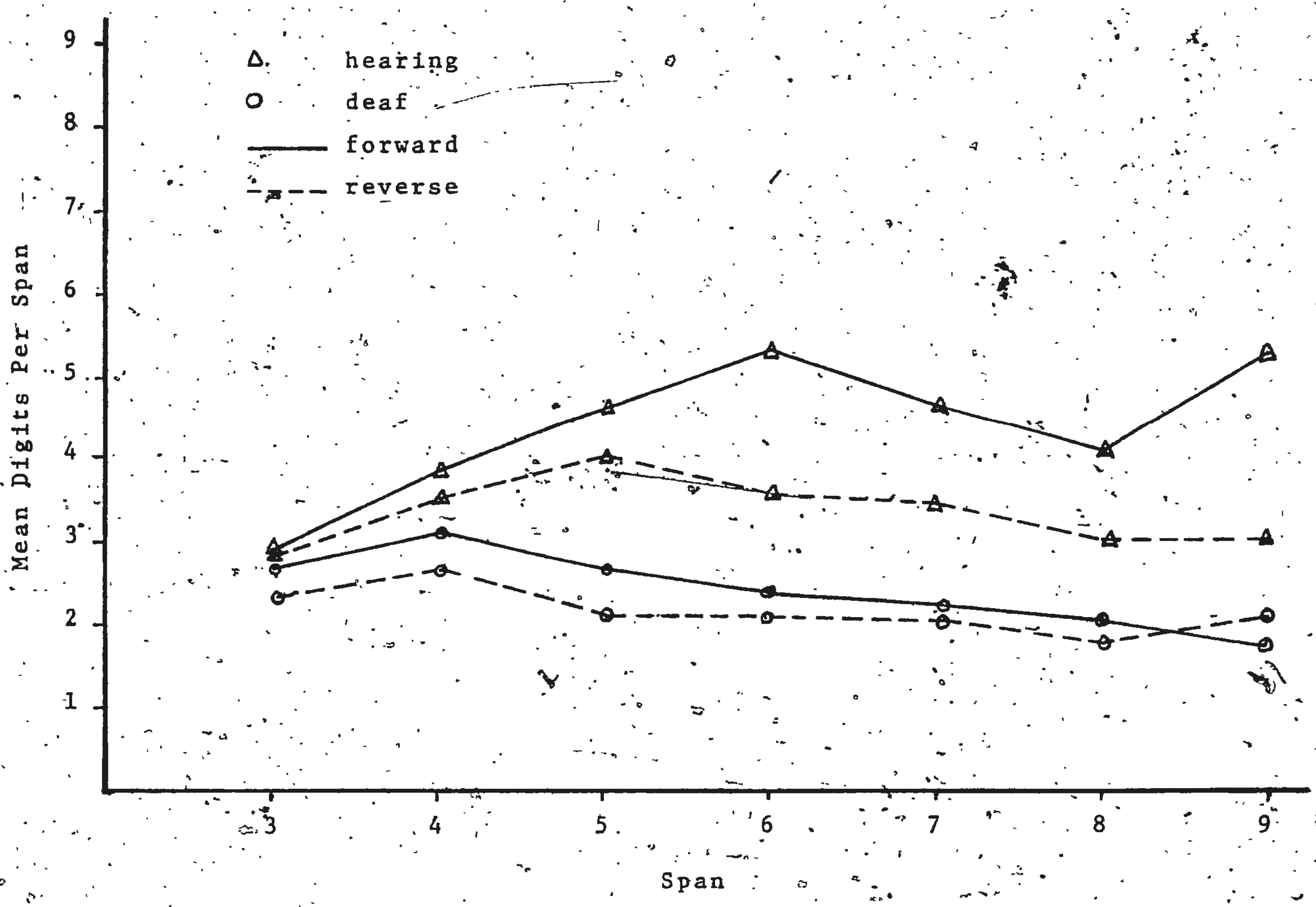

FIGURE 7. DFS Interaction: Ordered Recall
Experiment 2

TABLE 5

Experiment 2

DC Interaction: OR

	PRE-CUED	POST-CUED
DEAF	2.56	2.10
HEARING	3.97	3.86

condition (F=22.98, p<.01) while no such significance was observed for the hearing. This interaction was not significant in UOR.

The deafness by cueing by forward/reverse interaction (DCF) in UOR is shown in Table 6. This interaction indicates that while hearing Ss maintained a forward/reverse effect over pre and post-cued conditions, deaf Ss showed a forward/reverse effect in pre-cued conditions only.

All other interactions are outlined in Appendix 2.

Discussion:

The overall deficit in capacity of deaf Ss compared to hearing Ss in the recall of visually presented series of digits was again confirmed in this experiment despite the fact that added spatial and somatic sensory cues were given. Examination of the DS interaction in UOR again indicates that deaf Ss did not have as many correct digits available for ordering as the hearing Ss. Therefore, the additional cues were not sufficient to overcome the content deficiency in the deaf. That few correct digits were present again means that either the information did not enter the system or was lost very quickly. Explanations of this fact may include deficient memory processing factors or a lack of familiarity with the stimulus set.

The other results were also similar to those found in Experiment 1 with three exceptions. First, DF and DFS interactions, significant for both methods of scoring in Experiment 1, appeared only in OR here. In Experiment 1 the hearing Ss showed a forward/reverse effect in UOR at the 7, 8 and 9 spans. Here there were no such differences.

TABLE 6

Experiment 2

DCF Interaction: OR

		PRE-CUED	POST-CUED
DEAF	FORWARD	4.56	4.32
	REVERSE	4.24	4.34
HEARING	FORWARD	5.71	5.54
	REVERSE	5.67	5.48

The second exception is that the DC interaction, tending towards significance in Experiment 1, was significant here and in the same direction. While hearing Ss remained unaffected by cueing conditions, deaf Ss performed better in pre-cued than post-cued conditions in OR.

Third, the DCF interaction was not significant in Experiment 1 in either OR or UOR, but is significant here in UOR. Table 6 shows that deaf Ss had available more digits in forward recall in the pre-cued condition. This was not the case in the first experiment. However, the additional available digits were not given in the correct order because the DCF interaction in OR was not significant.

The overall results of digit span capacity in the deaf show little change relative to the hearing in this experiment. Therefore, the added spatial and/or somatic sensory information did not have any enhancing effect on the digit span capacity of deaf Ss. A look at the nature of the spatial and somatic sensory information used here may help to explain why no improvement was obtained.

Both the spatial and somatic sensory cues were redundant in that the Ss did not have to attend to them in order to perform the task satisfactorily. In all cases, the original digits from Experiment 1 were still present. In fact, most Ss in the somatic sensory condition, when questioned afterwards, reported not using the additional information. Therefore, that the additional spatial and somatic sensory information had no differential effect on the performance of deaf <u>S</u>s, may be due to the design of the experiment. A true test of the original hypothesis would involve digit span studies using only spatial cues in place of digits (e.g. the dots in a dominoe set) or only somatic sensory information (e.g. backtapping alone).

Experiment 3:

In Experiments 1 and 2, it was found that deaf Ss did not have as many correct digits available for ordering as hearing Ss. It has also been noted that the span capacity of deaf Ss varies with the type of stimulus presented. The purpose here was to increase the digit span capacity of deaf Ss by using stimuli more familiar to them. That was accomplished by showing the sign language equivalents for the digits. It was hypothesized that these more familiar stimuli would improve the digit span capacity of deaf Ss relative to the hearing. As in the previous experiments, forward and reverse recall in pre and post-cued conditions were examined.

Subjects:

Only 24 of the original 40 hearing Ss were available because school had closed for the year. Twenty-four of the 40 deaf originally tested were selected to match the hearing sample. Therefore, the results of this experiment are reported for 24 deaf and 24 hearing Ss.

Materials:

Colour slides for each of the nine digits in the American Sign Language of the Deaf were made. The hand of a native informant was photographed so as to permit for linguistic subtleties not apparent to the hearing or non-native speakers of sign language. A line drawing of the signs as in Rickehof (1963) is found in Figure 8.

The equipment used in this experiment was identical to that used in Experiment 1.

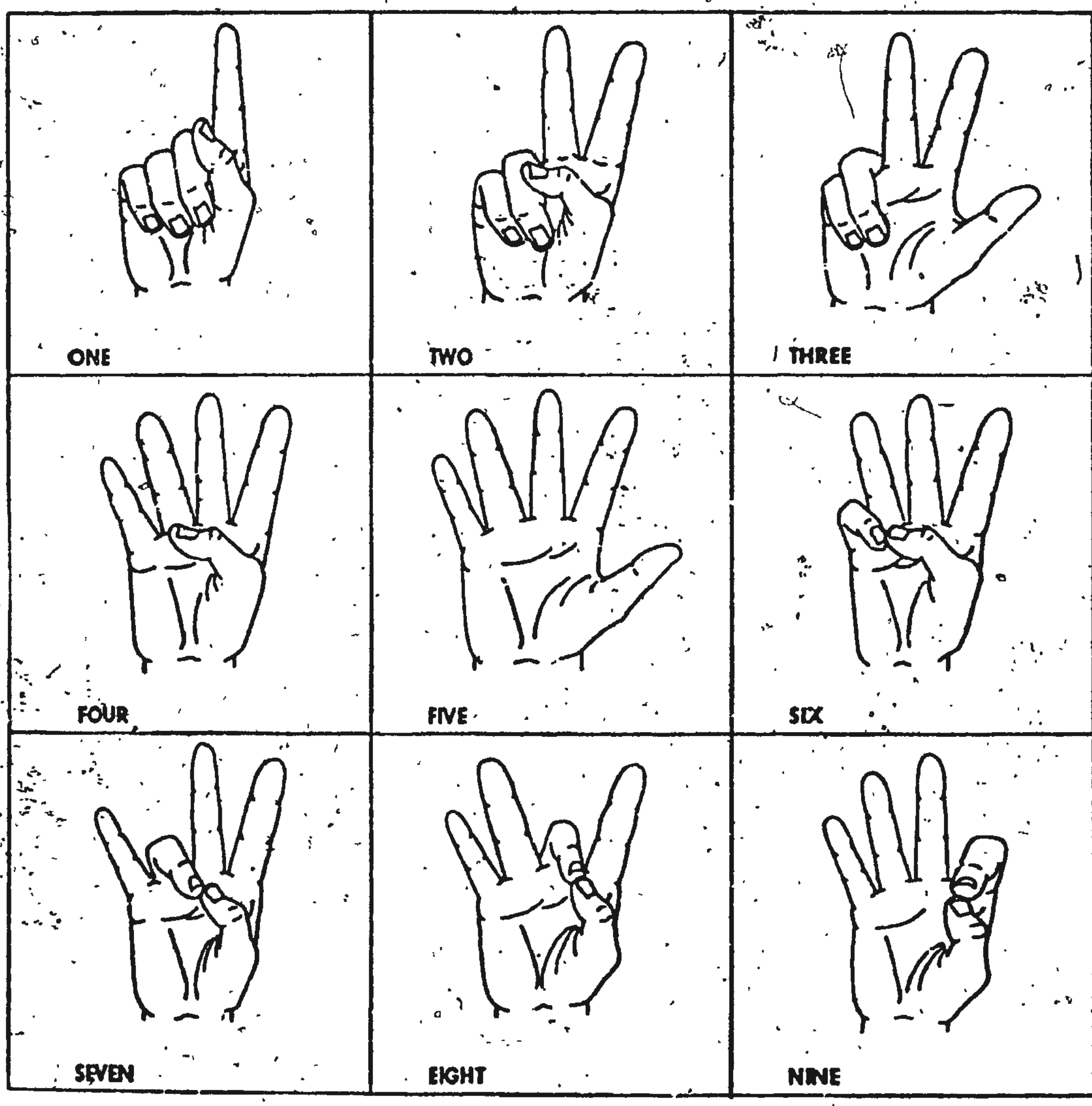

FIGURE 8. Sign Language Digits
Experiment 3

Procedure:

The procedure used in this experiment was identical to that used in Experiment 1 with two exceptions. First, hearing Ss were given additional practice with the projected signs as no hearing S was previously familiar with these symbols. Practice criteria were correct responses to nine individually randomly presented sign digits. Second, different random orders of digits were again chosen for presentation.

Design:

A four way analysis of variance with repeated measures on three factors was used for both OR and UOR. The between subject variable was Deafness (D), with two levels, hearing and deaf. There were three within subject factors: Cueing (C), with two levels, pre-cueing and post-cueing; Forward/Reverse (F), with two levels, forward recall and reverse recall; Series Length (S), with seven levels, one for each of the spans presented (i.e. a three digit series through a nine digit series). There were twenty-four observations per cell.

Results:

The results of the analyses of variance are shown in Table 7. There was a significant deafness (D) effect in OR but not in UOR. Hearing Ss ($\overline{X}_{OR}$=3.50, $\overline{X}_{UOR}$=5.28) recalled more digits than deaf Ss in OR ($\overline{X}_{OR}$=2.83, $\overline{X}_{UOR}$=5.06).

Overall, subjects of both deaf and hearing groups recalled more digits in the forward spans ($\overline{X}_{OR}$=3.44, $\overline{X}_{UOR}$= 5.25) than in the reverse spans ($\overline{X}_{OR}$=2.89, $\overline{X}_{UOR}$=5.09).

TABLE 7

Experiment 3

Analysis of Variance

Source	DF	Ordered MS	Ordered F	Unordered MS	Unordered F
Between					
Deafness (D)	1	154.04	8.54**	16.08	3.06
Subjects within Groups (R)	46	18.03		5.23	
Within					
For/Rev (F)	1	100.22	23.13**	9.17	8.02**
DF	1	7.29	1.68	3.54	3.08
RF	46	4.33		1.14	
Cueing (pre-post) (C)	1	2.42	1.13	6.44	3.05
DC	1	3.75	1.76	.60	.003
RC	46	2.14		2.11	
Series Length (S)	6	30.25	11.24**	517.13	327.99**
DS	6	18.80	6.98**	6.50	4.18**
RS	276	2.69		1.58	
CF	1	11.63	5.00*	1.51	1.27
DCF	1	.17	.07	.81	.68
RCF	46	2.32		1.18	
CS	6	2.67	1.20	2.15	2.94**
DCS	6	1.18	.53	.40	.67
RCS	276	2.22		.73	
FS	6	3.46	1.69	1.56	2.42*
DFS	6	2.43	1.19	.87	1.36
RFS	276	2.05		.64	
CFS	6	6.72	3.15**	1.32	2.10*
DCFS	6	2.56	1.20	1.70	2.70
RCFS	276	2.13		.63	

* $p < .05$
** $p < .01$

There was a significant deafness by series length interaction (DS) with both methods of scoring (see Figure 9). Hearing Ss recalled significantly more digits than deaf Ss at the 5 and 6 spans in OR and at the 5, 6 and 7 spans in UOR, while deaf Ss recalled significantly more digits than the hearing at the 9 span in UOR. (For these significant multiple comparison tests, see Appendix 3). All other interactions are outlined in Appendix 3.

Discussion:

Overall differences in digit span capacity between deaf and hearing Ss were lessened in this experiment. Hearing Ss recalled more digits than the deaf in OR, but, unlike in Experiments 1 and 2, there was no difference between groups in the total number of digits recalled regardless of order.

Examination of the relative performance of deaf and hearing Ss across the spans further confirms a lessening of differences in digit span capacity. Unlike the previous experiments, in which the deaf Ss did not recall as many digits at most of the spans in OR, deaf Ss here remained inferior at only the 5 and 6 spans. Similarly in UOR, in which deaf Ss were inferior at the 5 through 9 spans, deaf Ss here were only inferior at the 6, 7 and 8 spans, but were superior at the 9 span. This marks the only instance in all experiments that deaf Ss showed a greater span capacity than the hearing.

Examination of the curves in Figure 9 indicates that deaf Ss now have considerably more digits available for

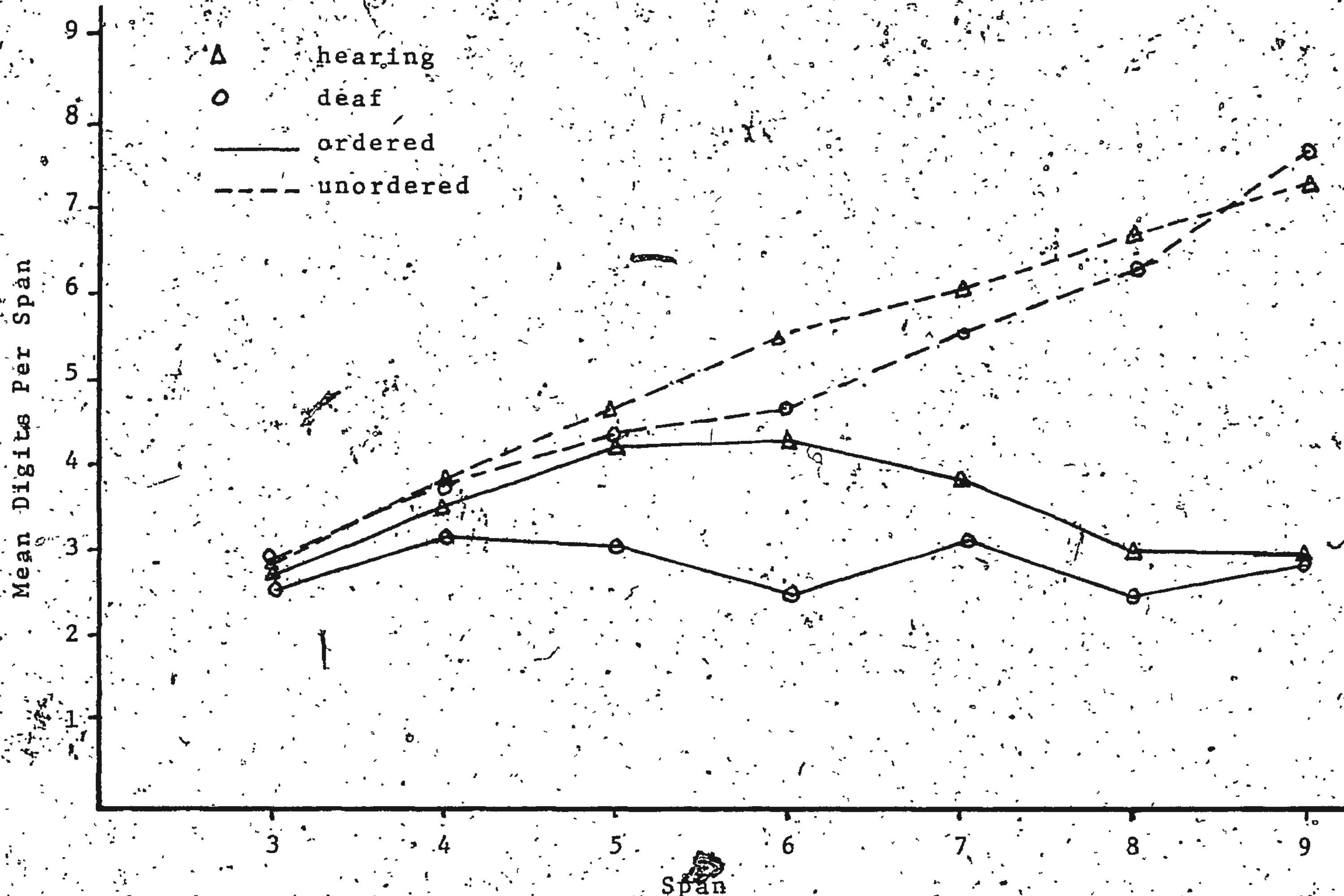

FIGURE 9. DS Interaction
Experiment 3

ordering, in accordance with which their performance in OR appears to improve slightly when compared with Experiments 1 and 2, while that of the hearing appears to decrease. However, even though deaf Ss have more digits available in UOR, their performance in OR did not show the same striking improvement.

Results here support the hypothesis that familiarity with the stimulus set improves the span capacity of deaf Ss relative to hearing Ss, at least in UOR. Further analyses will be performed within the deaf and hearing groups to assess these changes.

Supplementary Analysis 1:

Deaf

The present analysis was used to investigate the apparent fact that deaf Ss as a group improved their span capacity in OR and UOR in Experiment 3. Overall results of deaf Ss across the three experiments were then analyzed to assess the effect of stimulus type on span capacity. In addition, cueing effects were analyzed. Results of all forty Ss were used.

Design:

A five way analysis of variance with repeated measures on four factors was used for both OR and UOR. The between subject variable was the groups for which Backtapping (B) was used, with two levels, those who received added somatic sensory information in Experiment 2, and those who did not. There were four within subject variables: Presentation (P), with three levels, regular digits from Experiment 1 (RD), spatial somatic sensory digits from Experiment 2 (SD), and sign language or manual digits from Experiment 3 (MD); Cueing (C), with two levels, pre-cueing and post-cueing; Forward/Reverse (F), with two levels, forward recall and reverse recall; and Series Length (S) with seven levels, one for each of the spans. There were twenty observations per cell.

Results:

The results of the analyses of variance are shown in Table 8. There was no significant backtapping (B) effect.

TABLE 8

Deaf

Analysis of Variance

Source	DF	Ordered MS	Ordered F	Unordered MS	Unordered F
Between					
B	1	3.04	0.1	.69	.019
Subjects within Groups (R)	38	30.37		36.66	
Within					
P	2	87.86	19.25**	276.78	37.78**
BP	2	3.22	0.71	5.44	.74
RP	76	4.56		7.33	
C	1	95.01	39.22**	.76	.0399
BC	1	1.95	.81	.43	.023
RC	38	2.42		1.91	
F	1	10.26	66.59**	.48	.36
BF	1	32.21	4.97	1.72	1.29
RF	38	6.49		1.33	
S	6	41.98	16.03**	660.44	125.36**
BS	6	4.17	1.59	9.99	1.895
RS	228	2.62		5.27	
PC	2	8.73	3.37	6.35	2.81
BPC	2	4.67	1.80	1.18	.52
RPC	76	2.59		2.26	
PF	2	1.75	.93	1.35	1.21
BPF	2	4.39	2.34	.42	.38
RPF	76	1.88		1.12	
CF	1	30.67	18.51**	17.72	9.95**
BCF	1	.73	.0044	.23	.13
RCF	38	1.66		1.78	
PS	12	5.97	3.67**	44.08	29.495**
BPS	12	1.33	.82	1.84	11.23
RPS	456	1.63		1.49	
CS	6	2.22	1.18	.66	.70
BCS	6	3.33	1.78	.65	.69
RCS	228	1.88		.94	
FS	6	5.34	2.76*	1.73	1.62
BFS	6	1.57	.81	1.05	.98
RFS	228	1.94		1.07	

Table 8 (cont'd).

Source	DF	MS	F	MS	F
PCF	2	.28	.16	.16	.14
BPCF	2	1.77	.98	1.22	1.05
RPCF	76	1.80	1.16		
PCS	12	2.37	1.25	1.51	1.36
BFCS	12	2.19	1.16	.94	.85
RPCS	456	1.89		1.11	
PFS	12	1.86	1.19	.75	.82
BPFS	12	2.51	1.60	1.30	1.41
BPFS	456	1.56		.92	
CFS	6	.88	.49	1.32	1.41
BCFS	6	1.41	.79	1.08	1.15
RCFS	228	1.79		.94	
PCFS	12	3.68	2.13*	2.41	2.44**
BPCFS	12	.54	.31	1.29	1.31
RPCFS	456	1.73		.99	

* $p < .05$
** $p < .01$

There was a significant presentation (P) effect in both OR and UOR. MD ($\overline{X}_{OR}$=2.67, $\overline{X}_{UOR}$=5.09) produced better performance than both RD ($\overline{X}_{OR}$=2.12, $\overline{X}_{UOR}$=4.13) and SD ($\overline{X}_{OR}$=2.33, $\overline{X}_{UOR}$=4.37).

The significant presentation by series length interaction (PS) in both OR and UOR is shown in Figure 10. In OR, MD produced better performance than RD at the 5 through 9 spans; MD produced better performance than SD at the 5, and 7 through 9 spans; SD produced better performance than RD at the 6, 7 and 8 spans (for these and other multiple comparison tests, see Appendix 4). In UOR, MD produced better performance than both SD and RD at the 5 through 9 spans and SD produced better performance than RD at the 7, 8 and 9 spans.

There was a significant cueing effect in OR. Pre-cueing ($\overline{X}$=2.54) produced better performance than post-cueing ($\overline{X}$=2.21).

Overall, recall was greater in forward spans ($\overline{X}$=2.52) than reverse spans ($\overline{X}$=2.23), as found in the significant main effect forward/reverse (F) in OR.

The results of the significant cueing by forward/reverse interaction (CF) in both OR and UOR are found in Table 9. In both cases, forward recall was greater than reverse recall in pre-cued conditions but not post-cued conditions.

All other interactions are outlined in Appendix 4.

Discussion:

Interpretation of the type of presentation effect could be questioned on the basis of a practice effect. Although administered several weeks apart over an eight month period,

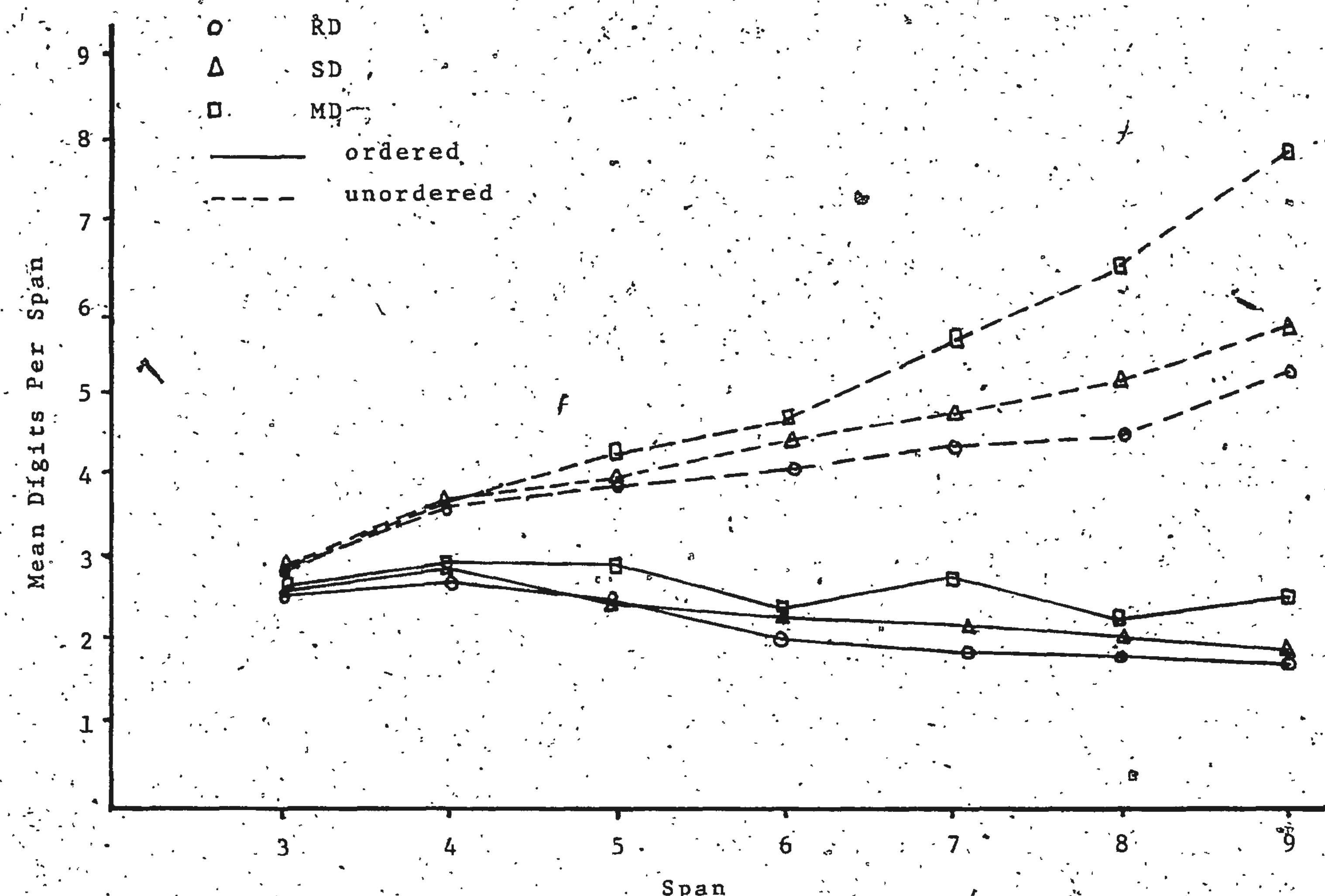

FIGURE 10. PS Interaction: Deaf
Supplementary Analysis 1

TABLE 9

Supplementary Analysis 1

CF Interaction

		Forward	Reverse
OR	Pre-cued	2.78	2.31
	Post-cued	2.25	2.16
UOR	Pre-cued	4.62	4.45
	Post-cued	4.46	4.58

Experiments 1, 2 and 3 were performed by all subjects in that order. However, if a systematic practice effect were present, one would expect consistent and chronological improvement in performance over the three experiments. In fact, this was not the case. Overall results confirm the fact that performance with MD was superior to performance with the other two sets of stimuli. There was no overall difference in performance between the RD and SD material, indicating the unlikelihood that results analyzed here are contaminated by a practice effect.

Close examination of the PS interaction further demonstrates the superiority of the MD over the previous two stimulus conditions. This superiority is evident in OR and UOR at spans 5 through 9, with only one exception. This confirms the improved span capacity of deaf Ss in Experiment 3.

The significant CF interactions in OR and UOR seem discrepant with the results of between group analyses where no significant DCF interactions were recorded. The significant interaction here indicates that the forward/reverse effect, evident in the pre-cued condition, was not found in the post-cued condition. Hearing Ss did not show the same effect (see Supplementary Analysis 2). The significant CF interaction is probably a more reliable indicator of the effect of cueing in the deaf because the within group analysis is more powerful than the between group one.

That deaf Ss performed better with pre than post-cued instruction shows that they used a response directed storage strategy. The recall strategy of deaf Ss was contingent on the direction of recall demanded: When they knew beforehand that forward recall would be demanded, they stored the incoming digits for forward recall. Similarly, when they knew that reverse recall would be demanded, they stored the digits for reverse recall. A forward-reverse effect was then shown in this pre-cued condition because forward recall is more efficient than reverse recall, demanding less processing capacity. When they did not know beforehand what direction of recall would be demanded, deaf Ss could not consistently and satisfactorily use a response directed storage strategy. The forward/reverse effect then disappeared. This was not only true for the ordering of the digits but also for the total number of digits available for ordering.

Supplementary Analysis 2:

Hearing

The present analysis was used to investigate the apparent decrease in span capacity of hearing Ss in Experiment 3. In addition, cueing effects were analyzed. Because only 24 hearing Ss were available for Experiment 3, this overall analysis was completed for these 24 Ss only.

Design:

A five way analysis of variance with repeated measures on four factors was used for both OR and UOR. The between subject variable was the groups for which Backtapping (B) was used, with two levels, those who received added somatic sensory information in Experiment ~~2 and~~ those who did not. There were four within subject variables: Presentation (P), with three levels, regular digits from Experiment 1 (RD), spatial and somatic sensory digits from Experiment 2 (SD), and sign language or manual digits from Experiment 3 (MD); Cueing (C), with two levels, pre-cueing and post-cueing; Forward/Reverse (F), with two levels, forward recall and reverse recall; and Series Length (S), with seven levels, one for each of the spans. There were twelve observations per cell.

Results:

The results of the analyses of variance are shown in Table 10. There was no significant backtapping effect.

In OR, the significant presentation (P) effect showed that RD ($\overline{X}$=3.73) and SD ($\overline{X}$=3.84) produced better overall performance than MD ($\overline{X}$=3.50). In UOR, SD ($\overline{X}$=5.63)

TABLE 10

Hearing

Analysis of Variance

Source	DF	Ordered MS	Ordered F	Unordered MS	Unordered F
Between					
B	1	1.096	.028	7.75	1.28
Subjects within Groups (R)	22	38.88		6.04	
Within					
P	2	19.84	5.25**	23.25	10.28**
BP	2	11.001	2.91	3.22	1.42
RP	44	3.78		2.26	
C	1	2.23	.67	.92	1.38
BC	1	.48	.14	1.19	1.80
RC	22	3.35		.66	
F	1	460.004	61.78**	43.75	33.20**
BF	1	9.04	1.21	4.67	3.54
RF	22	7.45		1,32	
S	6	100.88	21.54**	797.43	364.08**
BS	6	.66	.141	3.12	1.43
RS	132	7.45		2.19	
PC	2	1.01	.47	1.89	2.83
BPC	2	.103	.048	1.88	2.81
RPC	44	2.14		.67	
PF	2	8.74	3.35*	4.19	5.65**
BPF	2	.36	.14	1.09	1.47
RPF	44	2.61		.74	
CF	1	4.67	1.71	.11	.19
BCF	1	.92	.34	.18	.30
RCF	22	2.72		.60	
PS	12	5.28	2.34**	3.89	4.20**
BPS	12	1.07	.47	1.14	1.23
RPS	264	2.26		.93	
CS	6	.34	.13	.78	1.31
BCS	6	.55	.21	1.02	1.73
RCS	132	2.62		.59	

Table 10 (cont'd.)

Source	DF	Ordered MS	Ordered F	Unordered MS	Unordered F
FS	6	30.33	13.84**	4.07	6.01**
BFS	6	.42	.19	1.85	2.73*
RFS	132	2.19		.68	
PCF	2	1.58	.51	.14	.20
BPCF	2	4.18	1.36	.54	.78
RPCF	44	3.08		.69	
PCS	12	3.91	1.68	.67	1.09
BPCS	12	2.72	1.17	.62	.99
RPCS	264	2.33		.62	
PFS	12	5.05	2.05*	1.47	2.12*
BPFS	12	1.09	.44	1.28	1.85
RPFS	264	2.46		.69	
CFS	6	.39	.19	.69	1.15
BCFS	6	2.59	1.25	.21	.34
RCFS	132	2.07		.61	
PCFS	12	4.43	2.15*	.38	.58
BPCFS	12	1.53	.74	.91	1.38
RPCFS	264	2.06		.66	

*p<.05
**p<.01

produced better performance than both RD ($\overline{X}$=5.36 and MD ($\overline{X}$=5.28).

There was no significant cueing (C) or cueing by forward/reverse (CF) interaction in either OR or UOR.

The significant presentation by series length interaction (PS) in both OR and UOR is shown in Figure 11. SD produced better performance than both RD and MD at the 9 span in OR and at the 8 and 9 span in UOR (for these and other multiple comparison tests, see Appendix 5).

Forward/Reverse (F) appeared as a main effect in both OR and UOR. In both cases, this showed that forward span ($\overline{X}_{OR}$=4.17, $\overline{X}_{UOR}$=5.57) was greater than reverse span ($\overline{X}_{OR}$=3.22, $\overline{X}_{UOR}$=5.28) performance. All other interactions are outlined in Appendix 5.

Discussion:

As in the within group deaf analyses, the possibility exists here that results are contaminated by a practice effect. Experiments 1, 2 and 3 were performed by all subjects in that order, although several weeks apart. Results here are not, however, consistent with this notion. Overall performance with MD was worse than performance with SD and RD in OR and SD in UOR. Examination of results across the spans indicates that SD performance was greater than both MD and RD at a few higher spans. If a practice effect was present, one would expect MD performance to be the best. This was not the case.

That performance with MD was inferior to performance with both other stimulus sets is not a striking one. Hearing

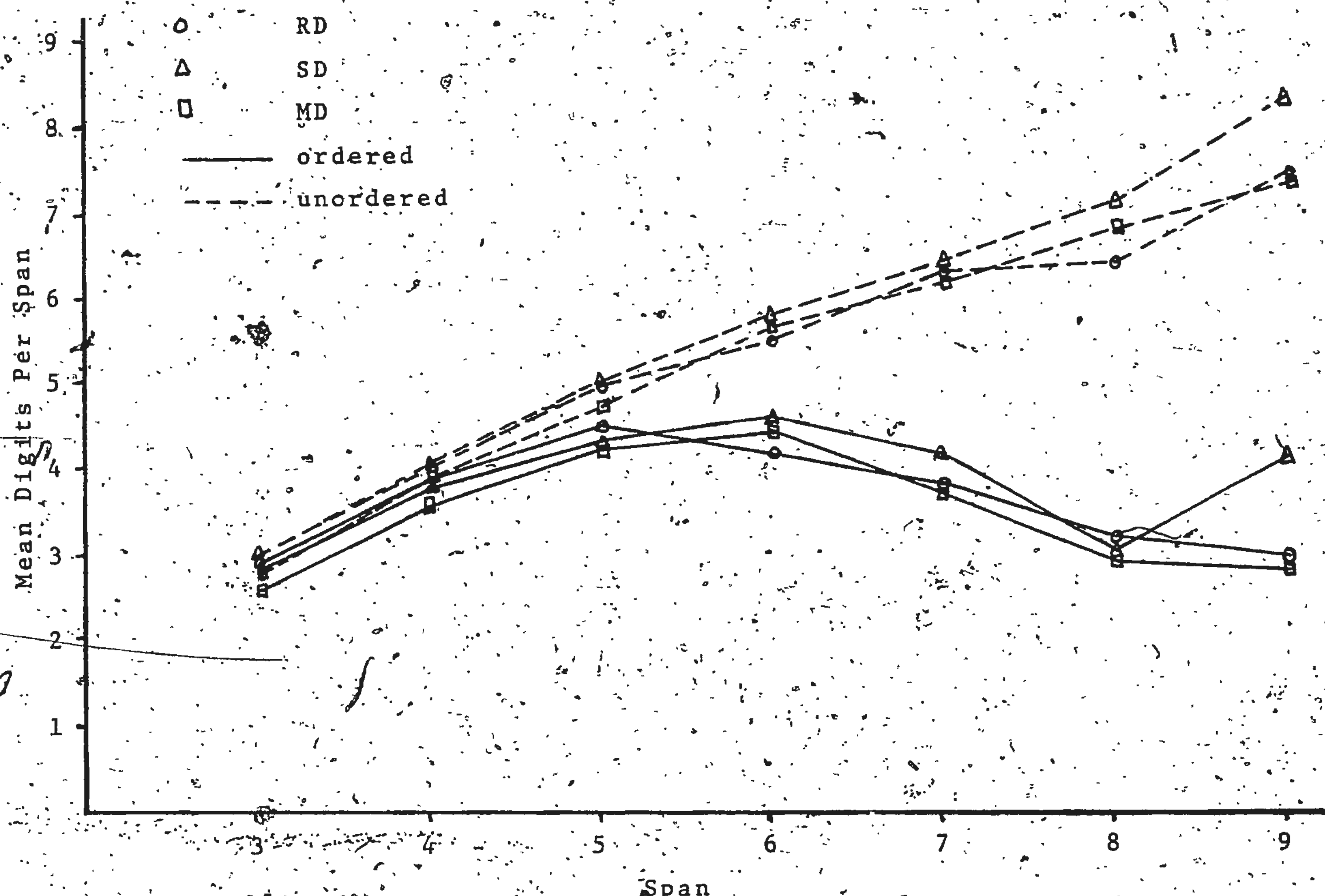

FIGURE 11. PS Interaction: Hearing
Supplementary Analysis 2

Ss were unfamiliar with manual signs as the stimulus material. Accordingly, they were less efficient with the signs than with the other two stimulus sets. Also, as E observed, hearing Ss probably made more recognition errors of some signs which look alike (e.g. 3 and 6), despite warnings in practice sessions.

In fact, the most striking result with hearing Ss was the lack of significant effects produced by treatment conditions. Aside from a slight deficit in performance with the sign language digits, hearing Ss remained relatively unaffected by treatment conditions. This must reflect the high degree of efficiency at which the hearing S must work in the digit span task.

Pre and post-cued conditions had no differential effect on the performance of hearing Ss, nor did cueing interact with forward and reverse recall. This most likely means that hearing Ss used a stimulus directed storage strategy. That is, regardless of response conditions, they stored the incoming digits for forward recall and hence showed forward/reverse differences in both pre and post-cued conditions.

Supplementary Analysis 3:

Serial Position Analyses

One source of difficulty with earlier findings concerning the assessment of forward/reverse effects in the deaf was that mean span analysis was performed on the data. That type of analysis, which averages the largest completely correct span over subjects, ignores much of the information collected. Forward and reverse differences here are assessed using a serial position analysis of results collapsed across all three experiments. Serial position analyses were not assessed separately within each experiment because of the small number (i.e. only two) of observations per cell. It is possible that this may distort the analyses but, because of the lack of difference in performance of hearing Ss and the relatively small difference in performance of deaf Ss across experiments, this is not expected.

Design:

Each S had six trials at each span for both forward and reverse recall throughout the entire study. A two way analysis of variance (Forward/Reverse by Series Length) was done separately for each of the deaf (N=40) and hearing (N=24) groups. Mean correct scores (out of six) were then converted to percent error scores at each span level and averaged for forward and reverse recall for each of the deaf and hearing groups.

Results:

Results of the analyses of variance on number correct for deaf and hearing groups are reported in Appendix 6. Mean

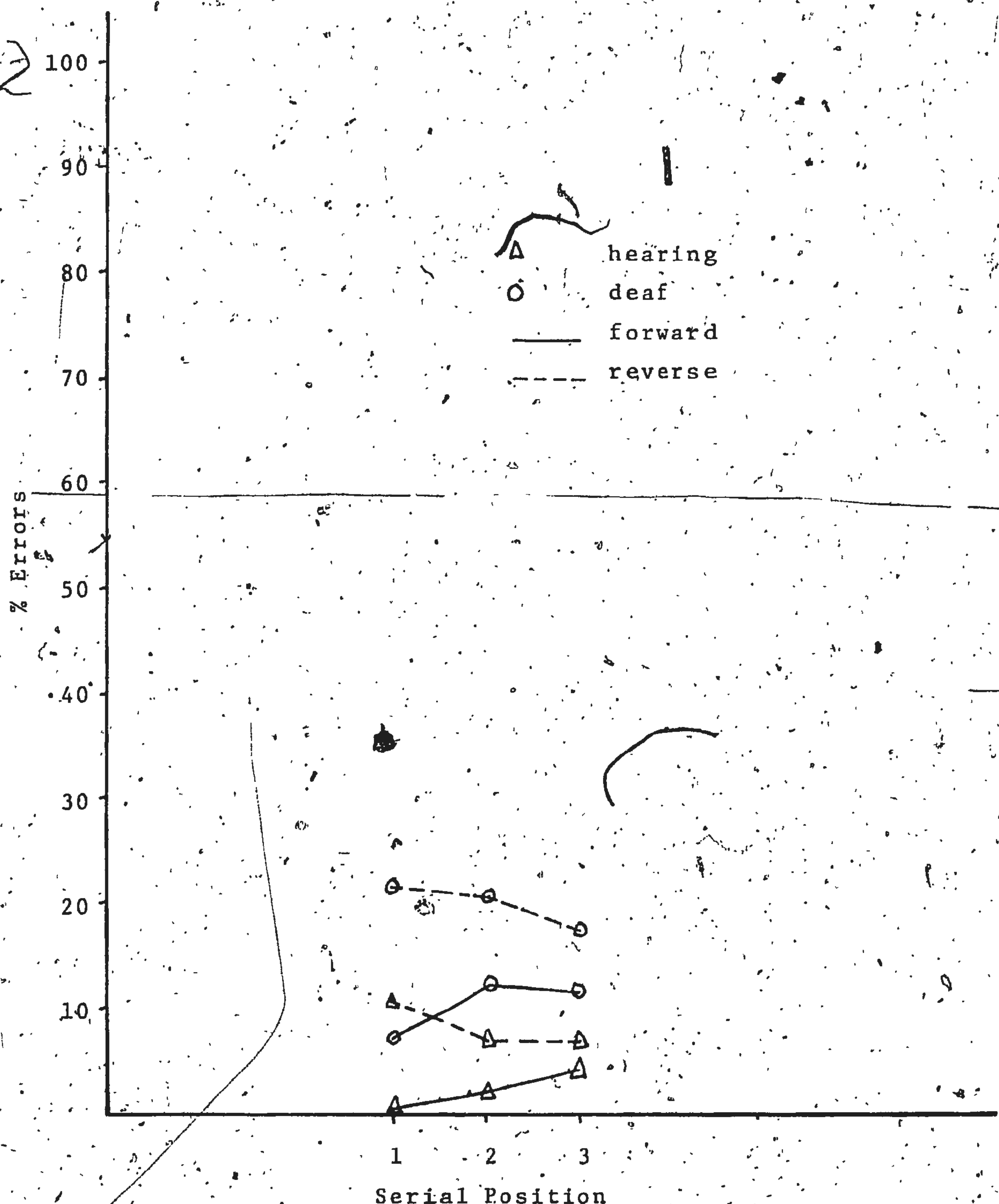

FIGURE 12. Serial Position Analysis: 3 Span

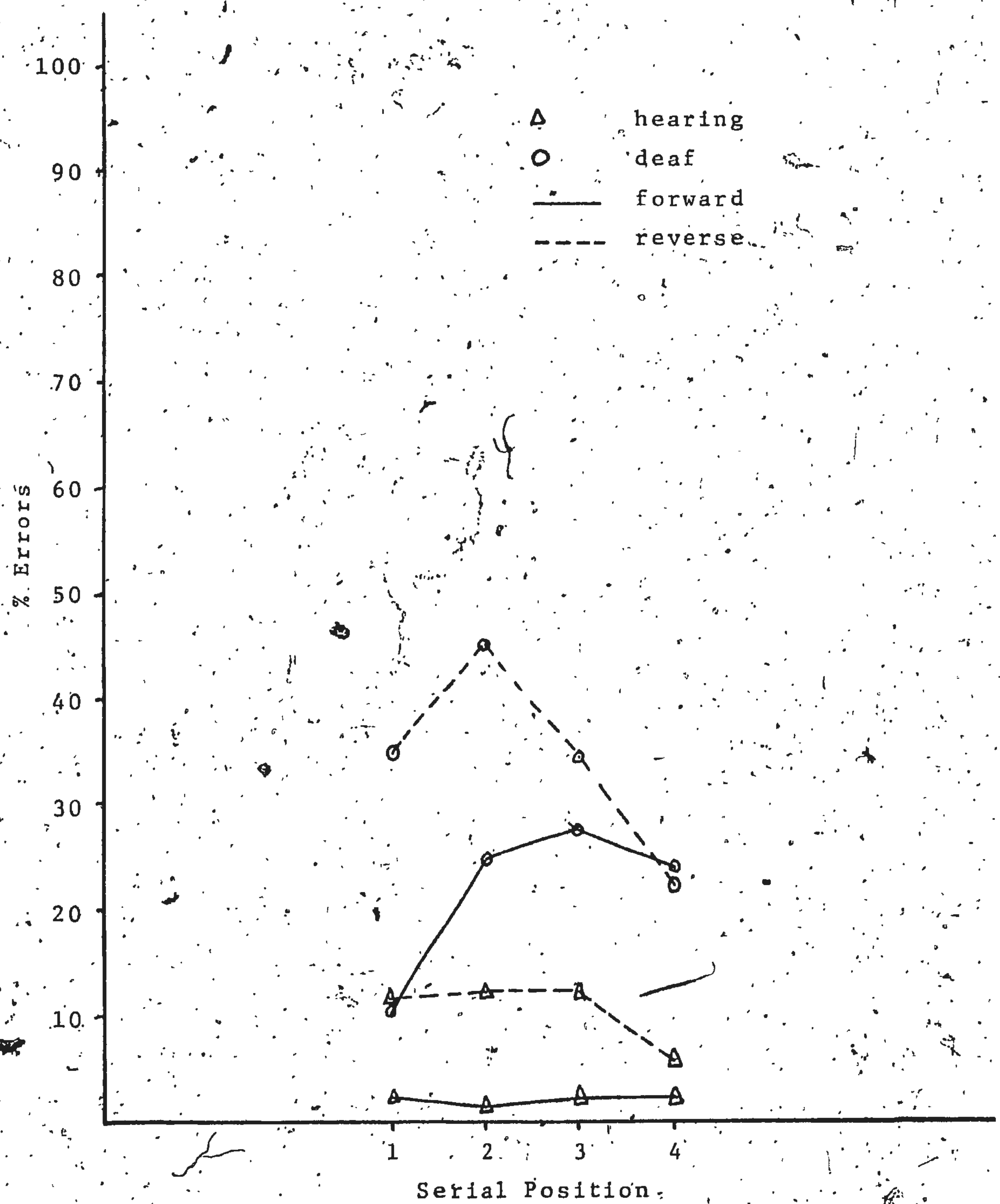

FIGURE 13. Serial Position Analysis: 4 Span

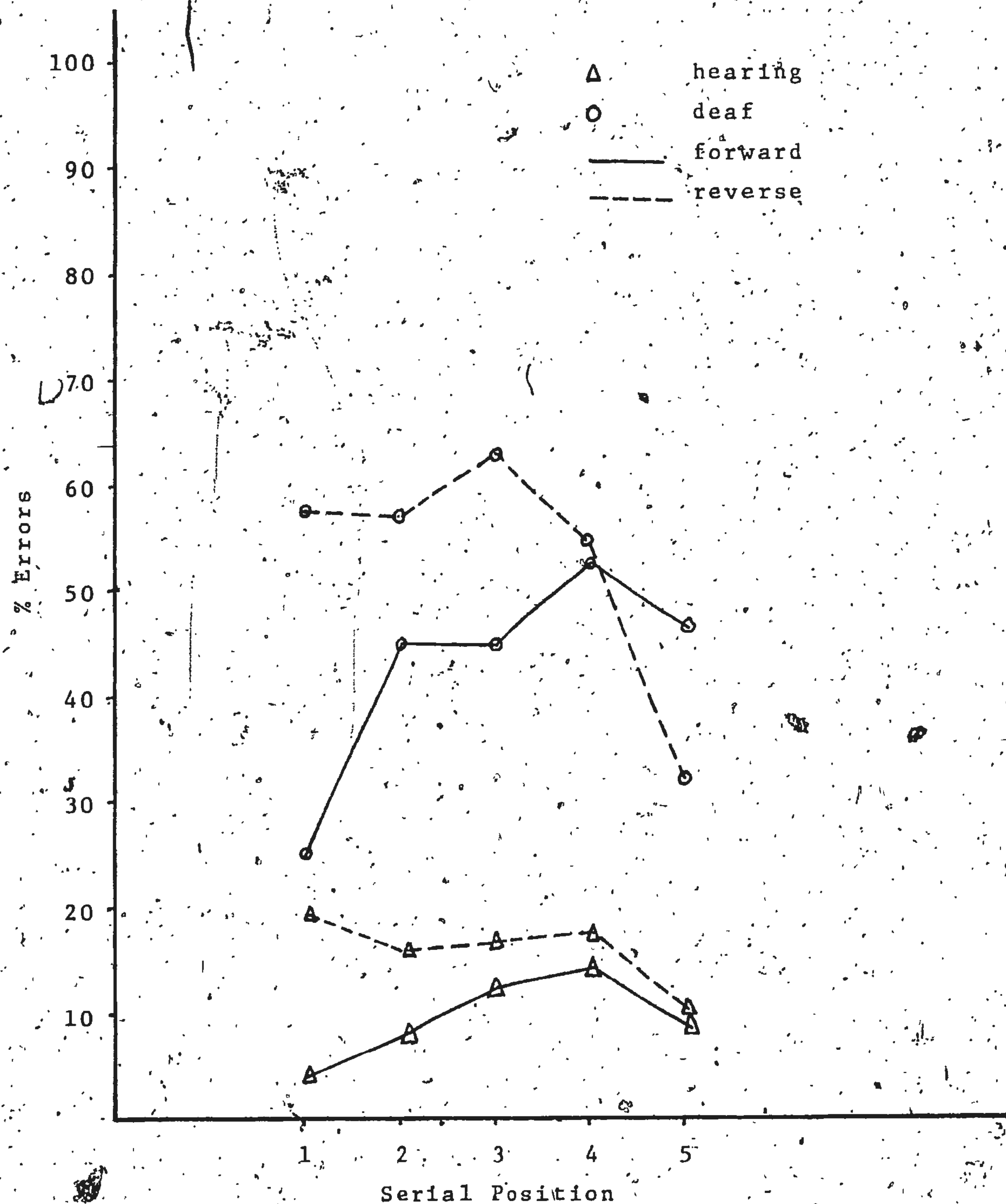

FIGURE 14: Serial Position Analysis: 5 Span

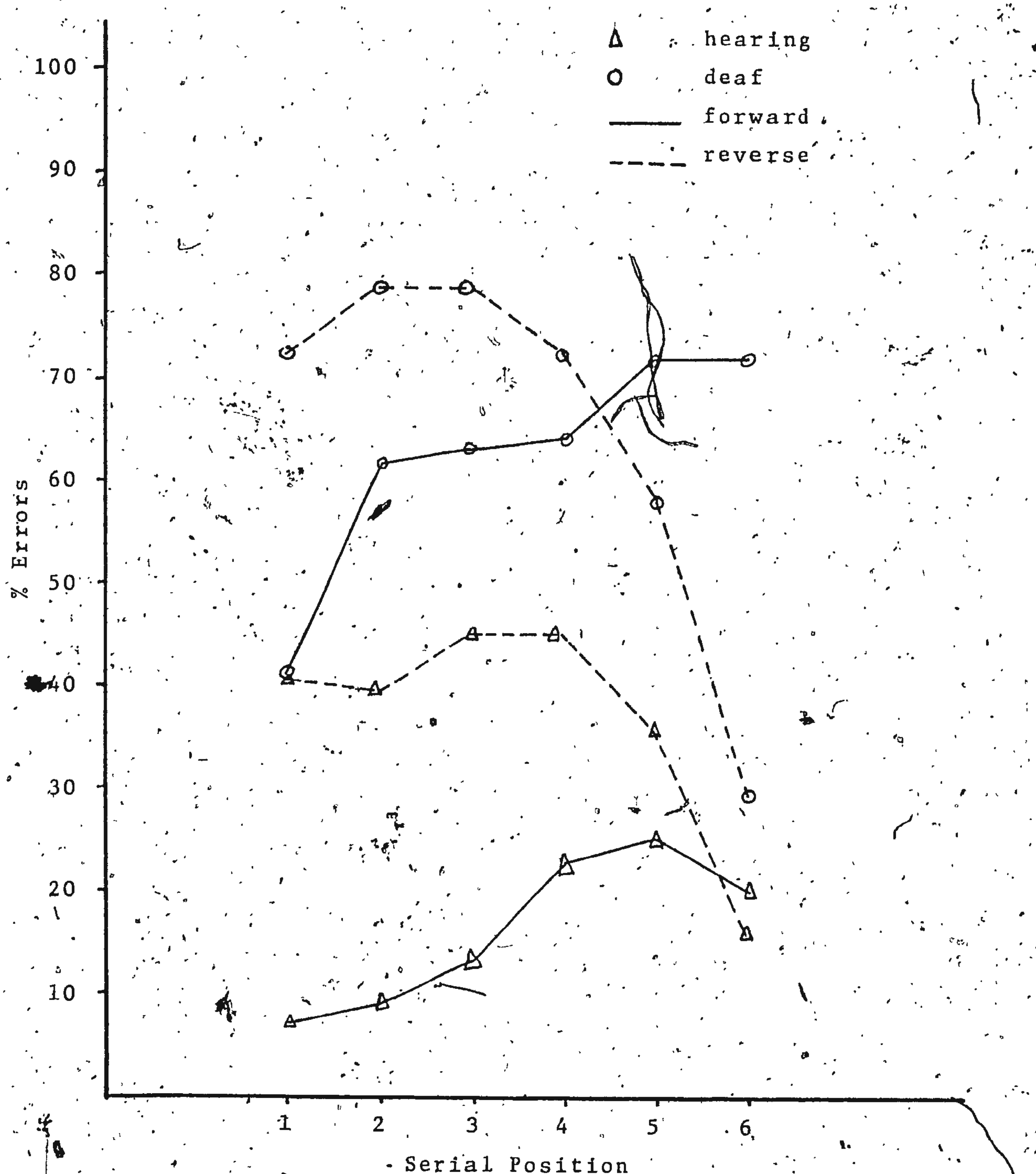

FIGURE 15. Serial Position Analysis: 6 Span

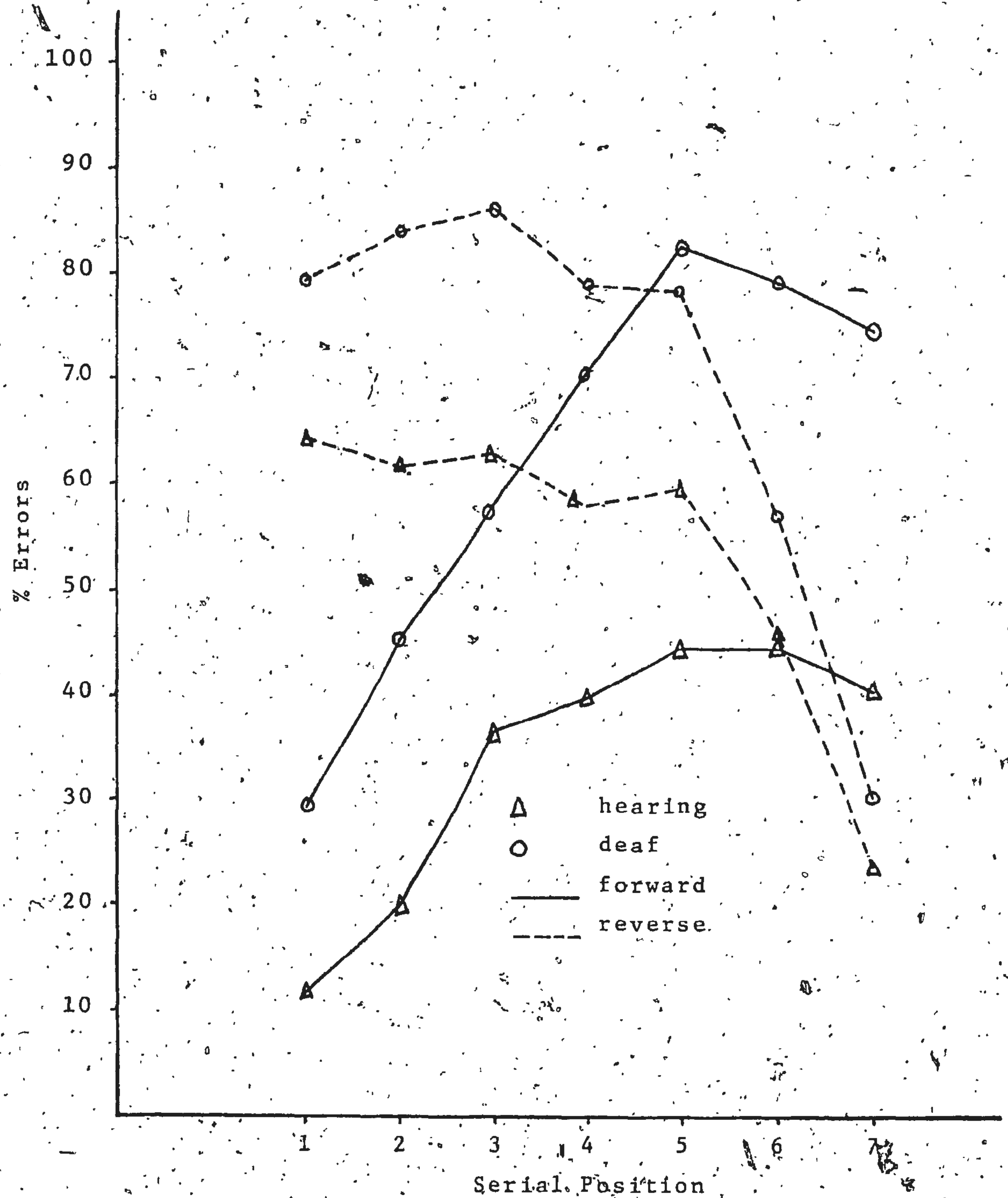

FIGURE 16. Serial Position Analysis: 7 Span

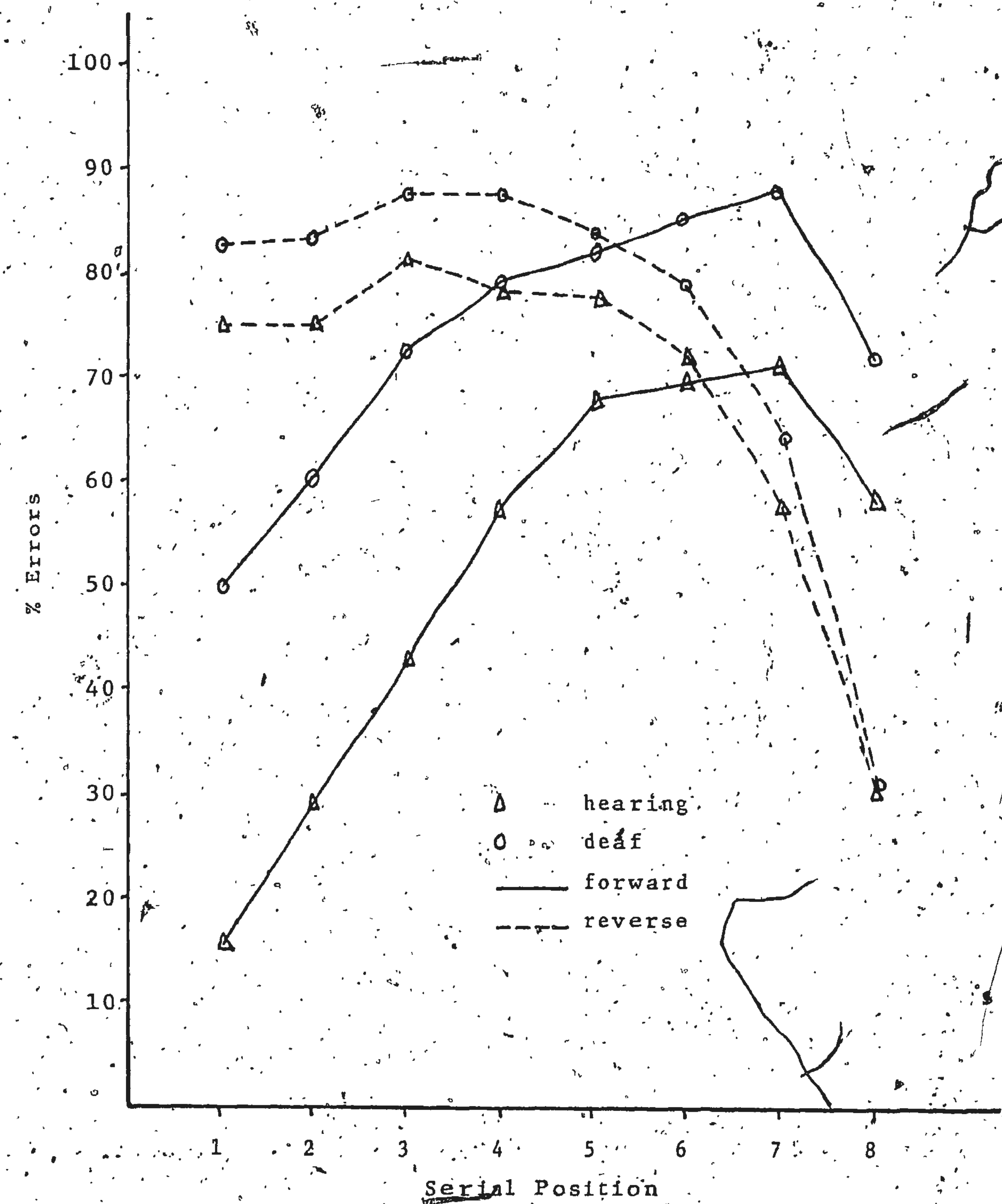

FIGURE 17. Serial Position Analysis: 8 Span

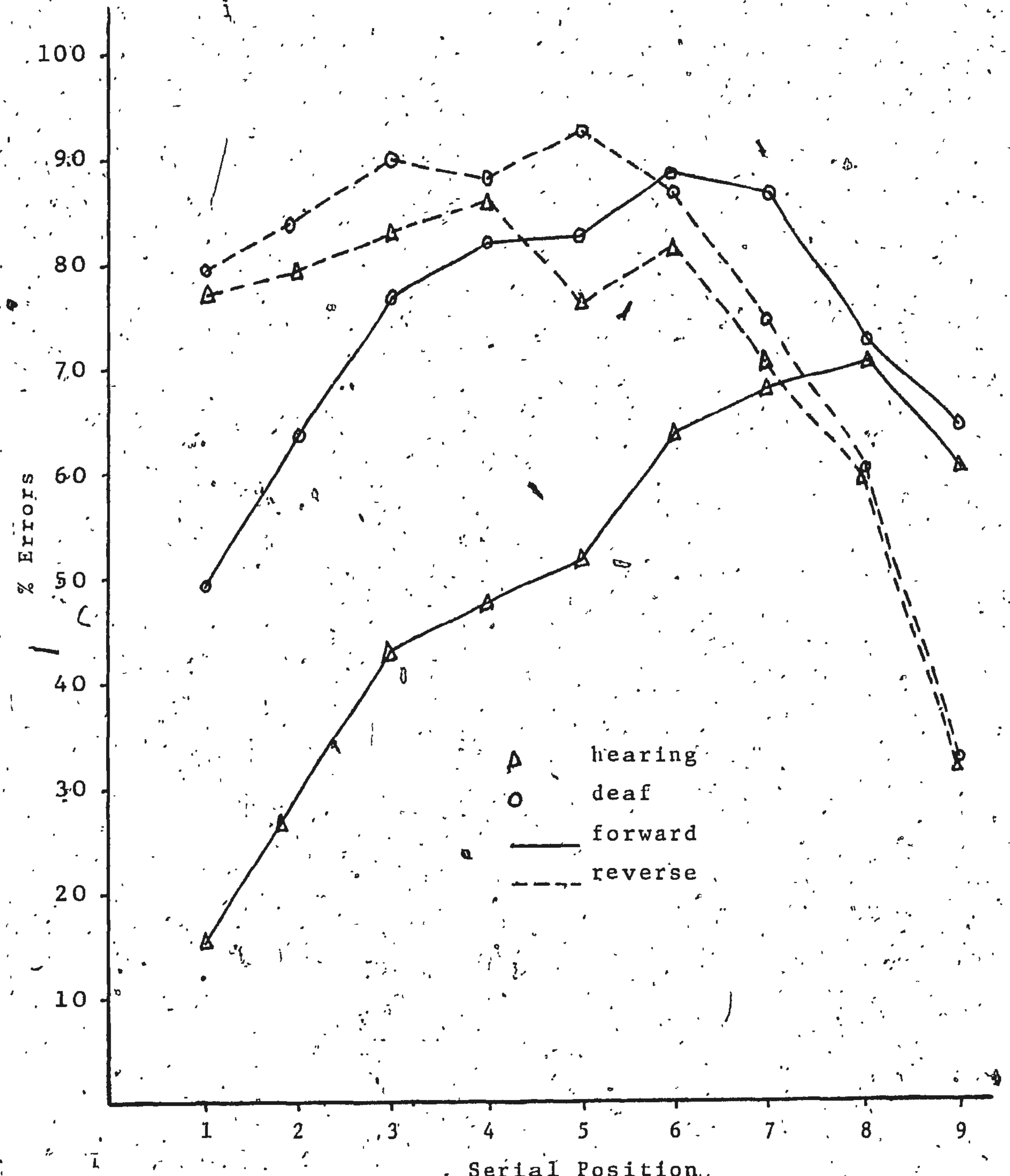

FIGURE 18. Serial Position Analysis: 9 Span

errors are graphed in Figures 12 through 18 for each digit series, three through nine. Forward and reverse recall are reported in the serial position of presentation. For example, in a four span reverse series, the fourth presented digit would be graphed in serial position 4, even though it would be reported on the answer sheet in serial position 1.

A summary of the results of the serial position analyses appears in Table 11. Statistical significances of forward over reverse span, and reverse over forward span, for each serial position, are reported for both deaf and hearing groups.

<u>Discussion</u>:

A primary effect here is a significant forward over reverse recall at a serial position, while a recency effect is a significant reverse over forward recall at a serial position. Examination of Table 11 shows that while hearing <u>S</u>s showed consistent primacy effects, deaf <u>S</u>s did not. For the deaf, primacy effects were predominant in the first few spans, but recency effects were as predominant in the later spans. This difference is probably the result of two factors.

First, hearing <u>S</u>s have a larger span capacity than deaf <u>S</u>s and do not show serial position curves as soon. Figures 12 through 18 illustrate this fact. In Figure 12, both groups showed forward/reverse effects at all serial positions, but deaf <u>S</u>s made more errors. In Figure 13, hearing <u>S</u>s showed forward/reverse effects at all serial positions, while deaf <u>S</u>s showed forward/reverse effects at the first three serial positions. The curves of the deaf begin to indicate serial position effects, as relatively more errors are made in the middle of the series.

TABLE 11

Serial Positions in which either forward or reverse recall was significantly better

	DEAF		HEARING	
Span	Forward Better	Reverse Better	Forward Better	Reverse Better
3	1,2,3		1,2	
4	1,2,3		1,2,3,4	
5	1,2,3	5	1,2	
6	1,2,3,4	5,6	1,2,3,4,5	
7	1,2,3,4	6,7	1,2,3,4,5	7
8	1,2,3	6,7,8	1,2,3,4,5	7,8
9	1,2,3,5	7,8,9	1,2,3,4,5,6	8,9

In Figure 14, hearing Ss showed forward/reverse effects at only the first two serial positions and errors began to increase in central positions. With the advent of the first significant recency effect (at the 5 span), deaf Ss do show serial position curves. They continue to show forward/reverse effects at the first three serial positions. In Figure 15, hearing Ss are almost showing serial position curves. They showed forward/reverse effects at the first 5 serial positions, there being no difference at the 6 span. Deaf Ss continue to show serial position curves, with more pronounced recency effects. Figure 16 shows the first serial position curves for hearing Ss. Deaf Ss continue to show serial position curves with equal primacy and recency effects. Through Figures 16 to 18, serial position curves of deaf and hearing Ss appear strikingly similar. While reverse spans of both groups become more and more alike, differences still remain in the forward spans.

Second, this reflects the differences in storage strategies noted before. Hearing Ss store for forward recall and forward span performance is consistently better than reverse. Deaf Ss store for both forward and reverse recall and although forward recall is superior overall, it is not consistently superior as is the forward recall of the hearing.

Although the forward/reverse effect in the deaf is not as strong as that of the hearing, these analyses offer no support for the hypotheses that forward span capacity is the same as reverse span capacity in the deaf. That other research (Blair 1957, Fuller 1959) has supported this contention is probably the result of methods of analyses used and not any performance factors in the deaf.

Final Discussion:

Implications of the results of this study are discussed in reference to capacity, rehearsal, and coding aspects of short term memory.

Capacity

The major result of this study has been confirmation of the inferior capacity of deaf Ss as reported by Pintner and Paterson (1917), Blair (1957), Fuller (1959), in the serial recall of visually presented sequences of digits. Treatment presentations were generally unsuccessful in raising the capacity of the deaf to that of the hearing. At best (in Experiment 3), deaf Ss recalled as many digits overall without regard to order as hearing Ss, but remained inferior in the recall of these same digits in the proper order. This has suggested that a major factor in the digit span deficit of deaf Ss is their inability to order information.

It was suggested earlier that the span capacity of the deaf compared to the hearing might vary with the stimulus set. Spatial cues and stimulus familiarity were cited as important features. It was argued that adding these features to the stimulus might improve the span capacity of the deaf relative to the hearing. No support was found for the hypothesis that added spatial (and somatic sensory) cues were important, but methodological reasons were used to account for lack of supportive results here. Support was found, however, for the hypothesis that added familiarity of the stimulus improved the span capacity of the deaf relative to the hearing. That treatment improved the span capacity of the deaf and gave slight decrements in the span capacity of the hearing. This demonstrated that span capacities of both groups were susceptible to the effects of differential familiarity of the stimulus.

Familiarity was defined here as frequency of use. Deaf Ss encounter and use sign language more frequently than hearing Ss, therefore sign language digits were more familiar to the deaf. However, the correlative argument, that regular digits were more familiar to the hearing is not completely adequate. Deaf Ss do use regular digits in day to day commerce, although probably not as consistently as hearing Ss (e.g. as in the use of telephones). Most probably, differential effects of familiarity of the stimulus set on span capacity reflect different short term memory performance factors, such as coding processes, between the two groups. This is discussed further below (see Coding).

Human subjects retain more ordered stimulus information in forward than reverse recall. Presumably that is because the original stimulus presentation is itself forward. Reverse recall must require additional processing capacity because it involves the reordering of the original stimulus presentation. Forward recall is more efficient than reverse recall then because it requires less processing capacity and thus reduces the probability of error.

It is not surprising then, that results of this study support the hypothesis that both deaf and hearing Ss show better forward than reverse recall. Insensitive statistical analysis in other studies (Blair 1957, Fuller 1959) and not performance factors in the deaf have accounted for the previous finding that there was no forward/reverse effect in the deaf.

The parameters of the forward/reverse effect in the deaf do, however, differ from those in the hearing. Primarily it is not as strong an effect in the deaf. That results from differential storage strategies and a reduced overall capacity. While deaf Ss show differential performance over pre and post-cued conditions, hearing Ss do not. Hearing Ss store digits to maximize forward recall, regardless of response conditions and thus show strong forward/reverse effects. Deaf Ss do not consistently choose to maximize forward recall. Even if deaf Ss did store to maximize forward recall, there is some doubt that their ordering abilities would allow for as strong differences between forward and reverse recall.

Finally, examination of the DS interactions in OR (Figures 1, 6, 9) demonstrates quite clearly that an increase in the number of digits presented beyond the capacity of both deaf and hearing Ss reduces their overall capacity. This has been demonstrated for hearing Ss (Waugh 1960), but never before for deaf Ss.

To summarize then, deaf Ss do show serial digit recall deficits when compared to hearing Ss. Their deficit is a function of the type of stimulus. Both deaf and hearing Ss show forward/reverse effects, although of different strengths. Increasing the number of digits in the stimulus beyond the capacity of the Ss decreases span capacity of both groups.

Prior knowledge of response conditions does affect the span capacity of deaf but not hearing Ss.

Rehearsal

Although not primarily concerned with rehearsal strategies, this study has revealed some interesting possibilities for research in this area. This stems from observations of cumulative and grouping manual rehearsal strategies in the deaf. Of particular interest has been some grouping strategies where deaf Ss rehearsed different stimuli at the same time on different hands. This corroborates the observation of Locke and Locke (1971). This type of exercise, for example, fingerspelling two different words on different hands at the same time, is a favourite game of some deaf children. Research investigating the relative independence of deaf S's arm systems may prove interesting.

That deaf Ss use manual rehearsal systems, either overtly in the form of signing, or covertly in the form of dactyllic rehearsal, may affect their performance in tasks demanding written recall. It may be, as noted before, that the actual response of writing is interfering with recall for deaf Ss. As writing is a motor task, and as forms of manual rehearsal certainly involve motor elements, this is a distinct possibility. Interference may occur because there is transformation of information from one form (manual) to another (written) within the same modality. Results with sign digits in Experiment 3 suggest that such interference affects the ordering of digits. As mentioned before, definite ordering deficits were still apparent in Experiment 3. This speculation, if valid, has very definite implications for educational methods used with the deaf involving written responses. Further studies designed to investigate the effects of other types of response systems (e.g. signing recall) on span capacity in the deaf would help clarify this issue.

Deaf Ss then do make use of complicated manual rehearsal systems. These systems are differentially effective with the stimulus material. In addition, there is reason to suspect that these systems may interact with the modality of response required.

Coding

There is a reason to suspect that capacity difficulties in the deaf are in part a function of coding problems. That comes from the finding that deaf Ss have problems in getting digits into their memory system. For the hearing, digits are always correlated with sounds and hence with the overtly or covertly vocalized names of the digits. The deaf obviously cannot correlate the visually presented digit with its sound. Deaf Ss must use other modalities to code.

Conrad and Rush (1965), Conrad (1970, 1971) and Allen (1969) have hypothesized that deaf Ss use a visual code. Conrad and Rush based this notion on the assumption that deaf Ss did not show forward/reverse effects and could therefore extrapolate information with equal facility in either direction. Results of this study, however, have demonstrated that deaf Ss do indeed show forward/reverse effects. Further, these authors failed to verify the use of visual codes by deaf Ss. The only data to support this notion is that of Allen. It has been noted that Allen's results are discrepant with those of Locke and Locke (1971), and also are not inconsistent with another hypothesis, namely one which postulates a dactyllic code.

The results of this study are consistent with a dactyllic code hypothesis. If memory necessitates a set of successive transformations performed upon the stimulus material, then it follows that the fewer the transformations, the more efficient the system. Fewer transformations of stimulus material decreases the possibility that information will be lost or altered. It is obvious that if deaf Ss use a dactyllic system, sign language digits would require fewer transformations than regular digits, and produce better performance. Such was the case.

If one accepts the notion of Wicklegren (1965, 1966) that auditory coding systems in the hearing are articulatory in nature, one notices that coding in the hearing is a response function. A dactyllic code is also a response function, whereas a visual code is not. In addition, the auditory coding systems of the hearing have certain properties, such as temporal and sequential ones, which are suited for serial recall. One can easily attribute these same properties to a dactyllic system. Sign language is temporal in that it functions over time and is sequential in that the order of signs is critical to functioning. It is difficult to attribute these properties to a visual system. What does seem clear, however, is that if a dactyllic code is used by the deaf, it is not as efficient as that used by the hearing.

It is worth speculating then why a dactyllic system would not be as efficient as the auditory coding system of the hearing. First, there is the possibility that dactyllic systems are not used consistently across all deaf Ss, a fact corroborated by E's informal observation. The deaf Ss varied considerably in their abilities to use overt signs because the philosophy of the school was such that signing was discouraged and in some cases prohibited. Any signs used by deaf Ss were not learned formally or through home instruction (except in the case of one deaf S who came from a deaf family), but rather were learned surreptitiously. In this sense sign language is very much an underground language in this school. Second, there exists the possibility that dactyllic systems are not even consistently used within any given deaf S. Informal observation by E corroborates this notion that deaf Ss were not as consistent as hearing Ss in the use of recall strategies. Again, this is not surprising given the fact that deaf Ss are discouraged from signing. Finally, the possibility exists that even a fully efficient dactyllic system is not as efficient as the auditory system of the hearing. This may be particularly relevant to the sequential or ordering functions of the two systems. The channel capacity of the dactyllic system may be inferior to that of the auditory system.

If deaf Ss do use dactyllic systems, then it follows that if one wants to maximize the possibility of recall, stimuli presented to deaf Ss should be in a form which is easily codable into this system. Sign language naturally fits this specification. Deaf Ss are obviously more sensitive to this type of presentation. In fact, a few deaf Ss even communicated to E that they recognized the hand of the native deaf informant used in Experiment 3. This, without any previous knowledge of this deaf person's involvement in the study. This notion is obviously relevant to those philosophies of education of the deaf which do not admit sign language use in the classroom as an educational and communicative aid. It also suggests that deaf Ss would have particular difficulty with static visual stimuli, as in reading. As has been noted, deaf Ss are on the average exceptionally poor readers. In part, this may be a function of memory capacity limits on their reading abilities. It may be, however, that a symbol system premised on sign language itself is what is necessary here, if one assumes that certain peculiarities of sign language lend themselves to adequate visual translation.

In summary, results of this study are consistent with the hypothesis that deaf Ss use a dactyllic coding system.

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APPENDIX 1

Experiment 1: Ordered Recall: Cell Means and Tests of Simple Effects

S

	3	4	5	6	7	8	9
	2.68	3.28	3.42	3.08	2.86	2.60	2.54

DS

	3	4	5	6	7	8	9
Deaf	2.49	2.72	2.43	1.92	1.79	1.76	1.73
Hearing	2.88	3.84	4.41	4.25	3.92	3.44	3.36
F=	3.13	25.34	80.81	110.10	92.42	56.99	54.34
	ns	**	**	**	**	**	**

FS

	3	4	5	6	7	8	9
Forward	2.75	3.48	3.66	3.43	3.39	3.05	3.01
Reverse	2.62	3.08	3.18	2.75	2.33	2.15	2.07

CS

	3	4	5	6	7	8	9
Pre-Cued	2.72	3.37	3.49	3.28	2.87	2.83	2.89
Post-Cued	2.65	3.19	3.34	2.89	2.84	2.37	2.19

DFS

Deaf	3	4	5	6	7	8	9
Forward	2.55	2.98	2.61	1.96	1.95	1.78	1.66
Reverse	2.43	2.45	2.24	1.88	1.64	1.75	1.79
F=	.58	11.69	10.59	.31	3.93	.03	.58
	ns	**	**	ns	ns	ns	ns

(cont'd.)

Appendix 1 (cont'd.)

Hearing	3	4	5	6	7	8	9
Forward	2.95	3.98	4.70	4.89	4.83	4.33	4.36
Reverse	2.81	3.71	4.13	3.61	3.01	2.55	2.35
F=	.40	2.73	13.35	107.34	132.65	128.02	163.24
	ns	ns	**	**	**	**	**

Unordered Recall

S

	3	4	5	6	7	8	9
	2.95	3.75	4.41	4.83	5.35	5.61	6.43

DS

	3	4	5	6	7	8	9
Deaf	2.91	3.55	3.91	4.13	4.38	4.67	5.38
Hearing	2.99	3.94	4.90	5.52	6.32	6.55	7.47
F=	.16	3.32	20.33	32.42	72.59	74.09	90.61
	ns	ns	**	**	**	**	**

FS

	3	4	5	6	7	8	9
Forward	2.94	3.76	4.39	4.84	5.58	5.87	6.56
Reverse	2.95	3.74	4.43	4.81	5.13	5.35	6.29

DFS

Deaf	3	4	5	6	7	8	9
Forward	2.89	3.51	3.81	4.07	4.49	4.69	5.28
Reverse	2.93	3.59	4.01	4.19	4.28	4.65	5.49
F=	.01	.38	2.75	1.76	3.01	.09	3.34
	ns	ns	ns	ns	ns	ns	ns

(cont'd.)

Appendix 1 (cont'd.)

Hearing	3	4	5	6	7	8	9
Forward	3.00	4.00	4.96	5.60	6.66	7.05	7.84
Reverse	2.98	3.89	4.84	5.44	5.98	6.05	7.10
F=	.03	.90	.93	1.80	31.52	68.97	37.76
	ns	ns	ns	ns	**	**	**

APPENDIX 2

Experiment 2: Ordered Recall: Cell Means and Tests of Simple Effects

S

	3	4	5	6	7	8	9
	2.71	3.30	3.33	3.40	3.19	2.83	3.08

DS

	3	4	5	6	7	8	9
Deaf	2.54	2.90	2.41	2.26	2.22	2.05	1.96
Hearing	2.89	3.70	4.26	4.54	4.16	3.62	4.21
F=	2.29	11.99	64.81	96.54	71.24	45.59	95.19
	*	**	**	**	**	**	**

FS

	3	4	5	6	7	8	9
Forward	2.84	3.54	3.63	3.89	3.55	3.22	3.64
Reverse	2.59	3.07	3.04	2.91	2.82	2.45	2.53

DFS

Deaf	3	4	5	6	7	8	9
Forward	2.74	3.18	2.74	2.41	2.31	2.19	1.88
Reverse	2.34	2.63	2.08	2.11	2.13	1.91	2.04
F=	6.18	11.73	16.89	3.49	1.26	3.04	1.02
	**	**	**	ns	ns	ns	ns

Hearing	3	4	5	6	7	8	9
Forward	2.94	3.90	4.51	5.38	4.80	4.25	5.41
Reverse	2.84	3.51	4.01	3.70	3.51	2.99	3.01
F=	.39	6.20	9.70	66.15	63.54	63.54	223.37
	ns	**	**	**	**	**	**

(cont'd.)

CFS

Pre-Cueing	3	4	5	6	7	8	9
Forward	2.95	3.71	3.81	4.15	3.98	3.20	3.84
Reverse	2.70	3.05	3.36	2.93	2.74	2.65	2.65
Post-Cueing							
Forward	2.73	3.36	3.44	3.64	3.14	3.24	3.45
Reverse	2.48	3.09	2.73	2.89	2.90	2.25	2.40

Unordered Recall

S

3	4	5	6	7	8	9
2.95	3.82	4.41	5.08	5.53	6.10	7.00

DS	3	4	5	6	7	8	9
Deaf	2.93	3.66	3.89	4.36	4.73	5.15	5.85
Hearing	2.99	3.98	4.93	5.79	6.34	7.04	8.14
F=	.01	2.03	22.07	43.65	53.89	75.20	110.10
	ns	ns	**	**	**	**	**

CF

	Forward	Reverse
Pre-Cued	5.14	4.93
Post-Cued	4.96	4.91

DCF

Deaf

	Forward	Reverse
Pre-Cued	4.56	4.32
Post-Cued	4.25	4.34
F=	40.56	.01
	**	ns

(cont'd.)

Appendix 2 (cont'd.)

Hearing

	Forward	Reverse
Pre-Cued	5.71	5.54
Post-Cued	5.67	5.48
F=	.81	.73
	ns	ns

CFS

Pre-Cued	3	4	5	6	7	8	9
Forward	3.00	3.95	4.49	5.26	5.83	6.29	7.15
Reverse	2.85	3.80	4.54	4.99	5.31	6.04	6.89
Post-Cued							
Forward	2.89	3.76	4.41	5.00	5.41	6.09	7.14
Reverse	2.98	3.78	4.26	5.05	5.59	5.98	6.81

APPENDIX 3

Experiment 3: Ordered Recall: Cell Means and Tests of Simple Effects

S

	3	4	5	6	7	8	9
	2.63	3.33	3.63	3.43	3.49	2.75	2.91

DS	3	4	5	6	7	8	9
Deaf	2.58	3.13	3.04	2.53	3.10	2.53	2.88
Hearing	2.67	3.53	4.22	4.32	3.88	2.97	2.95
F=	.03	.71	5.86	13.87	2.60	.83	.09
	ns	ns	*	**	ns	ns	ns

CF

	Forward	Reverse
Pre-Cued	3.57	2.84
Post-Cued	3.30	2.94

CFS

Pre-Cueing	3	4	5	6	7	8	9
Forward	2.94	3.67	4.17	3.79	3.60	3.29	3.56
Reverse	2.31	3.15	3.27	3.25	2.96	2.46	2.50
Post-Cueing							
Forward	2.73	3.38	3.48	3.73	4.48	2.56	2.77
Reverse	2.52	3.13	3.60	2.94	2.92	2.69	2.81

Unordered Recall

S

	3	4	5	6	7	8	9
	2.83	3.74	4.48	5.12	5.87	6.58	7.56

(cont'd.)

Appendix 3 (cont'd.)

DS	3	4	5	6	7	8	9
Deaf	2.84	3.69	4.31	4.71	5.67	6.45	7.75
Hearing	2.82	3.80	4.66	5.52	6.07	6.70	7.37
F=	.02	.35	4.40	24.38	6.10	2.38	5.50
	ns	ns	*	**	*	ns	*

CS	3	4	5	6	7	8	9
Pre-Cueing	2.77	3.78	4.53	5.14	5.73	6.36	7.40
Post-Cueing	2.90	3.71	4.44	5.10	6.01	6.79	7.73

FS	3	4	5	6	7	8	9
Forward	2.92	3.75	4.53	5.15	6.13	6.59	7.70
Reverse	2.75	3.74	4.44	5.09	5.61	6.56	7.42

CFS	3	4	5	6	7	8	9
Pre-Cueing							
Forward	2.94	3.81	4.69	5.02	6.04	6.46	7.56
Reverse	2.60	3.75	4.38	5.25	5.42	6.27	7.23
Post-Cueing							
Forward	2.90	3.69	4.38	5.27	6.21	6.73	7.85
Reverse	2.90	3.73	4.50	4.94	5.81	6.85	7.60

APPENDIX 4

Supplementary Analysis 1: Deaf

Ordered Recall - Cell Means and Tests of Simple Effects

P		F_{MD}	
RD	2.19	11.36	**
SD	2.33	4.29	*
MD	2.67		

PS	3	4	5	6	7	8	9
RD	2.49	2.72	2.43	1.92	1.79	1.76	1.73
SD	2.54	2.90	2.41	2.26	2.22	2.05	1.96
MD	2.59	2.95	2.96	2.34	2.85	2.38	2.64
F_{RD-SD}=	.19	3.54	.25	5.74	8.66	4.13	2.51
	ns	ns	ns	*	**	*	ns
F_{SD-MD}=	.90	.25	12.81	.63	20.11	5.02	23.37
	ns	ns	**	ns	**	*	**
F_{MD-RD}=	.35	3.08	15.39	13.27	55.14	18.26	40.65
	ns	ns	**	**	**	**	**

(cont'd.)

Appendix 4 (cont'd.)

PCFS

		3	4	5	6	7	8	9
RD	Pre	2.54	2.91	2.46	2.30	1.94	2.11	2.03
	Post	2.44	2.53	2.39	1.54	1.65	1.41	1.43
SD	Pre	2.74	3.10	2.79	2.40	2.50	2.15	2.26
	Post	2.34	2.70	2.03	2.13	1.94	1.95	1.65
MD	Pre	2.53	3.05	3.10	2.39	2.74	2.55	2.84
	Post	2.66	2.85	2.83	2.50	2.96	2.20	2.45
RD	For	2.55	2.99	2.61	1.96	1.95	1.78	1.66
	Rev	2.42	2.45	2.29	1.88	1.64	1.75	1.79
SD	For	2.74	3.18	2.74	2.41	2.31	2.19	1.88
	Rev	2.34	2.63	2.08	2.11	2.13	1.91	2.04
MD	For	2.80	3.18	2.11	2.43	3.31	2.31	2.76
	Rev	2.39	2.73	2.81	2.26	2.39	2.44	2.53
Pre	For	2.88	3.39	3.13	2.51	2.68	2.36	2.53
	Rev	2.33	2.65	2.44	2.22	2.11	2.18	2.23
Post	For	2.52	2.83	2.52	2.03	2.38	1.83	1.68
	Rev	2.44	2.55	2.31	1.95	1.99	1.88	2.01
Pre RD	For	2.80	3.30	2.60	2.48	2.13	2.18	2.03
	Rev	2.28	2.53	2.33	2.13	1.75	2.05	2.03
Post	For	2.30	2.68	2.63	1.45	1.78	1.38	1.30
	Rev	2.56	2.38	2.15	1.63	1.53	1.45	1.55
Pre SD	For	2.95	2.48	3.13	2.75	2.80	2.35	2.35
	Rev	2.53	2.73	2.45	2.05	2.20	1.95	2.18
Post	For	2.53	2.88	2.35	2.08	1.83	2.03	1.40
	Rev	2.15	2.53	1.70	2.18	2.05	1.88	1.90
Pre MD	For	2.88	3.40	3.65	2.30	3.10	2.55	3.20
	Rev	2.18	2.70	2.55	2.48	2.38	2.55	2.48
Post	For	2.73	2.95	2.58	2.55	3.53	2.08	2.33
	Rev	2.60	2.75	3.08	2.05	2.40	2.33	2.58

(cont'd.)

Appendix 4 (cont'd.)

Unordered Recall

P		F_{MD}	
RD	4.13	27.80	**
SD	4.36	15.85	**
MD	5.09		

CF

	Forward	Reverse
Pre-cueing	4.62	4.45
Post-Cueing	4.40	4.58
t=	1.98	1.39
	*	ns

PS	3	4	5	6	7	8	9
RD	2.91	3.55	3.91	4.13	4.38	4.67	5.38
SD	2.92	3.66	3.89	4.36	4.73	5.15	5.85
MD	2.86	3.65	4.26	4.66	5.68	6.57	7.93
F_{RD-SD}=	.11	1.29	.04	2.59	6.58	12.89	11.86
	ns	ns	ns	ns	**	**	**
F_{SD-MD}=	.27	.11	7.32	4.83	47.44	106.75	233.29
	ns	ns	**	*	**	**	**
F_{MD-RD}=	.37	1.29	6.57	5.58	89.35	193.83	348.13
	ns	ns	*	*	**	**	**

(cont'd.)

Appendix 4 (cont'd.)

UOR

PCFS

		3	4	5	6	7	8	9
RD Pre		2.90	3.51	3.86	4.23	4.33	4.71	5.51
Post		2.91	3.59	3.96	4.04	4.44	4.63	5.25
SD Pre		2.96	3.76	4.04	4.41	4.73	5.33	5.85
Post		2.88	3.56	3.75	4.30	4.74	4.98	5.85
MD Pre		2.79	3.73	4.31	4.59	5.59	6.35	7.73
Post		2.94	3.58	4.21	4.73	5.76	6.88	8.14
RD For		2.88	3.51	3.81	4.08	4.49	4.69	5.23
Rev		2.93	3.59	4.01	4.19	4.29	4.65	5.49
SD For		2.90	3.73	3.94	4.35	4.79	5.25	5.88
Rev		2.94	3.60	3.85	4.36	4.68	5.05	5.83
MD For		2.98	3.56	4.24	4.50	5.90	6.56	7.99
Rev		2.75	3.74	4.29	4.75	5.45	6.58	7.88
Pre For		2.98	2.68	4.10	4.44	5.16	5.49	6.48
Rev		2.79	3.65	4.04	4.38	4.60	5.43	6.25
Post For		2.87	3.52	3.89	4.22	4.96	5.51	6.28
Rev		2.95	3.63	4.06	4.49	5.00	5.42	6.54
Pre RD	For	2.95	3.50	3.85	4.33	4.63	4.60	5.43
	Rev	2.85	3.53	3.88	4.13	4.03	4.83	5.60
Post	For	2.83	3.53	3.78	4.83	4.35	4.78	5.13
	Rev	3.00	3.65	4.15	4.25	4.53	4.48	5.38
Pre SD	For	3.00	3.90	3.98	4.60	5.03	5.48	5.96
	Rev	2.93	3.63	4.10	4.23	4.43	5.18	5.75
Post	For	2.80	3.55	3.90	4.10	4.55	5.03	5.80
	Rev	2.95	3.58	3.60	4.50	4.93	4.93	5.90
Pre MD	For	2.98	3.65	4.48	4.40	5.83	6.40	8.05
	Rev	2.60	3.80	4.15	4.78	5.35	6.30	7.40
Post	For	2.98	3.48	4.00	4.73	5.98	6.73	7.93
	Rev	2.90	3.68	4.43	4.73	5.55	6.85	8.35

APPENDIX 5

Supplementary Analysis 2: Hearing

Ordered Recall: Cell Means and Tests of Simple Effects

P

		F_{RD}	F_{SD}
RD	3.73		
SD	3.84		
MD	3.50	7.84	17.13
		**	**

PS

	3	4	5	6	7	8	9
RD	2.92	3.93	4.55	4.21	3.93	3.36	3.24
SD	2.88	3.75	4.30	4.67	4.01	3.18	4.08
MD	2.67	3.53	4.22	4.32	3.88	2.97	2.95
F_{RD-SD} =	.11	.78	1.16	1.49	.14	.76	17.05
	ns	ns	ns	ns	ns	ns	**
F_{SD-MD} =	1.14	1.14	.19	1.61	.42	1.14	29.60
	ns	ns	ns	ns	ns	ns	**
F_{MD-RD} =	1.34	1.79	1.30	.34	.26	1.43	1.99
	ns	ns	ns	ns	ns	ns	ns

(cont'd.)

Appendix 5 (cont'd.)

OR

<u>PCFS</u>

			3	4	5	6	7	8	9
RD	Pre		2.92	3.92	4.65	4.17	3.77	3.46	3.58
	Post		2.92	3.94	4.46	4.25	4.08	3.27	3.90
SD	Pre		2.90	3.75	4.35	4.85	4.46	3.23	3.79
	Post		2.80	3.75	4.25	4.48	3.56	3.15	4.38
MD	Pre		2.71	3.48	4.21	4.46	3.67	2.96	2.98
	Post		2.63	3.58	2.23	4.19	4.08	2.98	2.92
RD	For		3.00	4.00	4.69	4.79	4.77	4.33	4.27
	Rev		2.83	3.85	4.92	4.63	3.08	2.40	2.21
SD	For		2.92	4.00	4.50	5.44	4.63	3.85	5.44
	Rev		2.85	3.50	4.10	3.90	3.40	2.52	2.73
MD	For		2.83	3.73	4.38	4.90	4.50	3.35	3.27
	Rev		2.50	3.33	4.06	3.75	3.25	2.58	2.63
Pre	For		2.94	3.92	4.60	5.25	4.69	3.97	4.39
	Rev		2.74	3.51	4.21	3.74	3.24	2.46	2.51
Post	For		2.89	3.90	4.44	4.83	4.57	3.72	4.26
	Rev		2.72	3.61	4.18	3.78	3.25	2.54	2.53
Pre	RD	For	3.00	4.00	4.79	5.03	4.75	4.38	4.71
		Rev	2.83	3.83	4.50	3.29	2.79	2.59	2.46
Post		For	3.00	4.00	4.58	4.54	4.79	4.29	3.83
		Rev	2.83	3.88	4.33	3.96	3.38	2.25	1.96
Pre	SD	For	2.92	4.00	4.50	5.58	5.42	3.83	4.92
		Rev	2.88	3.50	4.21	4.13	3.50	2.63	2.67
Post		For	2.92	4.00	4.50	5.29	3.83	3.88	5.96
		Rev	2.83	3.50	4.00	3.67	3.29	2.42	2.79
Pre	MD	For	2.92	3.75	4.50	5.13	3.92	3.71	5.54
		Rev	2.50	3.20	3.92	3.79	3.42	2.21	2.42
Post		For	2.75	3.71	4.25	4.67	5.08	3.00	3.00
		Rev	2.50	3.45	4.21	3.71	3.08	2.96	2.83

(cont'd.)

Appendix 5 (cont'd.)

Unordered Recall

<u>P</u>

		F_{RD}	F_{SD}	
RD	3.36		18.06	**
SD	5.64			
MD	5.28		30.35	**

<u>S</u>

3	4	5	6	7	8	9
2.93	3.92	4.83	5.60	6.22	6.73	7.75

<u>PF</u>

	Forward	Reverse
RD	5.59	5.13
SD	5.71	5.56
MD	5.41	5.15

<u>PS</u>

	3	4	5	6	7	8	9
RD	2.98	3.97	4.92	5.49	6.27	6.42	7.50
SD	2.99	3.98	4.93	5.79	6.32	7.07	8.36
MD	2.82	3.80	4.66	5.52	6.07	6.70	7.38
F_{RD-SD}=	.01	.01	.01	1.65	.11	21.81	38.17
	ns	ns	ns	ns	ns	**	**
F_{SD-MD}=	1.03	1.54	3.79	1.87	2.25	7.07	50.59
	ns	ns	ns	ns	ns	**	**
F_{MD-RD}=	1.02	1.46	3.79	.09	1.86	3.09	.98
	ns	ns	ns	ns	ns	ns	ns

(cont'd.)

Appendix 5 (cont'd.)

UOR

FS

	3	4	5	6	7	8	9
Forward	2.96	3.96	4.87	5.72	6.47	6.99	8.05
Reverse	2.90	3.88	4.80	5.48	5.98	6.47	7.44

BFS

	3	4	5	6	7	8	9
With B Forward	2.97	3.94	4.88	5.79	6.43	6.94	8.15
Reverse	2.88	3.89	4.81	5.50	6.06	6.68	7.91
No B Forward	2.94	3.97	4.86	5.65	6.50	7.04	7.94
Reverse	2.93	3.86	4.79	5.46	5.90	6.26	6.97

PFS

		3	4	5	6	7	8	9
RD	For	3.29	4.00	4.96	5.83	6.63	7.04	7.96
	Rev	2.92	3.94	4.88	5.40	5.92	5.79	7.04
SD	For	3.00	4.00	4.94	5.90	6.46	7.15	8.54
	Rev	2.98	3.96	4.92	5.69	6.19	7.00	8.19
MD	For	2.88	3.88	4.71	5.69	6.31	6.79	7.65
	Rev	2.77	3.73	4.60	5.35	5.83	6.63	7.10

APPENDIX 6

Analyses of Variance

Deaf Source		Error Term	3 Span F	SS	df	4 Span F	SS	df	5 Span F	SS	df	6 Span F	SS	df
Mean		R		6181.35	1		5856.75	1		3844.00	1		2323.20	1
R				127.65	39		305.62	39		411.60	39		384.13	39
For/Rev	(F)	RF	13.87	21.60	1	16.78	52.00	1	10.29	34.81	1	2.72	6.08	1
Series Length	(S)	RS	1.24	.93	2	17.09	37.51	3	10.52	54.45	4	13.80	86.42	5
RF				60.73	39		120.87	39		131.99	39		87.26	39
RS				29.07	78		85.61	117		201.94	156		244.23	195
FS		RFS	2.35	2.42	2	13.86	30.60	3	24.65	90.29	4	44.74	270.65	5
RFS				40.24	78		80.02	117		142.85	156		235.94	195

(cont'd.)

Appendix 6 (cont'd.)

Deaf Cell Means		Serial Position 1	2	3	4	5	6	7	8	9
3	F	5.55	5.25	5.33						
	R	4.68	4.73	4.98						
4	F	5.40	4.50	4.30	4.53					
	R	3.90	3.30	3.65	4.65					
5	F	4.48	3.26	3.28	2.83	3.15				
	R	2.53	2.55	2.18	2.75	4.03				
6	F	3.53	2.65	2.23	2.13	1.68	1.68			
	R	1.63	1.28	1.28	1.63	2.50	4.23			
7	F	3.95	3.30	2.48	1.75	1.08	1.20	1.50		
	R	1.23	.95	.80	1.28	1.33	2.60	4.15		
8	F	3.00	2.35	1.63	1.18	1.08	.85	.98	1.68	
	R	1.05	1.00	.73	.75	1.00	1.35	2.13	4.15	
9	F	3.03	2.15	1.40	1.10	1.03	.65	.73	.98	1.50
	R	1.28	.93	.60	.68	.43	.75	1.48	2.58	3.93

(cont'd.)

Appendix 6 (cont'd.)

Deaf		7 Span			8 Span			9 Span		
Source	Error Term	F	SS	df	F	SS	df	F	SS	df
Mean	R		2172.52	1		1546.91	1		1408.40	1
R			273.55	39		166.27	39		135.88	39
F/R (F)	RF	12.56	24.44	1	.25	.83	1	.004	.125	1
Ser. (S)	RS	29.12	164.32	6	35.70	243.87	7	39.41	312.24	8
RF			75.91	39		127.61	39		112.04	39
RS			220.09	234		266.42	273		308.97	312
FS	RFS	74.26	476.04	6	38.22	285.56	7	36.40	295.12	8
RFS			250.01	234		291.39	273		316.19	312

(cont'd.)

Appendix 6 (cont'd.)

Analyses of Variance

Hearing Source	Error Term	3 Span F	SS	df	4 Span F	SS	df	5 Span F	SS	df	6 Span F	SS	df
Mean	R		4646.69	1		6030.08	1		6562.60	1		5486.28	1
R			23.31	23		55.67	23		141.70	23		285.96	23
For/Rev (F)	RF	6.28	4.00	1	7.83	13.02	1	2.70	9.2	1	41.60	134.75	1
Series Length (S)	RS	.42	.18	2	2.03	.75	3	3.60	5.8	4	6.17	26.49	5
RF			14.67	23		38.23	23		79.09	23		99.67	23
RS			9.8	46		8.5	69		37.36	92		98.75	115
FS	RFS	2.46	1.3	2	3.10	1.4	3	2.09	4.98	4	13.88	55.77	5
RFS			12.00	46		10.35	69		56.20	92		92.44	115

(cont'd.)

Appendix 6 (cont'd.)

	Hearing Cell Means	Serial Position 1	2	3	4	5	6	7	8	9
3	F	5.96	5.88	5.71						
	R	5.38	5.58	5.58						
4	F	5.83	5.92	5.58	5.83					
	R	5.33	5.25	5.21	5.58					
5	F	5.75	5.50	5.25	5.13	5.50				
	R	4.83	5.04	5.00	4.88	5.42				
6	F	5.58	5.45	5.21	4.67	4.54	4.83			
	R	3.58	3.04	3.29	3.29	3.88	5.00			
7	F	5.29	4.83	3.83	3.63	3.33	3.33	3.63		
	R	2.38	2.29	2.21	2.50	2.42	3.21	4.54		
8	F	5.08	4.21	3.38	2.54	1.92	1.83	1.75	2.50	
	R	1.50	1.50	1.13	1.21	1.29	1.63	2.54	4.17	
9	F	5.08	4.21	3.38	3.08	2.88	2.13	1.88	1.50	1.79
	R	1.38	1.21	1.00	.83	1.33	1.00	1.79	2.63	4.00

(cont'd.)

Appendix 6 (cont'd.)

Hearing

Source	Error Term	7 Span F	7 Span SS	7 Span df	8 Span F	8 Span SS	8 Span df	9 Span F	9 Span SS	9 Span df
Mean	R		3854.30	1		2185.04	1		2250.45	1
R			359.27	23		205.83	23		184.99	23
F/R (F)	RF	2.75	119.05	1	33.41	102.09	1	68.41	154.08	1
Ser. (S)	RS	11.00	59.04	6	16.58	159.21	7	16.25	113.67	8
RF			99.67	23		70.28	23		51.80	23
RS			123.39	138		216.91	161		160.87	184
FS	RFS	27.87	127.79	6	43.93	268.16	7	47.37	364.87	8
RFS			105.45	138		140.41	161		177.16	184