DOCUMENT RESUME

ED 229 889 EC 151 633

AUTHOR Karchmer, Michael A.; And Others
TITLE Investigations of Cognitive Strategies and Cognitive Flexibility in Hearing Impaired Children. Final Report.
INSTITUTION Gallaudet Research Inst., Washington, DC.
SPONS AGENCY Spencer Foundation, Chicago, Ill.
PUB DATE Dec 81
NOTE 135p.
PUB TYPE Reports - Research/Technical (143) -- Collected Works - General (020)

EDRS PRICE MF01 Plus Postage. PC Not Available from EDRS.
DESCRIPTORS *American Sign Language; *Cognitive Processes; *Deafness; Difficulty Level; Elementary Secondary Education; *Hearing Impairments; Item Analysis; Language Arts; Learning Processes; Memory; Spatial Ability; Time Perspective
IDENTIFIERS *Stroop Color Word Test

ABSTRACT

The final report consists of three studies on aspects of a common theme, that a hearing impaired (HI) person's performance on information processing tasks depends on interactions of that person's cognitive structure and strategies with properties of materials to be processed and task demands. The first study, "Recall of Temporal/Spatial Incongruent Letter Strings by Deaf and Hearing Children: A Test of Structural Determinants of Memory Performance," by J. Belmont et al., reports that comparison of 16 deaf and 16 hearing children, 11 years old, on a computerized memory test, yielded such results as that deaf children at age 11 years are better adapted to the spatial than to the temporal memory orientation. J. Bourg reports on the study, "American Sign Language and Stroop Interference," such results as that deaf Ss experienced more color-sign interference than hearing Ss and hearing Ss more color-word interference than deaf Ss. The last study, by T. Allen, "Test Response Variations between Hearing Impaired and Hearing Students," reports that nine language arts test items from a Rasch based item bank were administered to 1,542 HI students, aged 7 to 18, in 39 programs in six states with results such as finding discrepancies in the ordering of item difficulty between the hearing impaired and hearing Ss. (MC)

FINAL REPORT

to the

SPENCER FOUNDATION

for

INVESTIGATIONS OF COGNITIVE STRATEGIES AND COGNITIVE FLEXIBILITY IN HEARING IMPAIRED CHILDREN

Gallaudet College Research Institute
Washington, D.C. 20002

Investigators (Alphabetically)

Thomas E. Allen, Ph.D.
John M. Belmont, Ph.D.
James W. Bourg, Ph.D.
Michael A. Karchmer, Ph.D.
(Principal Investigator)
Raymond J. Trybus, Ph.D.
(Project Director)

December 1981

TABLE OF CONTENTS

INTRODUCTION AND OVERVIEW

This final report is arranged in three sections, each addressing significant aspects of the subject matter implied by the project's title, "Investigations of Cognitive Strategies and Cognitive Flexibility in Hearing Impaired Children." The first two sections report on experimental work from the cognitive laboratory; the third section describes results from a large-scale achievement testing study. The theme that unites the sections is that the nature of a person's performance on tasks involving information processing depends on the interactions of that person's cognitive structures and strategies with the properties of the materials to be processed and the task demands. In order to produce a satisfactory account of how deaf children's performances on cognitive tasks differ from normal-hearing children's, the relationships among these four variables must be understood. Only after these relationships are understood can professionals concerned with the education of deaf children hope to devise educational strategies that meet this population's special cognitive needs.

Each of the sections of this report concentrates on different subsets of the variables listed above. The work reported in Section A seeks to identify perceptual orientations or characteristic structures of profoundly deaf children and to examine the strategies used by these children in the face of changing task demands. Section B identifies fundamental structural differences between native, signing deaf individuals and hearing individuals and manipulates experimental materials in order to shed light on the reasons for these differences. Section C, using achievement test results from a sample of more than 1,500 hearing impaired children and youth, deals with considerations of how test materials and task demands interact with cognitive structures.

The work reported in this final report represents the efforts of a number of investigators affiliated with the Gallaudet Research Institute. The primary investigators for the work reported in Section A were Drs. Belmont (of the University of Kansas Medical School), Bourg, and Karchmer. Section B was the work of Dr. Bourg. Dr. Allen was the major investigator for the study reported in Section C. Dr. Karchmer provided overall coordination of the entire project and Dr. Trybus was responsible for administrative support. The significant contributions of many others are recognized in the Acknowledgements that follows Section C.

Below are overviews of the three sections of this report:

Section A: Recall of Temporal/Spatial Incongruent Letter Strings by Deaf and Hearing Children: A Test of Structural Determinants of Memory Performance

This study of profoundly deaf children's spatial and temporal orientations derived from the British work of O'Connor and Hermelin. These investigators discovered that deaf children tend to take a spatial orientation when attempting to memorize and recall short sequences of items such as digits or letters. In contrast, they found that hearing children take a temporal orientation. This striking difference in information processing was viewed as reflecting fundamentally different cognitive structures, but it was hypothesized that any limitations that might result from one structure or the other could be overcome by deliberate cognitive self-management or formal instruction. The present study was designed to test this hypothesis.

The study included 16 profoundly deaf children resident at a state school for the deaf, and 16 hearing children in a regular public school. The groups were matched for chronological age at approximately 11.5 years. All children received a three-part computerized memory test in which they viewed sequences of letters and then immediately reconstructed the order in which the letters appeared. Letters were presented in random order in four separate windows such that the temporal and spatial orders were thoroughly confused. Children reconstructed the presentation order by touching another randomized ordering of the same four letters presented as a single set in a second array of four windows.

In the first part, the O'Connor and Hermelin findings were confirmed: deaf children tended to reconstruct the letters' left-to-right spatial order, whereas the hearing children uniformly reconstructed the temporal order. Also consistent with the British work, a minority of the deaf children adopted the temporal orientation.

As a test of adaptability, in Part II the children were instructed to adopt the orientation they had not used in Part I. Then, in Part III, all children were instructed to adopt both orientations, one after the other. The findings for the instructed trials were that hearing children suffered a dramatic decrease in recall accuracy going into the non-preferred orientation, but they rapidly adjusted to it with almost complete recovery of recall accuracy. In contrast, the deaf children's recall accuracy decreased somewhat less than the hearing children's under the requirement to perform in alternative orientation, but they were also slower to recover.

Of particular interest were the data on memory reconstruction efficiency, which in this study was measured by response times. The spatially oriented deaf children and the temporally oriented hearing children showed practically identical recall efficiencies whereas the temporally oriented deaf children were markedly slower to execute their recall responses.

These findings suggest that profoundly deaf children at age 11 years are better adapted to the spatial orientation than to the temporal, and that the minority of deaf children who spontaneously chose the temporal orientation may, in fact, have been handicapped thereby.

Section B: American Sign Language and Stroop Interference

The complex spatial information required for the comprehension of American Sign Language (ASL) may provide an explanation of why a majority of deaf students in the experiment reported in Section A spontaneously chose to code the letter sequences using the spatial information available in the display instead of the temporal information. The study reported in Section B addresses the issue of spatial information processing in the comprehension of ASL more directly using Stroop's (1935) color-word interference technique. When one is asked to name the ink color in which a word naming a conflicting color is printed (e.g., the word <u>blue</u> printed in red ink), the word meaning interferes with one's ability to name the ink color. This study extended previous research (Bourg, 1980) which found that native deaf signers experienced more interference in a color-sign interference task than did normally hearing English speakers in a color-word interference task. In the present study, deaf, native signers and normally hearing English speakers who knew signs to some degree were given color-sign and color-word interference tasks. Deaf subjects experienced more color-sign interference than did hearing subjects while hearing subjects experienced more color-word interference than did deaf subjects. These results imply that there are different internal representations of sign and word meaning and different ways of accessing that meaning for deaf and hearing individuals.

Section C: Test Response Variations Between Hearing Impaired and Hearing Students

Nine language arts test items drawn from a Rasch-based item bank developed with large samples of hearing students were administered to a sample of 1,542 hearing impaired students located in 39 educational programs in six states. Two different item formats were used in administering the items to the students: a) teacher-dictated and b) student-read. The resulting patterns of responses to the test were analyzed to assess the degree to which the skill continuum defined by the Rasch item difficulty parameters for hearing students correctly predicted the ordering of the p-values observed for the hearing impaired group. The data were then factor-analyzed to determine whether or not there was a format factor. The results indicated that the p-values for the hearing impaired students were not ordered the same as the Rasch item difficulty parameters. Large discrepancies on at least two of the items were noted. The need for future research both in the area of comparing skill hierarchies between hearing and hearing impaired groups and in the area of exploring the role of item format in text performance is discussed.

SECTION A

RECALL OF TEMPORAL/SPATIAL INCONGRUENT LETTER STRINGS BY DEAF AND HEARING CHILDREN: A TEST OF STRUCTURAL DETERMINANTS OF MEMORY PERFORMANCE

Introduction

Flavell and Wellman's (1977) developmental scheme portrays memory performance as depending upon interactions among four variables. Structures (capacities, perceptual orientations, etc.) and strategies (attention, articulation, rehearsal, recording, etc.) interact with properties of the test materials (numerosity, presentation rate, image-evoking potential, meaningfulness, etc.) and memory task demands (immediate vs. delayed recall, recognition, partial recall, probed recall, etc.). The success of the child's attempt to memorize depends largely upon his knowledge of when his capacity limitations require capacity-stretching strategies that capitalize upon memorable qualities of the materials, yet also meet the task demands. Of the four variables, task demand (recall requirement) is ordinarily the only one mentioned to the child by the experimenter. The child's knowledge of the remaining terms is called his "metamemory" (Brown, 1978; Flavell, 1976), and what he does with that knowledge by way of selection, use, evaluation and revision of strategies, is called his "executive function" or "self-programming" (Belmont, 1978).

It is generally agreed that deficiencies of metamemory or self-programming contribute importantly to normal children's subadult memory performances. The most compelling demonstrations have come in studies where high recall accuracy has been obtained with instructed strategies that obviate the need and circumvent the use of metamemory or self-programming on the part of the child (see reviews by Belmont & Butterfield, 1977; Belmont, 1978). Very little is actually known, however, about how superordinate knowledge and functions interact to produce the child's spontaneous memory strategies, upon which his memory performance ultimately depends. In this paper we will approach the question by assuming that a child's <u>initial</u> attempt to deal with a cognitive problem is conditioned by habitual modes of information processing (i.e., metaknowledge). Such modes or orientations will be viewed as structural properties of the system that inform self-programming and are themselves changeable as a result (Wilcox & Katz, 1981). In order to test this assumption, we must of course identify and closely attend to individual differences in structure, yet such differences are not generally recognized among children of normal intelligence. A special opportunity arises, however, in the cognitive psychology of deafness: Congenitally deaf children, having by nature been deprived of normal acoustic experience and vocal-acoustic articulatory functions, often spontaneously employ alternative strategies that seem to reflect unique structural orientations.

Hung, Tzeng, and Warren (1981) studied characteristic structures of deaf children as these structures bear on reading and other language functions. Stated briefly, their hypothesis was that deaf children fare badly with written English because they apply inappropriate strategies, and they do so because appropriate ones require phonetic representations that are simply unavailable in the deaf children's cognitive structure.

Similar effects are seen in deaf children's deliberate memorization of written materials. To control for possible metamemory or self-programming deficiencies, we used an instructed manual articulation rehearsal strategy with deaf children, and a formally identical vocal articulation strategy with hearing children (Belmont, Karchmer & Pilkonis, 1976; Belmont & Karchmer, 1978). Even after considerable practice with the strategy and the materials, the deaf children's recall of letters and words was subnormal; yet with pictures of objects the groups were nearly equal, the advantage going if anything to the deaf children. Aside from pointing to faulty reading as a metamnemonic complication for research on deaf children's memory (not to mention the disastrous psycho-educational implications), these studies show that deaf and hearing children alike improve under strategy instruction, thus confirming superordinate deficiencies in both groups. The studies also show that given adequate external programming and congenial materials, deaf children's basic memory structures, including primary (echo) memory and secondary (rehearsal) memory, operate perfectly well. We may have some confidence, therefore, that future elaborations of these children's subnormal memory performance will be related to metamemory or self-programming, with the problem of language compatibility falling clearly into the metamemory domain.

A follow-up study was proposed by Belmont and Karchmer (1978) as a test of the language interpretation. We suggested substituting pictures of fingerspelled letters for the printed letters, and then using the instructed strategy with deaf students vs. hearing introductory students of sign language. It seemed self-evident that the hearing students would then suffer the language-based decoding handicap. Hung et al. (1981) likewise favored a "second language" interpretation of the deaf children's reading performance, arriving at a production deficiency explanation. They did not refer to executive functions or self-programming by name, but certainly did by implication in their conclusion that deaf children's shifting approaches to written vs. signed material represents problem-solving, with a strong conscious component to be found in their solutions for handling written materials. It is unknown whether or not there is also a conscious (or at least deliberative) component in the superordinate functions that lead to such solutions. Likewise, it is unknown to what degree deaf people's unique structures guide or limit their information-processing strategies generally. Therefore, if we are to use deaf children as markers for studying structural effects on memory performance, we will need to go beyond simple comparisons of deaf vs. hearing children. We will need to positively identify individuals within the deaf population whose initial structural orientations are clearly different from hearing children's. The next step will be to challenge each group to perform a task for which that group's particular structures are well-suited, and another task for which they will likely be maladaptive. In its general outline, this is the approach taken by O'Connor and Hermelin. The present study is designed to improve upon their work by sharpening the identification of initial structures, and by molding the challenge tasks to conform quite closely to those structures.

Identification of Initial Structures

Conrad (1970, 1972; Conrad & Rush, 1965) was concerned with speech vs. non-speech and acoustic vs. visual strategies in short-term memory (STM). He used acoustic errors vs. visual errors to classify deaf and normal hearing children's STM coding strategies for lists of letters. Deaf children made many more visual errors than acoustic, and hearing children made many more acoustic errors than visual (Conrad, 1972; Wallace & Corballis, 1973). From an error-based articulation index, Conrad inferred that the great majority of hearing children had used a vocal-acoustic/articulation strategy. The majority of the deaf children had apparently used non-acoustic (perhaps visual) coding, though other modes (e.g., dactylic articulation) were sometimes implicated as alternative or adjunct methods. Conrad concluded that the deaf children's coding strategies are possibly hypervariable, and in the main they are not similar to hearing children's strategies. One clear indication of their adaptive potential is seen in a subanalysis in which deaf and hearing children were selected for their equal error rates on visually confusing lists. On the acoustically confusing ones, the hearing children in this subsample made 3.6 times as many errors as the deaf. If it is assumed that the deaf children's strategies reflected their initial structures, it must be concluded that the structures themselves are non-acoustic, probably visual, and perhaps therefore spatially oriented.

Conrad's contemporaries in London came closer to identifying deaf children's structures as they probed vision, audition, space, and time. Their work is important not only because it provides a model for prospective tests of the structure's rigidity and adaptive potential, but as well because it invites one to think, rather more often and more critically than usual, about the importance of self-programming in memory development. The first few studies in the series will be reviewed in detail because they are the basis of the present research.

In order to disentangle visual vs. auditory coding, O'Connor and Hermelin (1972) serially presented three visual digits in three different locations (left, middle or right box) to normal hearing controls vs. deaf children; and three aural digits in three different locations (left, middle or right speaker) to normal sighted controls vs. blind children. The child's task was to report the middle digit. Stimulus presentation was managed such that the temporal middle digit was never seen or heard in the spatial middle position. Given this largely ambiguous temporal/spatial incongruity, the researchers noted that the child's interpretation of "middle" might be conditioned by his general orientation toward organizing sequential stimuli, leading him to report either the temporal middle digit, the spatial or perhaps even the numerical. In present terms, the test stands as a diagnosis of structure, but for openers it does not seem to stress the child's memory.

The results were simple enough: Test condition (visual vs. aural) determined the outcome for control children (who were the only ones tested under both conditions), and most children within each group performed similarly. In the aural test, all save two of the 10 blind and 10 control children consistently reported the temporal middle digit. In the visual test, 9/10 of the controls and 7/10 of the deaf children consistently reported the spatial middle. The errant 3/10 deaf children showed a unitary minority approach: They reported the numerical middle digit, which reflects an amusing strategy, certainly, but an inefficient one, compared to the mindless alternative of fixing an eye upon the (guaranteed) spatial middle box, ignoring surrounding digits regardless of when they appear, and then simply reporting the spatial middle digit. It is unknown whether or not any of the 3/10 deaf arithmeticians had even considered, much less deliberately rejected this simpler solution, but in a later test devised specially for them in which digits were replaced by geometric forms, all three children, like their peers, consistently reported the spatial middle item.

In a second experiment, hearing children simultaneously saw and heard the digits. They again reported the spatial middle on almost 100% of the trials, but a fresh sample who were first given the aural test and then the visual/aural test, overwhelmingly reported the temporal middle, for which it seems the initial aural test had securely biased them. Thus, test modality and prior set were both totally effective determinants of hearing children's expressed orientation, but bias was evidently stronger than modality because (as a moment's thought reveals), the temporal report must be more difficult to accomplish than the spatial report ordinarily made in the visual or visual/aural test.

At this early point, then, unbiased hearing children showed zero tendency toward spontaneous temporal processing in the visual or the visual/aural test; and the deaf children showed somewhat more strategy variability than the controls, at least until the deaf minority's specifically diagnosed numerical orientation had been specifically thwarted by altering the nature of the materials. The richness of the interaction between structural orientation, self-programming, materials and task demands is already clear. It also appears that under minimal information processing demands (pre-cued single digit in a 3-digit format), initial structure has some influence on problem solving, but it is easily modified by recent experience.

The next experiment shows that structure plays a heavier role when information processing demand is increased. O'Connor and Hermelin (1973a) again used 3-digit temporal/spatial incongruity, but this time they required total free recall instead of middle-item recall. Three digits were presented sequentially on three screens, but never in the left-to-right or right-to-left order. Hearing children were 90% accurate, deaf children 93%. In this context of nearly error-free responding, the major discovery was that 82% of the hearing children's correct responses reproduced the digits' original temporal order, while 89% of the deaf children's correct responses reproduced the left-to-right spatial order. The same children (N=10/group) were then given the same test, but instead of free recall, the requirement was to choose between two 3-digit displays presented simultaneously. One display reproduced either the original temporal or the original left-to-right spatial order. The other was a random foil. The child's choice was supposed to be "the one you have just seen." Hearing children chose the temporal alternative vs. the foil 71% of the time, but the spatial vs. the foil only 55% of the time (where 50% was chance). The deaf children picked the temporal 59%, the spatial 81%. This recognition test thus confirmed (albeit at a somewhat lower level of within-group concordance) the dominant orientations revealed by the recall test: In line with the middle-digit study, the deaf children had attended primarily to the digits' spatial order, regardless of temporal position. The hearing children, however, had attended primarily to the temporal order, which exactly contradicts the middle-digit demonstration of a 100% spatial response for hearing children with the visual display.

Perhaps because of hearing children's spontaneous temporal/spatial flexibility in the face of changing response requirements, and perhaps as well because of the flexibility shown by the 3/10 numerically oriented deaf children in the middle-digit study, O'Connor and Hermelin concluded by speculating that all subjects, deaf and hearing, had actually chosen their response orders, not in rigid adherence to any structural imperative, but rather as elected strategies; and that they could, therefore, "under appropriate conditions or instructions, be induced to use their non-preferred strategy or ordering code even if less efficiently" (1973a, pp. 342-343). This conclusion was the foundation for all remaining studies in the series, and it is the hypothesis to be tested in the present study. Regardless of whether or not the hypothesis is ultimately confirmed, the evidence in hand in 1973 could not support its sweeping generality and optimistic psycho-educational implications. After all, no strategy instruction had then been done in the experimental context; indeed, none could have been done, because neither the deaf nor the hearing children's actual strategies were known precisely enough to inform even a timid instructional effort. Hence, crucial tests could not be made because, e.g., normally hearing children could not be instructed to use deaf children's preferred strategies or ordering codes. Moreover, although hearing children had shown wide variability in temporal/spatial orientation, the deaf children had thus far shown only spatial or other orientations under all conditions where the choice of temporal might have been made. This is not to say that the deaf children's spatial responses were slavishly linked to coding strategies mandated by an uncompromising structure. It is to say, simply, that there was at the time no compelling evidence for any other view.

Two options were open. The work could have moved on to discover the shapes of the children's strategies; then to mold instructional routines around them; then to directly induce children to use preferred vs. non-preferred strategies; and finally to compare their efficiencies. The alternative was to continue to alter the experimental context (materials, recall requirements, stimulus presentation schemes, etc.), whilst depending on the children's self-programming to generate appropriate strategy shifts, and by that route, again, to compare initial vs. modified strategy efficiencies. As it happens, almost all subsequent work involved the experimental, rather than the instructional approach. As noted in the introduction, instructional studies did, however, highlight the importance of considering superordinate knowledge and functions as highly probable loci of deaf children's memory performance deficiencies. O'Connor and Hermelin's follow-up work is best read from this point of view.

Testing the Structure

Given the suggestion that a spatial orientation is peculiar to the deaf child, while the temporal belongs to the hearing child, the later studies were all designed to stress these structures in one way or another. In Hermelin and O'Connor's (1973) recognition work, the child's task was to decide on each trial whether or not the order of a sequential comparison array was the same as that of a sequential input array. Each child saw an equal number of correct temporal (TE), correct spatial (SP) and random comparison arrays. There were two (between-subject) conditions: The input was presented in one window, while the comparison was presented by the multi-window TE/SP incongruent method; or vice versa. It was argued that if deaf children's processing were dominated by the spatial orientation, then some recoding (visualization?) of a one-window (necessarily temporal) presentation would need to be done, either at the input or at the comparison stage. The question was whether, and at which stage, the deaf children would show a deficiency, given their presumably weak temporal operations.

To guarantee the child's understanding of the task from the outset, he was first shown cards on which were printed two pairs of digits (e.g., 7-2, or perhaps 6-3), and was asked in each case
7-2 3-6
to tell whether the two pairs were in the same order. This pretest is the first such to appear in the literature. It is useful because it permits the child to make crucial decisions without

recoding, and therefore stands as a non-biasing introduction to the task. Hermelin and O'Connor also, for the first time with their deaf subjects, did head-counts for SP vs. TE orientation: A TE orientation was tallied if the child successfully recognized at least twice as many TE arrays as he did SP arrays; SP orientation was tallied if the opposite. By these criteria, only 3/40=8% of the hearing children, but 31/57=54% of the deaf expressed the SP orientation. Looking closer at the deaf sample, we see in Hermelin and O'Connor (1973, Table II), that 65% of the younger deaf (CA=10.6), but only 48% of the older (CA=13.0) were classified SP. Moreover, when the input display was TE/SP incongruent and the comparison display was one-window temporal, 80% of the younger vs. only 36% of the older deaf were classified SP (Fisher p=.040). In contrast, the two age groups were not different (50% vs. 56% respectively) when the input was temporal and the comparison was TE/SP incongruent. From this it appears that the younger deaf children were generally more disposed to a SP orientation, but at all ages the intersubject variability was high. The study therefore did not confirm a unitary structure within the deaf sample (though it did show a unitary TE structure for hearing children).

It should be noted that although 54% of the deaf children were classified SP, the classification required only that they correctly recognize twice as many SP as TE comparison arrays. As the choice was not between two alternatives (per O'Connor & Hermelin, 1973a), but rather was same/different for one display, it is possible for a conservative child to reject all non-SP comparison arrays and most of the SP's, yet still be classified SP. In order to decide, therefore, whether the experimental manipulation made a difference, it is not satisfactory merely to note how many children were classified SP or TE under each condition. It would be necessary to report for each condition, the SP vs. TE recognition scores for SP vs. TE oriented children. Unfortunately, Hermelin and O'Connor (Table III) did not report or analyze hit rates for Condition x Item Type x Child's Structure, and so they did not strictly test the question of whether SP structure interferes with TE processing under any condition. The failure to attend to individual differences within the deaf sample is thus a major limitation of the study. It remained so in those that followed.

O'Connor and Hermelin (1973b) increased the challenge to the SP structure by forcing deaf vs. hearing children to make temporal judgments. Having seen 5 items TE/SP incongruent, they saw two that had been TE adjacent in the list. The task was to indicate which of those two had come first in time. The deaf children on the average performed the TE judgment less accurately than the hearing when the test materials were nonsense syllables, but more accurately than the hearing when tested with pictures of faces. O'Connor and Hermelin viewed these results from a strictly nomothetic perspective, concluding that the SP orientation seen in the previous studies was "an elective strategy rather than an incapacity to appreciate temporal order" (1973b, p. 441). This may be true, but the results as reported do not force the conclusion: It was by then known to the researchers (O'Connor, 1974) that going into the experiment, there was almost certainly a great deal of structural variability (SP vs. TE orientation) within the deaf group ($\overline{CA=12.8}$). Perhaps, therefore, the deaf children's overall advantage with the pictures on this TE judgment task was achieved by a subgroup of TE-oriented children. We are suggesting that a preference pretest might have yielded substantially important information about individual differences; might indeed have shown that SP-oriented children are in fact relatively deficient (if not totally incapacitated) in the TE stress test.

There is much more certainty about the question of deaf children's nonverbal capacities (the <u>other</u> deaf structure). O'Connor and Hermelin's (1973b) Groups x Materials interaction nicely confirms the hearing and deaf groups' distinctive structures, and hence reinforces the theory of interactions between structures and task variables as joint determinants of memory performance. It should be noted, however, that the conclusions were based on a between-subjects manipulation of materials (in this case, pictures vs. nonsense syllables). More power would have been achieved had the manipulation been done within-subjects because, strictly speaking, strategy modification can be observed only in a within-subjects design. We stress this point because Hermelin and O'Connor (1975, p. 208), in their notes about the

1973b study, concluded that "hearing as well as deaf children showed considerable flexibility in using differently organized displays." Since flexibility was not actually measured, and since there was previous evidence for cross-task biases operating in similar (though simpler) situations, an evenly counterbalanced within-subjects design, with a deaf vs. hearing comparison, might have led to less optimistic conclusions about deaf children's strategy flexibility.

In the final two studies in the series the hope was to observe an <u>advantage</u> accruing to the deaf children's SP orientation under a backward recall requirement. The hypothesis was that the hearing children's vocal/acoustic input's heavy TE component would resist restructuring for reversed output, compared with the deaf children's visual/spatial input's possibly bi-directional readability. As in the other stress studies, TE vs. SP orientation was not pretested, so individual differences were again not analyzed. For the first time, however, the crucial variable was handled within-subjects, so relative flexibility could at least roughly be appraised. Hermelin and O'Connor (1975) matched deaf children (CA=12.2) with hearing children (CA=10.3) on the basis of forward digit span. They then tested reverse recall. Per the prediction, the deaf children as a group were practically unaffected by the shift, whereas the hearing lost more than a digit of span. O'Connor and Hermelin (1976) confirmed the direction of these results with older deaf and hearing children, both at about CA=14. The magnitude of the difference was not as great as previously, however, and it appeared primarily in a measure of item order errors, rather than item errors absolute. O'Connor and Hermelin interpreted this finding according to the SP structure theory: Visual coding for the deaf children vs. sequential-associative coding for the hearing. We note again that there was no pretest for initial structure, and hence no possibility of interpreting the results as a structural stress test.

Results from Other Laboratories

At least three studies have involved O'Connor and Hermelin's (1973a) TE/SP-incongruent recall orientation test. By Freeman's (1975) counts, hearing children showed a decrease from 40% to 15% SP orientation over the CA range 5 to 8, and an increase from 45% to 80% TE over the same period. Freeman supposed that this normal developmental shift from SP to TE is mediated by increasing reliance on articulation, and he hypothesized that deaf children go through a similar, but delayed and protracted development. Hermelin and O'Connor's (1973) recognition results are the only ones available to test Freeman's idea. They involve only two CA's (10.6 vs. 14.0), but nevertheless tend to confirm the hypothesis. Davidson and Klich (1980) used the recall task with pictures of objects vs. the objects themselves to test the hypothesis that cultural imperatives would maintain an SP orientation in Australian desert aboriginal children. Using pictured objects as stimuli, over the CA range 9.5 to 15.5 they found with pictures a sharp decrease in SP orientation from 56% to 18%, and a shallow increase in TE from 33% to 45%. Using actual objects, there was a shallow SP decrease (67% to 55%) but a sharp TE increase (5% to 45%). Rough as the quantitative aspects of the Freeman and Davidson/Klich studies may be, they agree in showing an almost total disappearance of SP orientation using ordinary testing procedures; and for western children, Freeman's data agree with O'Connor/Hermelin in showing that beyond CA=8 or 9, the TE orientation is overwhelmingly dominant in hearing children.

In the third study, Beck, Beck and Gironella (1977) directly replicated O'Connor and Hermelin's (1973a) recall assessment using hearing children at CA=8.4 and deaf at CA=10.5. As expected, they found a 50% orientation among the deaf; but they also found a 56% SP orientation among the hearing, which is far above all previous estimates for children at that age. They therefore tested a group of college students, for whom they should surely obtain 100% TE orientation, but there were again substantial SP counts (50%). Moreover, these were confirmed within-subjects using O'Connor and Hermelin's force-choice recognition procedure. Beck et al.'s unique failure to confirm the normal developmental trend toward a unitary TE orientation is inexplicable on procedural grounds. We note, however, that contrary to their interpretation, the split results do not suggest that TE and SP processes are equally available to every individual: In fact, no individual in their study showed a shift from SP to TE or the reverse, and no stress tests were administered.

Summary

Notwithstanding the rather untidy complication introduced by Beck et al. (1977), the literature points to two mnemonically important differences between deaf and hearing children's initial structures. First, deaf children are greatly handicapped by second-language inefficiencies, and so they produce awkward strategies for memorizing written materials. Second, perhaps consequent on the nature of their congenital disabilities or the communication modes they use to circumvent those disabilities, a high proportion of deaf children are initially oriented toward memory problems' spatial features, while hearing children initially attend to their temporal features. Some tests have been devised to determine whether or not these distinctive orientations are importantly advantageous or disadvantageous under likely conditions. For technical reasons, no clear results have been obtained. The main such problem is a persistent failure to single out structural differences within the deaf group. A second is the failure to use repeated-measures where they are clearly called for. Aside from these problems, no tests have attempted to apply stress to structures in the context in which they are initially identified, yet that would seem to be the most direct approach to the question of structural influences on performance.

The present study was designed to meet all three of these difficulties. In the first session, each deaf and hearing child's initial structure was identified by requiring reconstructive recall of TE/SP incongruent letter strings presented at a moderate rate. Each child's dominant reconstruction order (TE or SP) was taken to reflect his initial structure, which was then immediately stressed by requiring the child to produce the other reconstruction order. In the second session, both orders were again required, but the stress was adjusted by increasing stimulus presentation rate following correct reconstructions, and decreasing it following failures. This titration was meant to determine thresholds of processing efficiency under structurally congenial vs. antagonistic conditions.

Method

Subjects

There were two groups of 16 subjects, each containing eight females and eight males. One group comprised congenitally and profoundly deaf children of mean chronological age (CA)=11.33, and mean unaided puretone hearing threshold=107.4 dB (ISO) in the better ear. They were students at the Kansas State School for the Deaf in Olathe, Kansas. The other group comprised normal-hearing 6th graders (mean CA=11.75) at the Highlands Elementary School in Fairway, Kansas.

Stimuli

Each subject saw 87 test lists. Each list contained four letters drawn from the 16 upper-case consonants matrixed in Table 1. The matrix confined close acoustic similarities to separate

Table 1. Letters Used as Test Stimuli

	1	2	3	4
1	B	M	J	S
2	P	N	K	X
3	D	R	H	W
4	G	F	L	Q

columns (e.g., all "ay" to Col. 3; all "ee" to Col. 1, etc.). To avoid potential acoustic confusions within lists and to assure that all letters were seen before any was repeated, the computer randomly sampled each column and each row once per list, and used each column/row combination exactly once in each block of four lists. It did this 30 times to create a sequence of 120 lists. It created 10 such sequences, coded 0-9. The last digit of the subject's arbitrary, coded ID number determined which sequence he received.

Apparatus

The computer was a 64K-byte Z80-based Exidy with two Micropolis floppy disks, a 4-digit BCD-coded 100 cps hardware clock, keyboard and two CRT monitors. The clock timed all intervals and inter-response times. The subject viewed a 30-cm

Hitachi high-resolution b/w monitor. It was fitted with a 40 x 24 infra-red beam-grid invisible touch panel (Carroll Mfg. Co., Champagne-Urbana, Illinois). The touch panel returned a unique screen address (resolved to within 3.2 mm) whenever the subject touched the screen (i.e., broke beams) with a finger. All programming for stimulus presentation, data acquisition (response location and inter-response times) and trial-by-trial response scoring was done in BASIC, with calls to assembly-language subroutines where speed was essential. This apparatus was carried to the schools where testing was done.

The subject's monitor permanently displayed the 9-window arrangement shown in Figure 1. Each window was 3.3 x 3.0 cm. The letters were 1.0 x 1.7 cm, centered within each window. The isolated center window was used to cue the child in the instructed response conditions (see below). Figure 1 shows the 1.5 x 0.5 cm word "START" that appeared at the bottom of the screen at the beginning of each trial. The subject initiated the trial by touching START, which disappeared, to be followed by a sequential display of four letters in the upper windows. The offset of the last of these was followed immediately by a simultaneous display of the same four letters in scrambled order in the lower windows. By touching each of these four in turn, the subject attempted to reconstruct their original order. Each response immediately produced a small indicator above the window just touched (Fig. 1 shows two such indicators). Three (3.0) sec after the last response, the letters and indicators all vanished;

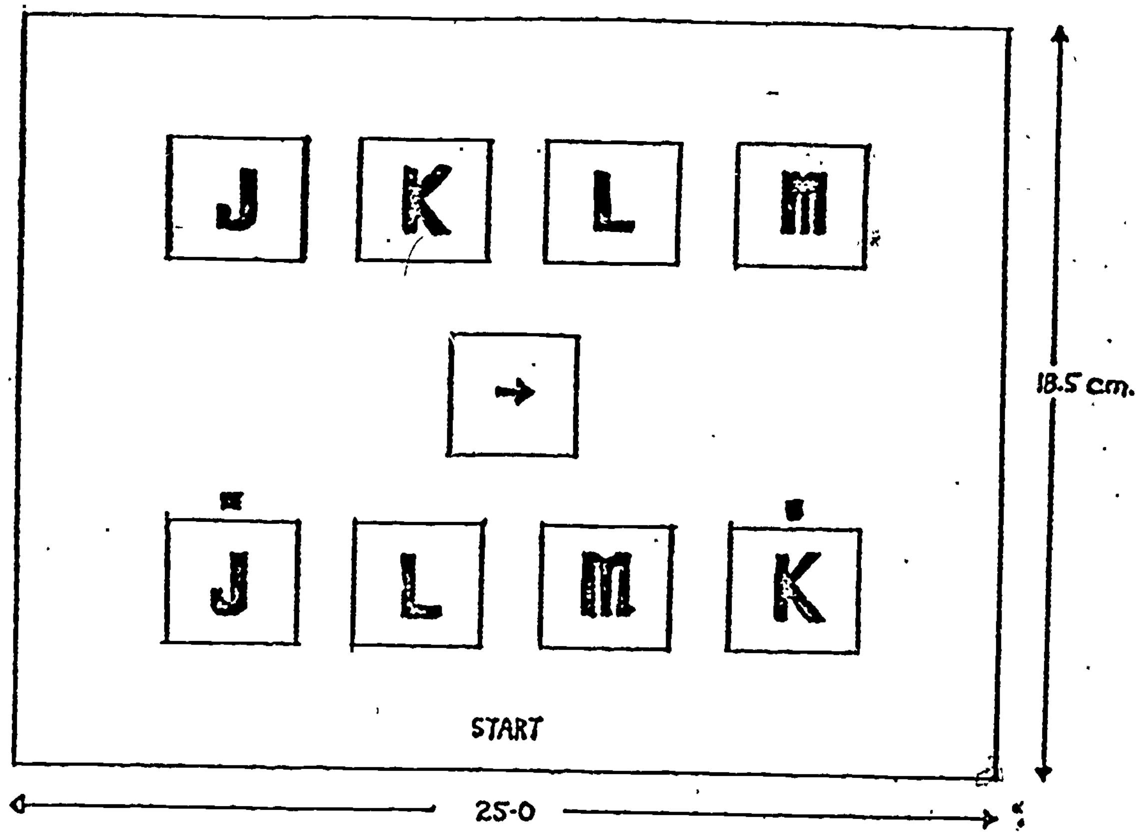


Figure 1. Subject's monitor (measured in cm). To initiate trial, subject touched START. Upper letters appeared sequentially; then lower ones, simultaneously. Subject touched lower letters in order to reproduce upper letters' sequence. Dots above lower windows reminded subject of which had been touched. Middle window cued force-response orders during stress tests.

the computer scored the responses and displayed the current and accumulated results on the experimenter's monitor; saved on disk the stimulus presentation information, response order, response times (to .01 sec) and response scores (relative to the correct temporal and spatial orders); then displayed "START" for the next trial. Intertrial interval from last response to next START was constant at 11.5 sec.

Stimulus Display Orders

Excepting practice trials, where stimulus presentation was always left-to-right, neither that nor the right-to-left order was ever used. This l ft 22 different TE/SP incongruent input orders. One was discarded because it did not permit adequate separation of TE vs. SP responses. The remaining 21 were marshalled into a fixed sequence to which 3 already-used input orders were added with new output orders attached, to make up 24 unique input/output arrangements. For each such arrangement, the correct spatial response order shared no more than two serial positions with the correct temporal response order; and the response letters were displayed such that for neither the correct spatial nor the correct temporal response would the child touch more than two windows that fell directly beneath those in which the letter had appeared at input. This was done to preclude directly visualized delayed matching.

Procedure

All children participated in two 30-minute sessions administered on separate days. Hearing children were given oral instructions. Deaf children were signed the instructions by a native-signing deaf experimenter.

Session 1. There were 6 practice trials, followed by 40 free-response trials to establish the child's initial orientation (TE vs. SP), followed by 10 forced-response trials in which the child was instructed to respond in the mode opposite his initial orientation.

Stimulus presentation rate for the practice trials is discussed below. On each practice trial, the four letters were presented sequentially from left-to-right so as to confound TE and SP ordering. In addition, to make matters even easier, on the first two practice trials the letters appeared in alphabetic order. Figure 1 shows the letters as they appeared on the first practice trial, while Table 2 shows all six practice trials.

Table 2. Input and response arrays for practice trials. Input was serial left-to-right; response letters were presented simultaneously.

	TRIAL					
	1	2	3	4	5	6
Input Array	JKLM	PQRS	BDFG	HNWX	LFQG	DHPK
Response Array	JLMK	QPRS	FGBD	XNHW	FGQL	PDKH

Instructions were brief, the critical passage telling the child to touch the letters in the bottom row of windows "in the same way that you saw the letters appear" in the top row. This wording was chosen to avoid bias towards a particular orientation. On the practice trials, the TE and the SP strategy resulted in the same window response sequence. As seen in Figure 1, the first practice trial's correct response order was 1-4-2-3 (J-K-L-M). If the child did not respond correctly on a practice trial, he was shown the correct response sequence. If he was correct on more than 2 trials, or on the last 2 trials, practice was terminated after 6 trials. Otherwise, all 6 lists were repeated. No child failed criterion a second time through.

Following practice, the child was told that the next 40 lists would be similar, excepting that the stimulus letters would not come on the left-to-right order, but rather would skip around (TE/SP incongruent). He was told to respond, however, "in the same way that you did during the practice." These 40 free-response lists were run in two blocks of 20, the distinction being the input stimulus duration (SD). In the slow block, SD= 0.6 sec; in the fast SD=0.3 sec. In both, interstimulus interval (ISI)=0.4 sec. Total stimulus presentation time for the slow lists was (4 x 0.3) + (3 x 0.4) = 2.4 sec/list. For the fast it was (4 x 0.6) + (3 x 0.4) = 3.6 sec/list. Half the children received the slow block first, and half the fast. Practice trials were run at the rate scheduled for the child's first block of free-response test trials.

On each trial, the computer compared the child's response order with each of the two possible correct response orders (first-to-last TE vs. left-to-right SP). It assigned a score of 4 for a perfect match; 3 if three windows were touched correctly one right after the other; 2 if only a pair were touched in correct order one right after the other; and 0 if none of these. It then tabulated the SP and TE score for that trial along with those of all previous trials and displayed an updated table on the experimenter's monitor showing the number of trials on which each score (4,3,2,0) had been achieved for each response type (TE,SP).

Some overlap in trial counts could be achieved for scores less than 4, so only the numbers of perfectly correct SP and TE responses were considered in defining the child's initial orientation. Following the 40th free-response list, the experimenter noted whether the majority of 4's were for SP or TE responses. All children showed a majority of one type or the other, and that majority was taken to reflect the child's initial orientation (TE or SP). He was required, on the last 10 trials of the session, to adopt the alternative (SP or TE) response strategy. During this forced-response stress test, just after the child touched START, a 1.0-sec cue appeared in the center isolated window. If the required response order was left-to-right SP, the cue was an arrow (Figure 1). If first-to-last TE, the cue was a clock. Following a 1.0-sec post-cue delay, the letters were displayed at the rate used in the second block of free-response lists. Thus, half the children viewed the forced-response stress lists at the fast rate, and half at the slow.

Session 2. There were 3 blocks of trials. The first contained 5 lists under the previous session's stress requirement, but at SD=0.6 sec, ISI=0.4 sec. The second and third blocks each had 16 titration lists. Subjects were required to give SP responses in one titration block, TE in the other. This variable was crossed with the child's Session-1 initial orientation so that half the children did the titration blocks in the stress-nonstress order, and half in the reverse order.

Each titration block was begun at the fast rate (SD=0.3 sec; ISI=0.4 sec). Following a perfectly correct response of the type required in that block, the next trial's SD and ISI were each decremented by 0.05 sec. An incorrect response incremented SD and ISI by 0.05 sec. The shortest practical SD (due to video refresh-time constraints) was 0.02 sec, so any SD decremented to 0.00 was immediately reset to 0.02. Although SD=0.02, ISI=0.00 was (rarely) achieved in this study, no child correctly responded even once at that rate, under either response requirement.

Results

Session 1

Recall Accuracy. Deaf and hearing children were classified as having either a TE or SP orientation depending on their performance on the 40 free-response lists. An orientation was determined if a child made at least twice as many perfectly correct responses in one response mode as in the other. On this basis, all 16 hearing children had a TE orientation. Nine of the 16 deaf children (56%) were SP oriented (the deaf-SP group), while the remaining 7 (44%) were TE oriented (the deaf-TE group). Our 0% SP orientation for the hearing group confirms Freeman's (1977) and all of Hermelin and O'Connor's very low estimates for hearing children age 11 years. Our 56% deaf-SP count is close to the 60% figure interpolated from Hermelin and O'Connor's (1973) recognition counts for young and old deaf children. It is also close to Beck et al.'s (1977) 50% deaf-SP count for children a year younger than ours, using an easier version of our task. Our 44% deaf-TE count is close to Beck et al.'s 45% deaf-TE count. By these comparisons the study's replicative aspect is sufficiently secure to warrant proceeding with elaborating analyses, all of which are done below using hearing, deaf-SP and deaf-TE as the grouping factor.

Table 3 shows the percentage of free-response trials on which the hearing, deaf-TE and deaf-SP groups made correct TE, correct

Table 3. Percentages of Correct Responses and Errors on Session 1 Free-response Trials

		Response Type		
	N	TE	SP	ERROR
Hearing(TE)	16	88	01	11
deaf-TE	7	35	04	61
deaf-SP	9	06	41	53

SP or incorrect responses. The deaf-TE and deaf-SP groups were about equally accurate in their orientation modes (35% and 41%, respectively), while the hearing were at least twice as accurate, at 88%. These orientation-mode scores were broken down by fast vs. slow block for each subject. The Group (3) x Rate (fast, slow) x Order (fast-first, slow-first) ANOVA (BMDP2V) confirmed the Groups main effect ($F(2,26)=29.3$, $p < .001$). It also netted a Rate x Order interaction ($F(1,26)=4.59$, $p < .05$), showing that fast-first children were less accurate in their fast block (55%) than in their slow (65%), and less accurate than the slow-first children in their slow (65%) and fast (67%) blocks. No other reliable main effect or interactions obtained in this analysis.

To determine how well each group stood up under stress, the % trials-correct scores for the last 10 free-response trials (31-40) were pitted against those for the 10 forced-response trials (41-50). The hearing group dropped from 98% to 49%; the deaf-TE from 40% to 27%; and the deaf-SP from 48% to 32%. The Group (3) x Condition (free, forced) ANOVA confirmed the Group main effect ($F(2,29)=7.89$, $p<.01$) and the interaction ($F(2,29)=4.08$, $p<.05$): The hearing children's 40% absolute loss and 45% relative loss were both larger than the deaf groups' losses, which ran about 14% absolute and 32% relative.

On the chance that these differential losses reflected scale effects unrelated to intrinsic group differences, the deaf children with the highest orientation-mode scores were compared with the hearing children who had the highest and lowest orientation-mode scores. Table 4 shows the top 4, top 6 and top 8 deaf children's accuracy on free and forced trials, and their absolute and relative losses, as compared with the top 7 and bottom 9 hearing children. All of the estimated losses for deaf

Table 4. Sub-analysis of high-scoring deaf vs. high-and low-scoring hearing children's free and forced-respsonse trials (32-40 vs. 41-50) recall accuracy (Session 1).

		Free %	Forced %	Absol. Loss	Relative Loss
Deaf:	highest 4	85	60	25	29
	highest 6	77	50	27	35
	highest 8	70	43	27	39
Hearing:	highest 7	100	59	41	41
	lowest 9	81	42	39	48

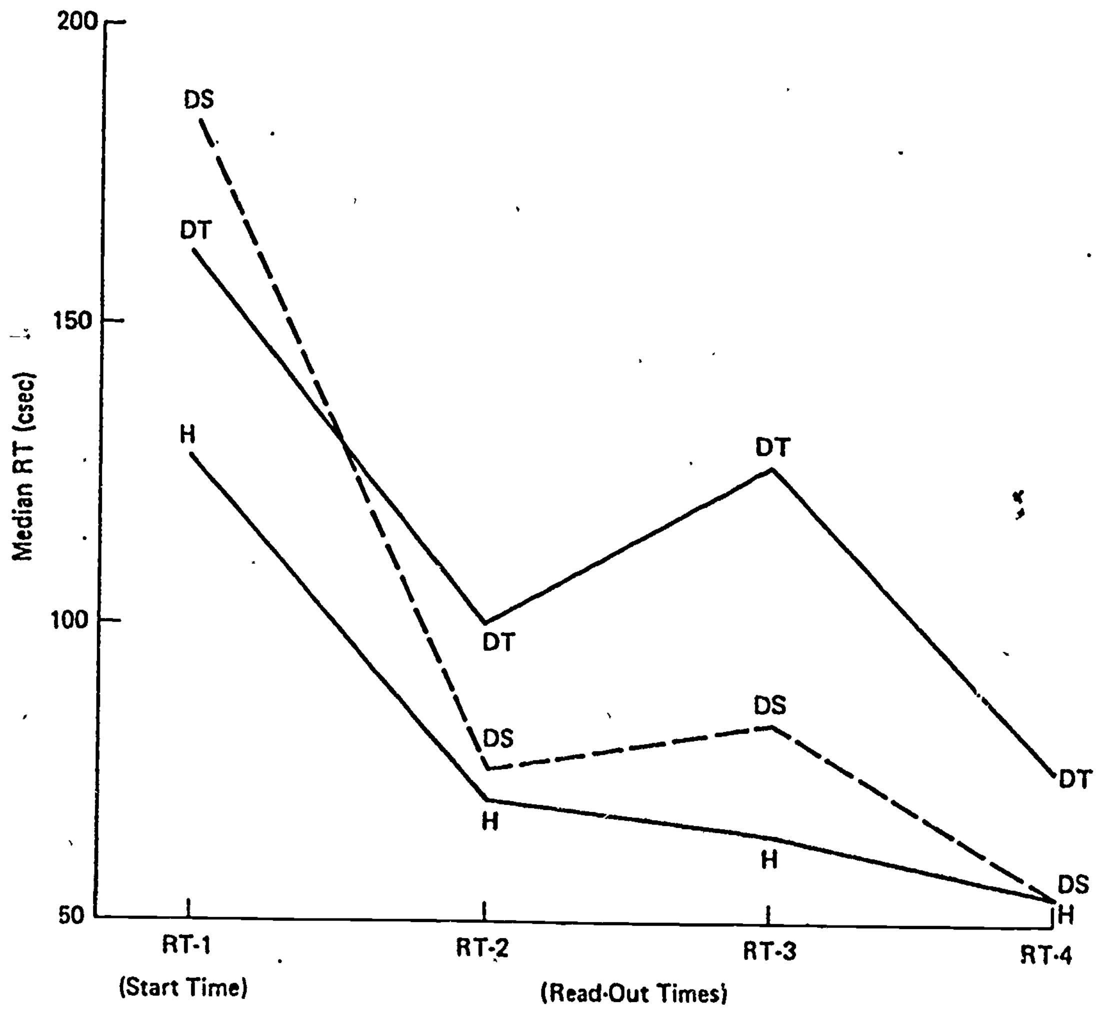
children are below those for hearing children, again suggesting that the hearing children were harder hit by the stress test. The final question was whether or not any group showed a recovery within the stress test trials. All children were subscored for the first and last 5 stress trials (41-45 and 46-50). As a control, the last two blocks of 5 free-response trials were also examined. The only significant blocks effect on either the free-response blocks or the stress blocks was the hearing childrens' increase from 39% to 60% going from the first to the second stress block ($t(15)=3.296$, $p<.01$). Thus, the hearing children alone showed reliable adaptation within Session 1's stress test.

Reaction Time. On each trial, four RTs were collected: RT-1 was measured from the last input-stimulus offset (i.e., the response array onset) to the first window touch. RT-1 thus reflects stimulus display organization and response execution processes. RT-2 was from the first window touch to the second, and RT-3 was from the second to the third. RT-2 and RT-3 thus relate to read-out from the internal organization of the stimulus display plus response execution. RT-4 was made to the last window remaining to be touched (i.e., the one that had no indicator illuminated above it). RT-4 is thus probably an exclusionary response time of little theoretical interest. It was not considered in the analyses, although it is shown with the other RTs in the following figures.

Each child's median RT-1, RT-2, RT-3, and RT-4 were computed for his last 5 (or less, if he had fewer than 5) perfectly correct orientation-mode responses in the free-response test. One deaf-TE child made only two such responses, so his RT's were not included in the analysis. The group median RT's are presented in Figure 2.

A one-way ANOVA showed that the groups differed marginally on RT-1 ($F(2,28)=3.15$, $.10>p>.05$. For RT-2 and RT-3, a Group (3) x RT (2) ANOVA yielded a Group main effect ($F(2,28)=6.19$, $p<.01$), with the hearing and deaf-SP children responding faster than the deaf-TE. The RT-1 analysis suggests that response organization was more efficiently accomplished under the TE orientation than under the SP (the hearing group tended to be faster than

Figure 2 Response Times for Correct Orientation-Mode Responses on Free-Response Trials, Session 1. DS = Spatially Oriented Deaf; DT = Temporally Oriented Deaf; H = Hearing (Temporal).



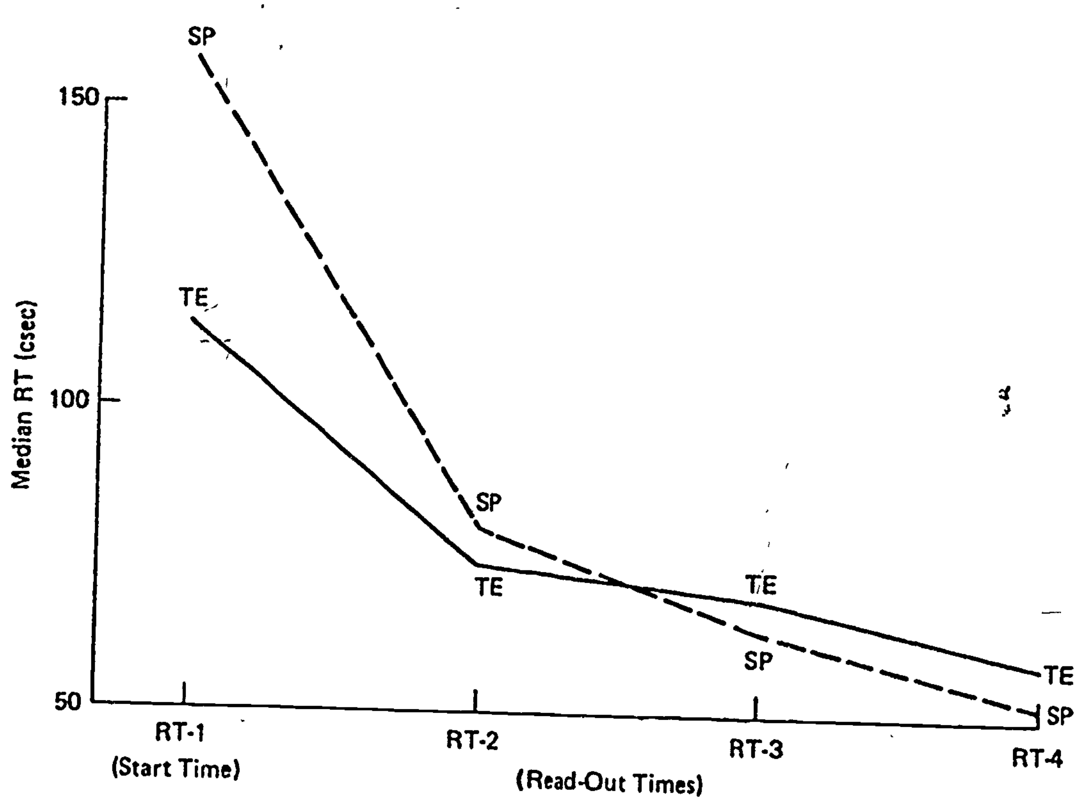
deaf-SP), but the RT-2, RT-3 analysis showed that once stimulus organization was accomplished, these two groups had equally efficient read-out; whereas the deaf-TE's TE-organized read-out was relatively inefficient.

Too few deaf children gave enough perfectly correct forced responses on the stress test to justify RT analyses. Of the 16 hearing children, 11 gave at least 3 correct orientation-mode (TE) responses on the free-response test, and at least 3 forced-mode (SP) responses on the stress test. Each of these subjects' median RT's for the last 5 (or fewer if there were less than 5) perfectly correct responses was computed for each response type. Figure 3 shows the group medians for these RT's. The only reliable difference between the TE and SP curves was at RT-1 ($t(10)=2.56$, $p<.05$): For every child, the SP RT-1's were longer than the TE RT-1's. It thus appears that the stress (SP) response for hearing children resulted in less efficient response organization; but once organized, the read-out was as efficient as in free-response orientation-mode (TE) responding.

Session 2

Trials 1-5. The first 5 trials were run under the session 1 stress condition. Neither of the deaf groups' mean trials-perfectly-recalled changed reliably between Session 1's last 5 (stress) trials and this continuation of the stress test. Both groups were close to 35% accurate, again leaving too few correct trials for an RT analysis, but suggesting a recovery from the first 5 stress trials of Session 1 (27%). This recovery was not

Figure 3 Response Times for Correct Orientation-Mode Responses on Free-Response Trials (TE) vs. Those for Correct Forced-Mode Responses on Stress Test (SP). Hearing Children Only, Session 1.



consistent across subjects, however ($t(15)=1.19$, $p<.20$). Going from Session 1's last 5 to Session 2's first 5 trials, the hearing group showed a nonsignificant increase in accuracy (from 60% to 70%). This continued the previous Session's trend towards recovery, as was also reflected in RT-1 (but no other RT). For the 10 hearing subjects who made at least 3 correct responses on Session 1's last 10 trials and Session 2's first 5, median RT-1 decreased from 140 csec to 108 csec ($t(9)=2.28$, $p<.05$). Thus, going into Session 2, the hearing children's previous stress-mode RT-1 organizational deficiency was totally absent, and their recall accuracy had climbed from 39% to 70% in the course of only 15 trials ($t(15)=5.17$, $p<.001$). Over the same period, the two deaf groups climbed from about 28% to about 35% recall accuracy. The hearing vs. deaf groups respective stress-mode endpoint performances (70% vs. 35%) may be compared with their respective Session-1 orientation-mode endpoint performances (87% vs. 47%). The comparative recoveries (70/87=80% vs. 35/47=74%) are similar, and the normal recovery represents significant movement. At this point then, it is clear that whatever the stress-induced insufficiencies experienced by the hearing children, they were completely overcome in the RT analysis of perfectly recalled displays, and were well on the way to being erased from the accuracy record as well, all with only brief exposure to the stress condition. It is only a little less clear that the deaf children recovered, primarily because their performance was overall quite subnormal, but also because they had suffered relatively less under stress. The titration trials were designed to increase the burden of the stress test so as more clearly to define the limits of deaf and hearing children's processing efficiences.

Titration Trials. Session 2's titration trials were distinctive in two respects. (1) For the first time, all children were instructed to perform the task both according to their initial free-response orientations, and according to the stress orientation: A direct within-subjects instructed comparison. (2) Recall accuracy determined stimulus presentation rate on following trials: Correct responses led to faster presentations; errors led to slower. If recall accuracy was high in the early trials, presentation was fast on the later ones. Since fast presentation was a second stress condition, high initial accuracy would increase stress and hence would lead to lower accuracy later on. Conversely, low initial accuracy would reduce stress, and would therefore lead to higher accuracy. Since presentation rate was adjusted on every trial, it would average out to be the same for all children who achieved identical overall accuracy; but consistently accurate performance early-on would lead to faster presentation rates than inconsistent performance. On this account, for each child, the fastest stimulus presentations at which he made correct responses can be viewed as his best titration performance. RT analysis should be most conclusive for these optimum-rate trials.

Figure 4 shows each group's overall recall accuracy (trials correct) under each of the two response modes. For all groups combined, TE (54%) was higher than SP (48%) ($t(31)=2.55$, $p<.02$). The hearing vs. deaf difference was high and consistent, while the two deaf groups were practically identical. In all further analyses, the deaf groups have been combined, except when there were reliable differences between them.

Figure 5 shows the SP and TE blocks divided into their first-8 vs. second-8 trials. Only under the TE mode did the stress occasioned by high early recall (increased presentation rate) result in later recall decrements. To check this, we considered each child's item-presentation time (SD + ISI) for lists correctly recalled. The medians of the three fastest presentation times in the SP mode, and the three fastest in the TE mode were taken to be the child's optimum presentation times. Three deaf children were discarded from this analysis because they had too few correct trials. For the remaining 13 deaf and all 16 hearing children, the medians of the optimum times are shown in Table 5. The TE optima were reliably shorter than the SP for both groups (Hearing: $t(15)=3.33$, $p<.01$; Deaf: $t(12)=2.58$, $p<.05$). The hearing group was faster under both modes (SP: $t(27)=3.21$, $p<.01$; TE: $t(27)=4.55$, $p<.001$). Another view of the trials effect within modes is seen in Figure 5's comparison of SP trials 1-8 vs. TE trials 1-8: TE performance is higher than SP on these early trials, and this TE advantage is reliable for both groups (Hearing: $t(15)=3.88$, $p<.01$; Deaf: $t(13)=2.89$, $p<.02$).

Figure 4 Overall Accuracy under Spatial (SP) and Temporal (TE) Response Modes, Session 2. H = Hearing; DS = Spatially Oriented Deaf; DT = Temporally Oriented Deaf.

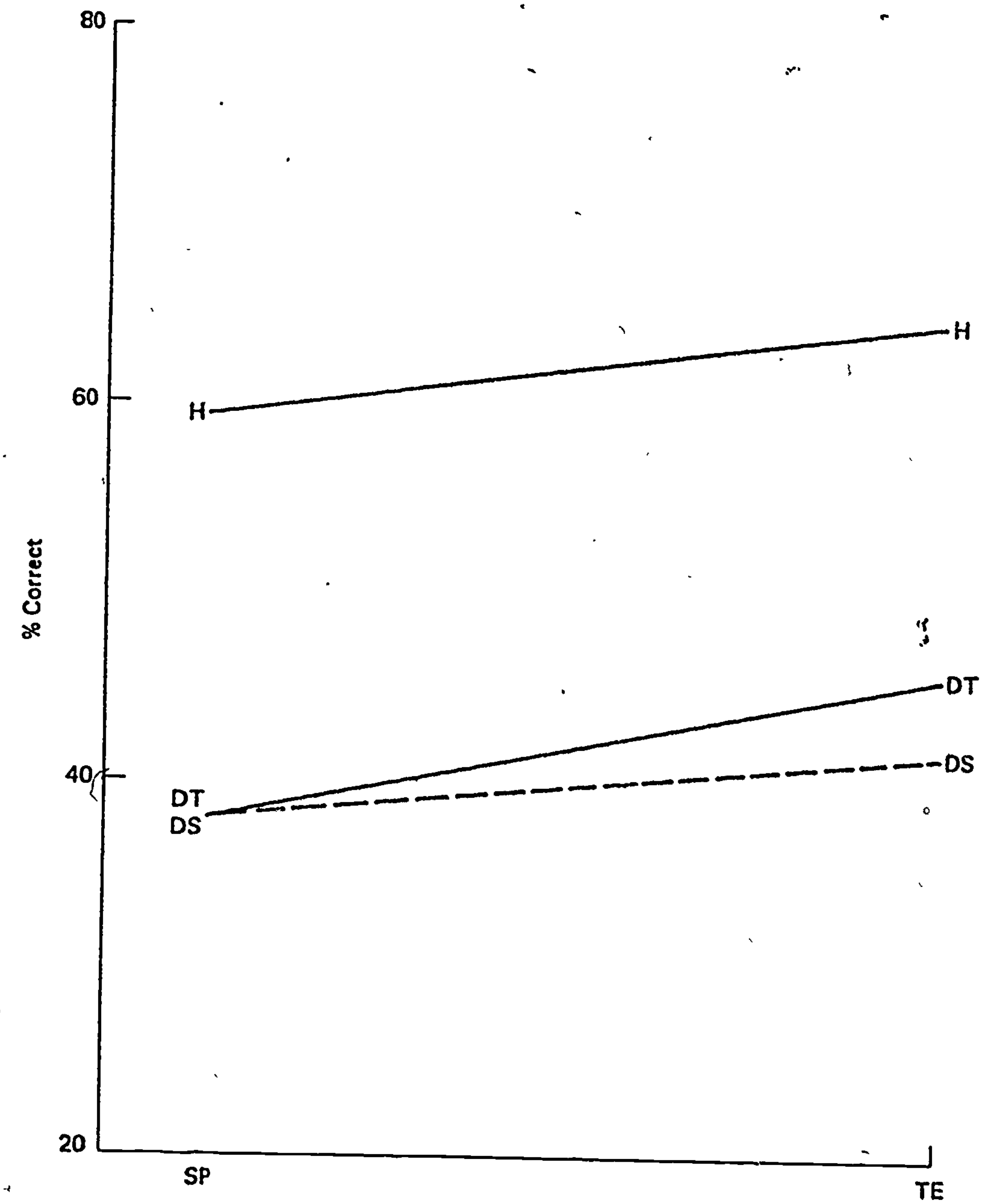


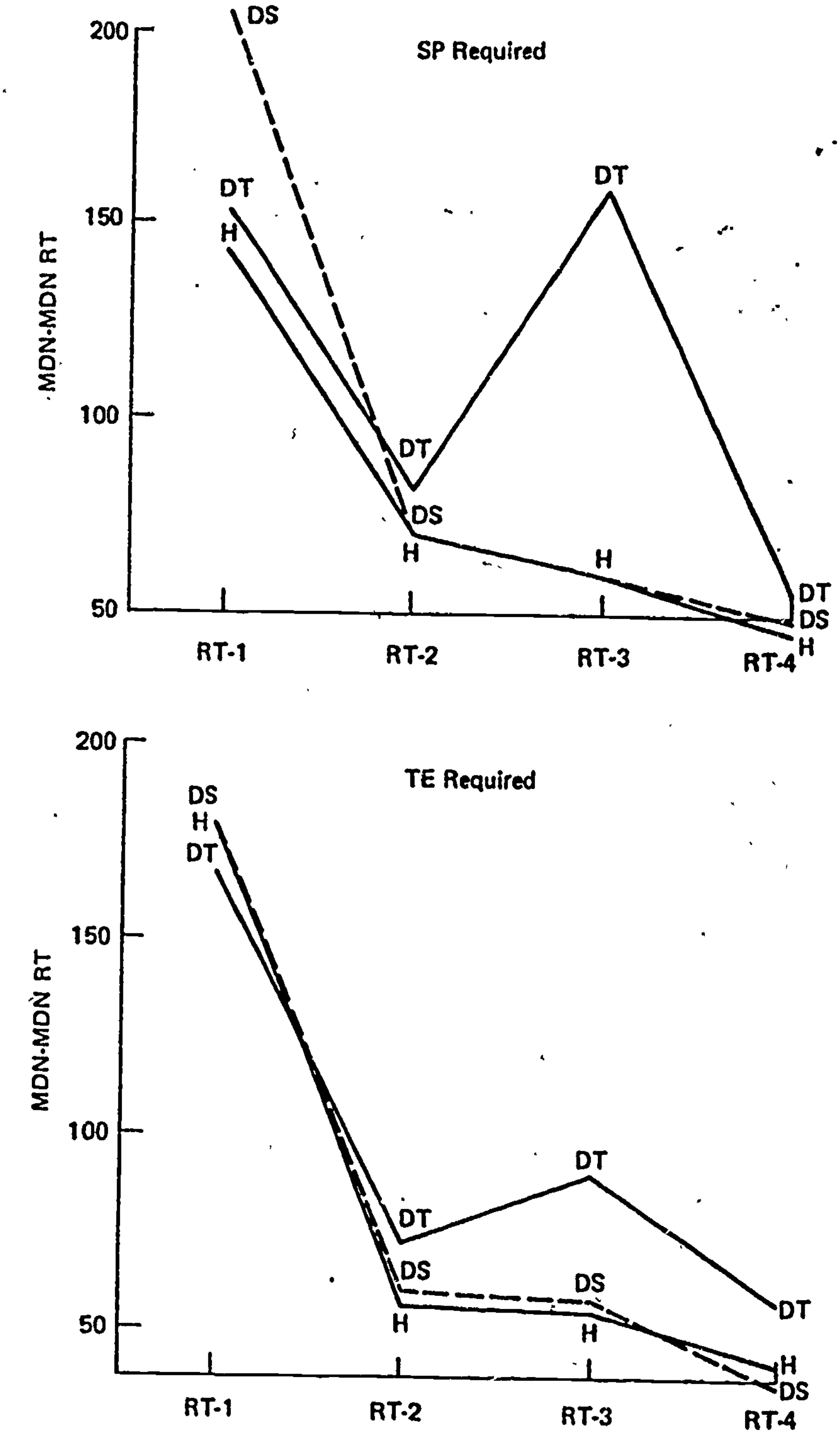
Table 5. Optimum item-presentation times (sec) for each group under each response mode (titration)

	N	SP	TE
Hearing:	16	.40	.22
Deaf:	13	.90	.70

To compare deaf vs. hearing recall efficiencies, each child's median RT's were computed for his 3 optimum-presentation-rate trials. Figure 6 shows the group median curves for each response mode. For RT-1, the Groups' differences were not reliable for either response mode. For the SP mode, the deaf-TE's RT-2, RT-3 values were reliably higher than the other two groups. For the TE mode the deaf-TE's RT-2, RT-3 was still higher than the others', but not reliably so. Thus, under optimum conditions, the only notable Groups effect is—for the SP-mode requirement, for the deaf-TE children. Their read-out remained relatively inefficient.

Our final question for the titration trials was whether or not recall accuracy had suffered for any group as the result of lapses into alternate-mode responding. It might be predicted, for example, that the deaf-SP children would occasionally yield to their initial orientation, and hence give perfect SP responses under the TE-mode requirement. In fact, they did this on 3.5% of the TE trials, but this is not informative because the deaf-TE did likewise on 3.6% of those same trials, and the hearing children slipped on 2% of them. The other slip (perfect TE recall on SP trials) was made by deaf-TE (9.8%), deaf-SP (8.3%)

Figure 6 Average Response Times for Each Subject's 3 Optimum Trials, Session 2. H = Hearing; DT = Temporally Oriented Deaf; DS = Spatially Oriented Deaf.



and hearing (2.3%). Thus, the deaf groups were overall comparable, and made more slips than the hearing group. Since the combined deaf group made more TE slips on SP trials (9.0%) than SP slips on TE trials (3.5%), it appears that the TE orientation had gained ascendency in the titration tests, regardless of initial orientation. The determining factor seems to have been the point in the titration trials (first vs. second block) where the slips were made. For the combined deaf groups, 17/23=74% of their TE slips on SP trials were made when the SP trials were given in the second block. For the hearing group, the figure was 5/6=83%. Similarly, for SP slips made on TE trials, 6/9=67% of the deaf's and 3/5=60% of the hearing's occurred when the TE trials came second. Overall, these figures show that 31/43=73% of all slips were made in the block following that in which the slip-mode was the required response; and this effect was somewhat stronger in the SP block following the TE-mode requirement (22/29=76%) than in the TE block following the SP-mode requirement (9/14=64%).

Discussion

The first part of this study was closely modeled after O'Connor and Hermelin's foundation work on deaf children's spontaneous responding to temporal/spatial incongruent STM materials. We found that all of the hearing children and 46% of the deaf gave responses that tended to reflect the materials' temporal (TE) aspect, while 56% of the deaf children responded to their spatial (SP) aspect. These figures nicely match the foundation results.

The initial response modes may have been selected as deliberate decisions, or simply followed blind adherence to structure. Lacking evidence of choice, we have used "initial response orientations" as a neutral descriptive, rather than "preferences" with its unsupportable implication of executive cognition. As far as we know, nobody has yet clearly demonstrated each of the two response modes (TE vs. SP) to deaf children, and then given them a choice on which reasonably to assess their preferences. Judging by our deaf children's errors and RT curves for the TE and SP titration trials of Session 2, we suppose that on our task, possibly all would have responded in the TE mode had they been given a choice at the end of Session 2.

This prediction is made from two sorts of evidence. First, a priori, one would expect children who were initially TE-oriented (deaf-TE) to follow the same light when once again free to respond. Second, the deaf-TE's RT curves for the TE response requirement indicated that their read-out was more efficient than for the SP requirement. Add to that their greater recall accuracy on the early TE trials vs. the early SP trials, plus their achievement of faster optimum stimulus presentation times under TE than SP, and we are forced to conclude that they found the TE task altogether easier than the SP task. That it was easier is sufficient reason (under the principle of least-effort) to assume that it would be preferred, given the choice.

The deaf children who were initially oriented to the task's SP features (deaf-SP) are only slightly more difficult to judge. They too recalled more accurately on the early TE trials vs. the early SP trials, and their optimum stimulus presentation times on TE trials were, if anything faster than the deaf-TE's. What troubles the analysis is their practically identical RT curves under SP and TE, from which it seems that their total recall efforts were quite similar. If one assumes that this represents overall greater efficiency under TE because the presentation times were faster, then all barriers fall away, and one concludes (under the equal-effort-for-greater-payoff principle) that, having had equal exposure to both tasks, the deaf-SP children would also have opted for TE if given the choice.

We can now address this study's main point, which was to decide whether or not the structures that underlie deaf and hearing children's untutored TE or SP orientations are strong enough to deminish performance under antagonistic stress. The answer is unequivocally yes. All groups, regardless of initial orientation (and particularly the hearing group) immediately showed lower recall accuracy when the stress test was introduced in Session 1. Moreover, the hearing children's RT curves indicated significantly increased difficulty in organizing their recall responses, even when these responses were destined to be totally correct. We should not judge from these results, however, that the immediate performance decrements observed in Session 1 have any great practical significance, because the weight of subsequent findings points to extremely rapid recovery by all groups. Indeed, on the first 8 trials of Session 2's second titration block, both deaf groups' recall accuracies were equal to their Session-1 pre-stress levels, and the hearing children (whose high accuracy produced extraordinary stress under titration) were nevertheless within 10% of their pre-stress accuracy level. These recoveries by all groups point to highly maleable structures, in view of which we may return to examine O'Connor and Hermelin's (1973a, pp. 342-343) speculation that all subjects, deaf and hearing, could "under appropriate conditions or instruction, be induced to use their non-preferred strategy or ordering code even if less efficiently." Our direct test of this idea, although the only one done to date, nevertheless fully substantiates O'Connor and Hermelin's hypothesis (excepting perhaps its last four words).

References

Beck, K., Beck, C., & Gironella, O. Rehearsal and recall strategies of deaf and hearing individuals. American Annals of the Deaf, 1977, 31, 544-552.

Belmont, J.M. Individual differences in memory: The cases of normal and retarded development. In M.M. Gruneberg & P. Morris (Eds.), Aspects of Memory. London: Methuen, 1978.

Belmont, J.M., & Butterfield, E.C. The instructional approach to developmental cognitive research. In R. Kail & J. Hagan (Eds.), Perspectives on the Development of Memory and Cognition. Hillsdale, N.J.: L. Erlbaum, 1977.

Belmont, J.M., & Karchmer, M.A. Deaf people's memory: There are problems testing special populations. In M.M. Gruneberg, P.E. Morris & R.N. Sykes (Eds.), Practical Aspects of Memory. New York: Academic Press, 1978.

Belmont, J.M., Karchmer, M.A., & Pilkois, P.A. Instructed rehearsal strategies' influence on deaf memory processing. Journal of Speech and Hearing Research, 1976, 19, 36-47.

Brown, A.L. Knowing when, where, and how to remember: A problem of metacognition. In R. Glaser (Ed.), Advances in Instructional Psychology, (Vol. 1). Hillsdale, N.J.: Erlbaum, 1978.

Conrad, R. Short-term memory processes in the deaf. British Journal of Psychology, 1970, 61, 179-195.

Conrad, R. Short-term memory in the deaf: A test for speech coding. British Journal of Psychology, 1972, 63, 173-180.

Conrad, R., & Rush, M.L. On the nature of short-term memory coding by the deaf. Journal of Speech and Hearing Disorders, 1965, 30, 336-343.

Davidson, G.R., & Klich, L.Z. Cultural factors in the development of temporal and spatial ordering. Child Development, 1980, 51, 569-571.

Flavell, J.H. Metacognitive aspects of problem solving. In L.B. Resnick (Ed.), The nature of intelligence. Hillsdale, N.J.: Erlbaum, 1976.

Flavell, J.H., & Wellman, H.M. Metamemory. In R.V. Kail & J.W. Hagan (Eds.), Perspectives on the Development of Memory and Cognition. Hillsdale, N.J.: L. Erlbaum, 1977.

Freeman, N.H. Temporal and spatial ordering in recall by five- and eight-year-old children. Child Development, 1975, 46, 237-239.

Hermelin, B., & O'Connor, N. Ordering in recognition memory after ambiguous initial or recognition displays. Canadian Journal of Psychology, 1973, 27, 191-199.

Hermelin, B., & O'Connor, N. The recall of digits by normal, deaf and autistic children. British Journal of Psychology, 1975, 66, 203-209.

Hung, D.L., Tzeng, O.J.L., & Warren, D.H. A chronometric study of sentence processing in deaf children. Cognitive Psychology, 1981, 13, 583-610.

O'Connor, N. Memory coding-order in deaf and subnormal subjects. Journal of Psychological Research in Mental Subnormality, 1974, 1, 3-7.

O'Connor, N., & Hermelin, B. Seeing and hearing and space and time. Perception & Psychophysics, 1972, 11, 46-48.

O'Connor, N., & Hermelin, B. The spatial or temporal organization of short-term memory. Quarterly Journal of Experimental Psychology, 1973, 25, 335-343. (a)

O'Connor, N., & Hermelin, B. Short-term memory for the order of pictures and syllables by deaf and hearing children. Neuropsychologia, 1973, 11, 437-442. (b)

O'Connor, N., & Hermelin, B. Backward and forward recall by deaf and hearing children. Quarterly Journal of Experimental Psychology, 1976, 28, 83-92.

Wallace, G., & Corballis, M.C. Short-term memory and coding strategies in the deaf. Journal of Experimental Psychology, 1973, 99, 334-348.

Wilcox, S., & Katz, S. The ecological approach to development: An alternative to cognitivism. Journal of Experimental Child Psychology, 1981, 32, 247-263.

SECTION B

AMERICAN SIGN LANGUAGE AND STROOP INTERFERENCE

Introduction

Only recently has American Sign Language (ASL) come under the scrutiny of psychologists and linguists. ASL, the fourth most frequently used language in the U.S. (Mayberry, 1978), is a nonphonetic, visual/kinetic natural language which exhibits complex structural properties of aural/vocal natural languages on both lexical and sentential levels (e.g., Stokoe, 1960; Stokoe, Casterline, & Croneberg, 1965; Klima & Bellugi, 1979; Siple, 1978; Battison, 1978; Liddell, Note 1). Because different modalities are used for the comprehension and production of ASL (visual, kinetic) and English (aural, vocal) and because ASL is a nonphonetic language, questions have arisen concerning differential hemispheric involvement in the early stages of perception of ASL. Differential patterns of cerebral asymmetry for nonphonetic languages such as ASL for phonetic languages such as English would suggest unique processing requirements for the two classes of languages. For example, an ASL sign may require a greater degree of spatial and configurational processing (and, therefore, greater right hemisphere processing) than an English word. The complex spatial information processing required for comprehension of ASL may provide an explanation of why a majority of deaf subjects in the experiment reported above spontaneously chose to code the letter sequences using the spatial information available in the display instead of the temporal information.

This experiment examined some hemispheric processing requirements of ASL signs in congentially deaf native signers using an ASL version of Stroop's (1935) color-word interference task. The classic Stroop effect is slower naming of ink color when the ink appears in a color word whose referent conflicts with the ink color (e.g., the word RED printed in green ink) than when the ink appears in a neutral color patch such as a rectangle or a random geometric shape. The color word produces interference in the ink color naming task. This interference, produced by the automatic semantic processing of the color word, has been attributed to both input, or perceptual, and output, or response, competition sources.

A Stroop task was initially chosen for this experiment in part because of the recent finding of greater Stroop interference for Chinese ideographs than for English words (Biederman & Tsao, 1979). The authors' speculative interpretation of these results suggests that the greater Stroop interference for Chinese may be attributable to the increased load on right hemisphere processing of both the ideographic symbol and the color. This interpretation is based on an inference from evidence that recognition of Japanese ideographs (Kanji) is lateralized in the right hemisphere while recognition of Japanese phonetic symbols

(Katakana & Hirakana) is lateralized in the left hemisphere. Likewise, it has been shown that information about color is processed with a right hemisphere advantage.

An analogous situation seems to hold between ASL and Japanese ideographs in that there is evidence for a right hemisphere involvement in the processing of ASL signs (e.g., Poizner & Lane, 1979). Following Biederman & Taso (1979), one would predict greater color-sign interference in native signers of ASL than color-word interference in native speakers of English if this effect is attributable to the nonphonetic and configurational properties of ASL signs and Chinese ideographs. In an experiment similar to the Biederman & Tsao study, Bourg (1980) reported greater Stroop interference for native ASL signers to ASL Stroop stimuli than for English speakers to English Stroop stimuli. Bourg (1980) failed to demonstrate conclusively that this effect was attributable to a greater right hemisphere processing load, however.

Before reporting the present experiment, relevant studies in the three areas that impacted the development of the experimental hypotheses will be reviewed. The linguistic structure of ASL and the hemispheric laterality literature will be reviewed briefly including a more detailed review of the ASL laterality literature. Finally, the Stroop phenomenon and the various models proposed to explain it will be discussed.

Some Linguistic and Cognitive Aspects of ASL

In the first linguistic analysis of ASL, Stokoe (1960) described a sign (lexical unit) of ASL as a unitary motoric act comprised of three aspects: (1) location of articulation of a sign with respect to the signer's body (called tab by Stokoe), (2) the handshape(s) used in forming the sign (called dez by Stokoe) and (3) the movement used to produce the sign (called sig by Stokoe). Stokoe, et al. (1965) presented the more than 2000 manual signs in A Dictionary of American Sign Language using these three aspects with 12 places of articulation, 19 handshapes and 24 movements. Since Stokoe's work, linguists have proposed changes to that analysis; these changes have been of degree, not kind. Battison (1974), for example, has proposed a fourth aspect, hand orientation, in order to distinguish between certain minimal parts of signs.

Nonmanual signals also play an important role in ASL. Liddell (1977) argued that standardized facial expressions can determine lexical and phrasal scope in ASL. RECENTLY and JUST RECENTLY, for example, are distinguished by a tilted head and more exaggerated facial expression while the manual components are identical. Likewise, head position and facial expression mark negation and, according to Liddell, certain clausal boundaries and interrogatives. Baker & Padden (1978) analyzed eye blinks in dyadic communication and found that eyeblinks tend to occur systematically in both signer and receiver near, or at, what seem to be clausal and constituent boundaries.

One of the interesting aspects of ASL signs that most hearing people who have attempted to learn ASL note is the high degree of isomorphism between signs and their referents. ASL is highly iconic relative to, say, English. Evidence from the historical changes in signs suggests that a sign, when first introduced to the language, may be highly iconic, or representational with respect to its referent, but that the sign, in time, tends to become more arbitrary and abstract with respect to that referent (Frishberg, 1975). The rules of sign formation and change seem to act to constrain or modify the evolving sign as dictated by the permissible values of sign formation parameters discussed above (Klima & Bellugi, 1979). Iconic elements clearly are still incorporated in signs, however, and it may be these iconic elements that make signs (not sign languages) easier to learn than words (Brown, Note 2). Also, Schwam (1980) attributed the finding that deaf children comprehend the highly iconic sign LESS earlier than the more abstract sign MORE to that sign's iconicity. This represents a reversal of the pattern of acquisition of MORE and LESS in English (Donaldson & Balfour, 1968).

Both short- and long-term memory experiment results for ASL signs parallel those for English words. Bellugi & Siple (1974) and Bellugi, Klima & Siple (1975) have demonstrated primacy and recency effects in free recall of signs. STM recall errors tended to be instrusions or substitutions of particular values of a single aspect (either location, place of articulation or movement) of the presented signs suggesting "phonological" representation of signs in STM analogous to the phonological coding of words in STM (Crowder, 1976). Siple, Fischer & Bellugi (1977) reported that, in final free recall, semantically related signs clustered together suggesting similar patterns of LTM coding for ASL and oral languages.

Rates of speaking and signing differ in interesting ways with signs taking longer to produce than words. Grosjean (1979) and Bellugi & Fischer (1972) reported that the mean duration of signs is about twice that of words. While individual signs take longer to produce, however, propositions are transmitted at the same rate in ASL and English (Bellugi & Fischer, 1972). This longer duration of signs may have important implications for the laterality of ASL to be discussed below following a brief review of hemispheric asymmetry literature.

Hemispheric Laterality

Much research suggests that language functions are lateralized in the left hemisphere and visuospatial functions in the right (See Milner (1974) for a review). It is well known that left hemisphere lesions produce various types of aphasia (Geschwind, 1970; Zangwill, 1960). Right hemisphere lesions have produced visuospatial impairment (e.g., discrminiation of geometric forms) and degraded musical ability (Lansdell, 1968; Milner, 1971). Split-brain patients have also shown similar patterns of defects (Gazzaniga, 1970; Nebes, 1974). These patients were able to name objects presented tactually or visually only if the information were presented to the left hemisphere (i.e., right or right visual field); these same patients identified the objects via a nonverbal response, however, when the information was presented to the right hemisphere. On the other hand, split-brain patients are better at manipulating and perceiving spatial relationships in the right hemisphere than the left.

Neurologically normal subjects show similar asymmetry patterns. Auditory perception of phonemes, nonsense syllables and words is known to have a right ear/left hemisphere advantage in dichotic listening tasks (e.g., Kimura, 1966; Studdert-Kennedy & Shankweiler, 1970; Schwartz & Tallal, 1980) Perception of musical melodies, however, has shown a left ear advantage (Kimura, 1964, 1973a). Visual perception of language also has demonstrated a left hemisphere advantage (LHA). Tachistoscopically presented words and letters are better and more quickly identified in the right visual field (RVF) than the left visual field (LVF) (e.g., Hines, 1976; Bryden, 1965); word/non-word decisions are better made in the RVF (Leiber, 1976).

Tasks requiring visuospatial processing have shown LVF advantages. Random geometric shapes are better identified and classified in the LVF (Hellige & Cox, 1976; Simion, Bagnara, Bisiacchi, Roncato & Umilta, 1980). Kimura (1966) reported a LVF advantage in a dot enumeration task, and Rizzolotti, Umilta & Berlucchi (1971) and St. John (Note 3) found LVF advantages for face recognition. Finally, using Posner's (1969) same/different paradigm for physical and name matching between two letters, several investigators have found LVF advantages for physical identity matches requiring visuospatial processing and RVF advantages for name identity matches requiring language processing (Davis & Schmit, 1973; Geffen, Bradshaw & Nettleton, 1972; Umilta, Sava & Salmaso, 1980). These effects tend to be found for "same" responses only, however.

Interpretations of data like the above vary. Liberman (1974), for example, has attributed left hemisphere specialization to speech functions and right hemisphere specialization to non-speech functions. By demonstrating a right ear advantage for melody recognition by musically experienced listeners, Bever & Chiarello (1974) argued that hemisphere specialization is more general than Liberman's speech/non-speech distinction; that is, they argue that the left hemisphere is specialized for analytic processing while the right hemisphere is specialized for holistic processing. Analytic or holistic processing required in a task is dependent on an individual's task-related experience. Left hemisphere advantages for language processing and right hemisphere advantages for visuospatial processing, therefore, are consequences of the analytical/holistic distinction. Kimura (1973b,c, 1976) proposed that the left hemisphere is specialized for skilled motor and temporal sequencing activities of which speech production and perception is just one such activity.

Laterality Studies of ASL. There are a few laterality studies of ASL, with most laterality research on the deaf using English stimuli or ASL hand-shapes used in the manual alphabet (e.g., Phippard, 1977). The cerebral laterality literature for sign language that does exist, however, provides conflicting evidence for both left and right hemisphere lateralization as well as no lateralization for the perception of ASL signs. The balance seems to be tipped slightly towards a right hemisphere advantage for sign perception, however.

McKeever, Hoemann, Florian & VanDeventer (1976) presented English letters and words and line drawings of ASL handshapes and signs in four recognition tasks to congentially deaf signers and to hearing subjects who knew ASL. The hearing subjects showed the usual RVF advantage to the English stimuli in two of three tasks while the deaf subjects showed RVF advantage in one of three tasks. Both groups showed minimal LVF advantages for the ASL handshapes and signs.

Manning, Goble, Markman and LaBreche (1976) presented line drawings of signs, English words and geometric shapes bilaterally to both hearing and deaf subjects. A left hemisphere advantage (LHA) -- percent correct recognition -- was found for the English words for both hearing and deaf subjects. No hemispheric advantage was found for the line drawings of signs when the subjects responded by signing the sign stimulus back to the experimenter (Experiment 1). However, when deaf subjects were presented with still photographs of signs and responded by pointing to a drawing of the referent of the sign stimulus among several distractor items on a choice board (Experiment 2), a right hemisphere advantage (RHA) was reported. Manning et al. argue that the task in Experiment 2 required deeper semantic processing of the stimuli than the task in Experiment 1 and claim that a RHA does exist for the perception of signs because of the spatial processing required by ASL signs.

Lubert (cited in Poizner & Lane, 1979) tachistoscopically presented congentially deaf and hearing subjects English letters, photographs of ASL signs and manual alphabet handshapes and a dot enumeration task. Deaf and hearing subjects demonstrated a LVF advantage for the signs, but no lateral differences to the other stimuli. Because hearing subjects did not show the usual RVF advantage for English material, these data are difficult to interpret.

Poizner & Lane (1979) and Poizner, Battison, & Lane (1979) also reported a RHA for the recognition of signs. Poizner & Lane (1979) showed a RHA (RT to a target digit) for still photographs of ASL hands of the digits 7 and 9 (signs for numbers require no motion) and no hemispheric advantage for arabic digits. Hearing controls also showed a RHA for ASL digits and a LHA for arabic digits. While the deaf and hearing subjects showed the same patterns of asymmetry, the authors argue that the deaf subjects treated the ASL digits linguistically because (1) deaf subjects' RTs to the ASL digits were shorter than the hearing subjects' RTs, (2) deaf subjects responded faster to the ASL digits than to the non-ASL hands while the reverse was true for the hearing subjects, and (3) deaf subjects showed a LVF advantage to both ASL digit targets while the hearing subjects did not.

Poizner et al. (1979) reported a LVF advantage (percent correct identification) for deaf subjects to statically presented, bilaterally symmetric signs that could be identified by place of articulation and handshape alone. These subjects, however, showed only a small, nonsignificant LVF advantage for laterally symmetric signs presented with their characteristic movement. In the study, movement was simulated by copying three still photographs of a sign (one still from the beginning of the sign, one from the middle, and one from the end of the movement) to three frames of 8mm movie film for tachistoscopic presentation. Subjects mentally filled in the movement as in apparent motion phenomena. Twenty signs were presented in this manner, and the subject's task was to report (sign) back the sign that was just presented. It is not clear how sign-like these stimuli appeared. The task was difficult, however, as indicated by percent correct identification scores of about 52%. Poizner et al. suggest that the finding of no laterality effects with the moving signs is a result of both right hemisphere visuospatial processing and left hemisphere sequential movement processing. [Varga-Khadem (Note 4) also reported no hemispheric advantage for recognition of signs presented with simulated movement.]

The general conclusion of the two Poizner studies is that statically presented signs are processed in the right hemisphere because the spatial processing required for these stimuli overrides the language processing but that moving signs require both spatial and language processing and therefore do not show any hemispheric advantage (Poizner, et al., 1979).

However, Poizner and his associates have not clearly developed their distinction between spatial and language processing. In their first experiment (Poizner & Lane, 1979), they argue that the deaf subjects treated the stimuli (ASL digits) as linguistic stimuli but that the spatial processing required of these linguistic stimuli predominate over language processing. This argument assumes contradictorily that the ASL stimuli are being treated both linguistically and nonlinguistically. Also, because both deaf and hearing subjects showed similar patterns of asymmetry to words and statically presented signs, they concluded there was no cause to propose two "language centers" for ASL and English. Yet, it is argued that the signs, which are processed with a RHA, are treated linguistically by the ASL group.

Another interpretation of these data suggests that linguistic input requires differential processing depending on whether it is phonetic (and therefore sequential) or nonphonetic (visuospatial) with phonetic input requiring more left hemisphere processing and nonphonetic input requiring more right hemisphere processing. This interpretation places the source of differential right and left hemisphere processing on the physical characteristics of the stimulus not the fact of the stimulus being language or non-language. This is a position consonant with that of Kimura's. Other nonphonetic language stimuli have elicited right hemisphere processing advantages. Nonphonetic Japanese ideographs, Kanji, have shown a LVF advantage in visual recognition (Hatta, 1977), while the phonetic Japanese symbols for syllables, Katakana and Hirakana, have shown RVF recognition advantages (Sasanuma, Itoh, Mori, & Kobayashi, 1977; Hatta, 1976).

An interesting aspect of the Poizner et al. data reported in Poizner & Battison (1980) is that signs which naturally incorporate more complex movement tended to show a smaller LVF advantage than signs which incorporate less complex movement. This finding was true of signs presented statically or with simulated movement, indicating that subjects are perhaps mentally reconstructing the movement in the statically presented signs. This suggests that the left hemisphere becomes more involved in sign processing the more complex the motor activity. Perhaps related to this is a recent report of a <u>smaller</u> right ear/left hemisphere recognition advantage for synthetic stop consonants when the formant transition between the noise burst and steady state components is synthetically lengthened (Schwartz & Tallal, 1980). This reduction in the rate of acoustic change decreased the usual symmetry in speech perception. So, perception of a more complex sequential motor event occurring rapidly in time requires relatively greater left hemisphere involvement as does perception of a more rapidly changing acoustic event. With this in mind, the fact that the duration of signs is about twice the duration of words (and thus slower rates of change in movement compared to rates of acoustic change) may also contribute to less left hemisphere and greater right hemisphere involvement in sign perception overall.

Not all the experimental data indicate a LVF advantage or no visual field advantage for sign perception. Neville & Bellugi (1978) reported a RVF recognition advantage for line drawings of signs using a unilteral presentation, but no one visual field advantage when the same signs were presented bilaterally. Virostek & Cutting (1979) found a small, but reliable, RVF advantage for recognition of ASL handshapes. These are the only experimental data which show a left hemisphere advantage for sign perception, at least when using a static presentation of the stimuli.

<u>Stroop Interference Studies</u>

Since its first report in the literature (Stroop, 1935), literally hundreds of studies of various aspects of the Stroop phenomenon have been published (see Jensen & Rohwer (1966) and Dyer (1973) for reviews). A recent literature search of <u>Psychological Abstracts</u> resulted in a compilation of over 150 studies published since 1967 which either investigated the Stroop phenomenon directly or used a Stroop task methodologically. Only those studies directly relevant to the experiment conducted here will be considered.

As was stated above, the classic Stroop interference effect is relatively slower color naming when the color appears as the print of a color word printed in a color that conflicts with the referent of the color term, than when the color appears in a neutral color patch. For example, the color red is more difficult to name when it appears in the word GREEN than when it appears in a semantically neutral color patch such as a colored disk. Traditionally, the task is presented on a series of stimulus cards. One card consists of a number of color words printed in conflicting colors, another card consists of a number of neutral color patches, and a third card consists of a number of color words printed in black. Each card has the same number of items, so it is possible to time a subject on how long he takes to name the colors of all the items or read all the words on each stimulus card. Stroop interference is measured as the difference in the time for responding to the neutral color patch card and the time for responding to the colored word card. With this pre sentation method, subjects generally take 50% - 100% longer to name the colors on the colored word card than on the neutral patch card (Dyer, 1973). Reading time for either the black print color word card or the colored color word card is consistently shorter than color naming time for the neutral patch card. Thus, there is a marked asymmetry in the Stroop phenomenon in that the word interferes with color naming yet the color produces negligible or no interference in the reading task.

Stroop interference has been produced in tasks using many alternate presentation procedures including individual stimulus presentation (e.g., Hock & Egeth, 1970; Seymour, 1977; Hintzman, Carre, Eskridge, Owens, Shaff & Sparks, 1972) using verbal (e.g., Stirling, 1979), manual button press (e.g., Pritchatt, 1968; Schmit & Davis, 1974; Simon & Sudalaimuthu, 1979) and manual card sorting responses (e.g., Triesman & Fearnley, 1969; Morton, 1969). These alternate procedures, however, generally result in less interference than the traditional card presentation/verbal response procedure. When the presentation method involves individual stimuli <u>and</u> keypress response, a sizeable "reverse Stroop" effect has been reported; that is, the ink color in the word stimuli interferes with a subject's ability to respond to the word (Schmit & Davis, 1974; Simon & Sudalaimuthu, 1979; Warren & Marsh, 1978) and this reverse Stroop interference is of approximately the same magnitude as the Stroop interference. In addition, the advantage of reading times over color naming times with a verbal response is not found with the keypress response.

Three other theoretically important aspects of the Stroop phenomenon should also be mentioned. First, it has been shown that words semantically related to color words (e.g., blood, sky, Spring) also produce interference in color naming (Klein, 1964;

Harrison & Boese, 1976; Seymour, 1977). Second, Stroop stimuli where the color word and ink color are congruent tend to produce faster ink color naming times than neutral color patch stimuli (Hintzman et al., 1972; Dyer, 1973). Third, amount of interference can be experimentally controlled by speeding or slowing the processing of each dimension of a Stroop stimulus. Gumenik & Glass (1970) found that by degrading the word information in a Stroop stimulus, color naming interference was reduced. In a spatial analog of the Stroop task, Palef & Olsen (1975) found that by biasing spatial cues the spatial dimension of the stimulus interfered with reading and vice versa.

Various models have been proposed to explain the locus of the interference effects in the Stroop task. These models all tend to be variants of two classes of models. One class assumes the source of interference occurs at output and is due to response competition between the irrelevant (word) and relevant (ink color) dimensions of the stimulus (Morton, 1969). A second class of models assumes that interference occurs at the input stages of processing where the irrelevant aspect of the stimulus (the word) slows the formation of a perceptual (Hock & Egeth, 1970) or conceptual/semantic (Seymour, 1977) code in memory. These two types of models will be discussed briefly below.

Output Interference Models. The response competition models can be nicely illustrated using Morton's (1969) logogen model. In this model, activation of a logogen causes a verbal response production "program" to be inserted in a response buffer which stores only one response program at a time. Both word and color stimulus dimensions are processed in parallel. Because reading normally occurs faster than color naming (Fraisse, 1969), the irrelevant word response program is inserted into the buffer first. When the color response program arrives, the buffer is full and the response is delayed. When the color response arrives first (cf. Gumenik & Glass, 1970), the word dimension should not interfere. A problem with the model is in explaining how the fast-arriving word response programs are suppressed and removed from the response buffer (Stirling, 1979). Also, there is no straight forward way to account for the facilitation effect when the word and ink color are congruent. Since Morton's logogen model deals with verbal responses, it also has a problem in accounting for Stroop interference in manual key press response task unless it is assumed that these responses are verbally mediated or that a logogen-like system exists for nonverbal responses.

Input Interference Models. Using a Sternberg (1969) paradigm, Hock & Egeth (1970) found that response times to classify the ink color of color words, verbs or a string of Xs as a member of the positive set of color names varied linearly with set size. They found intercept effects of type of verbal material with color words causing slower color naming, but no interaction of set size and type of interfering stimulus. Using Sternberg's reasoning, they interpreted the intercept effect to mean that color words influence the encoding of the ink color; that is, the source of interference in their task was perceptual conflict at encoding time. As with the logogen response competition model, this model cannot readily explain the facilitation effect of congruent Stroop stimuli. If the semantic information in the word interferes with the encoding of the ink color, then this interference should occur when a semantically related, but congruent, word appears in the stimulus. This model has also been criticized for the interpretation of a lack of an interfering verbal material x set size interaction as indicating no response effects and (2) for the fact that covert color naming may be taking place in the task (Dalrymple-Alford & Azkoul, 1972; Dyer, 1973).

Another input interference model is Seymour's (1977) conceptual encoding model. Seymour (1973, 1977) views a conceptual code as a group or cluster of semantic features (cf. Clark & Chase, 1972); semantically related items will thus access conceptual codes with common features. In the Stroop task, retrieval of a single conceptual code (the color name code) must occur so that this code can be converted into a response code (Morton's response program) via the logogen system that can generate the naming response. According to this model, Stroop interference occurs because two conceptual codes are retrieved (color word code and color name code) which overlap to a large degree and it takes time to distinguish them. Stroop interference is realized in the time it takes to distinguish the two codes so that a single code can be retrieved and converted into a response. The model does not describe the process of distinguishing the codes. Thus, interference does not occur at stimulus registration time, but rather at a stage of retrieving the proper conceptual code from memory. This model explains that the facilitation of a congruent Stroop stimulus produced in color naming is due to the fact that both the word and the color dimensions of the stimulus access the same conceptual codes facilitating the retrieval of that code. Seymour argues that the traditional form of the Stroop task cannot, in principle, distinguish between encoding and response competition effects because "there is almost always a confounding of possible effects of the distractor word on encoding and response processes. If, for example, the word RED is printed in green ink, an incongruity exists both with respect to encoding of the color green and with respect to production of the vocal response 'green'" (Seymour, 1977, p.245). So, Seymour argues, in order to distinguish between response and perceptual competition models, a task must be devised that allows for a response which is neither the ink color nor the lexical item in a Stroop-like stimulus.

One of his experimental tasks required subjects to name the season of the year associated with the ink color in which a season was printed (the direct analog of the traditional Stroop task). In another task, subjects were required to name the season <u>opposite</u> to the one associated with the ink color of a season name (e.g., the word SUMMER printed in green ink - green was previously shown to be associated with Spring - would require the response "autumn"). In the first task, typical Stroop results were found: season naming based on ink color of a season name was faster if the season and ink color were congruent than if the season conflicted with the ink color. In the task which required a response of the season name opposite the season associated with the word color, responses were faster to stimuli in which the word and color dimensions were congruent than to stimuli in which the dimensions conflicted; that is, the "autumn" response to SPRING in green ink was faster than the "autumn" response to AUTUMN in green ink. The conceptual encoding model predicts this because the congruent stimuli access the same conceptual code thus facilitating its retrieval and conversion to the appropriate response. A response competition model would predict the opposite result because the interfering word (e.g., AUTUMN) corresponds to the required response.

A recent study involving a literal Stroop task (Simon & Sudalaimuthu, 1979) reported a similar result where a response opposite to the color was required: in a two-color (red, green) two-response Stroop task, subjects were faster at responding "green" to RED in red ink than to GREEN In red ink. The same was true for analogous "red" responses. Clark & Brownell (1975) also reported results consistent with a perceptual conflict model in a spatial analog of a Stroop task.

Stirling (1979) suggested Seymour's methodology may be concealing response competition effects. In Seymour's experiments, an irrelevant season name opposite the ink color (e.g., AUTUMN in green ink), produced more interference than a season name chronologically before or after the seasons associated with the ink color. This is also the task which provides evidence supporting the conceptual encoding model. Stirling argued that the semantic oppositeness effect in Seymour's data may hide any resonse competition effects in this task. Stirling's (1979) study attempted to test the conceptual encoding model using stimuli and responses that were semantically unrelated. Subjects learned arbitrary verbal letter name responses to colors. The color dimension of the Stroop Stimulus appeared in (1) a string of 4 identical letters congruent with the color (e.g., Ds in red ink when "D" is the response to red) (2) a string of incongruent letters, (3) congruent color words (e.g., green in red ink), (4) incongruent color words and (5) a neutral color patch consisting of a string of 4 plus signs. The results suggest both conceptual encoding <u>and</u> response competition effects. Response competition effects can be seen in that responses were faster to congruent letter strings than responses to incongruent letter strings. Conceptual encoding effects were noted by the finding that responses to congruent color name stimuli were faster than responses to incongruent color name stimuli.

All the above studies taken together suggest both perceptual or input (including Seymour's conceptual encoding model) competition and response or output competition sources of interference in Stroop and Stroop-like tasks. A complete model of

Stroop interference must accommodate possibilities of both types of interference. None of the models discussed above addresses the finding that manual keypress responses to colors in the Stroop task result in less interference than verbal responses. Also, manual keypress responses result in more reverse Stroop interference (Simon & Sudalaimuthu, 1979) than verbal responses. Findings of relatively reduced interference for button press responses may suggest that overt response competition is the single largest source of interference in the traditional Stroop task. In the manual button press response Stroop tasks, response competition sources of interference are reduced or eliminated altogether to the extent that covert verbal mediation does not occur during the task.

Another important point here is that Seymour (1977) and Simon & Sudalaimuthu (1979) did not use neutral color patch naming times as a baseline from which to assess interference. These studies used RT to congruently colored color words as the baseline (mixed presentation of these stimuli with the Stroop stimuli prevented a simple reading strategy). So, the "interference" consists of both conflicting color-word ~~interference~~ and consonant color-word facilitation.

Hemisphere Specific Stroop Effects. Dyer (1973) suggested that the Stroop task may prove a useful tool in analyzing functional cerebral asymmetry. Assuming more efficient language processing in the left hemisphere (RVF), greater interference should occur for a Stroop stimulus presented to the RVF because the relatively quickly. Dyer & Harker (reported in Dyer, 1973) presented subjects vertically printed Stroop stimuli to the right and left visual fields and found no differential RT Stroop effects in the two visual fields. The stimuli were printed vertically to reduce variabililty in the horizontal visual angle subtended by the color words. This presentation method, however, would also seem to make the color words more difficult to read, which would in turn serve to reduce the interfering effect of the word dimension of the Stroop stimulus. Tsao, Feustel & Soseos (1979), who replicated the Dyer & Harker study, using vertically printed Stroop stimuli, found a greater error rate in the RVF than the LVF for Stroop stimuli, but no differences in reaction time. This study also reports a RVF advantage on the reading portion of the task. Both studies required verbal responses. Using a keypress response, Warren & Marsh (1978) also reported no visual field differences in the portion of their experiment which represented a standard Stroop task.

Schmit & Davis (1974) did find hemispheric reaction time effects in a three-color Stroop task. In this experiment subjects responded to congruent and non-congruent Stroop stimuli by pressing one of three keys associated with a given color with either their right or left hands. In the color response condition, subjects responding with their right hand experienced equal amounts of interference to Stroop stimuli in the left and right visual fields. Subjects responding with their left hands, however, showed negligible interference to Stroop stimuli in the LVF; but they also showed interference comparable to the right hand responders to stimuli in the RVF. In the color word response condition, both right and left hand responders experienced greater reverse Stroop interference to stimuli presented in the RVF. Overall, color responses showed LVF advantage and color word responses a RVF advantage.

This finding of LVF advantage for color and RVF advantage for words is consonant with the general model of functional asymmetry with language processing the left hemisphere and visuospatial (including color) processing in the right. Moreover, the finding of negligible Stroop interference in the LVF for left hand responders suggests that when the relevant color dimension processing and resopnse organization can occur without the necessary involvement of the left hemisphere, the word dimension processing does not take place fast enough to interfere with the color processing and response organization. This may only be the case, however, because color word responses were slower overall than color responses; in fact, the mean color word RT for the fastest stimulus condition was <u>slower</u> than the mean color RT for the slowest stimulus condition. Right hand responders experienced equal amounts of interference in both visual fields. The left hemisphere is responsible for response organization for these subjects, and presumably the necessary involvement of the left hemisphere allows the color word processing to interfere with the color processing.

An extension of Schmit & Davis' reasoning would also suggest that a verbal response which should always require left hemisphere involvement would increase the amount of interference for the left hand responders to Stroop stimuli in the LVF. If their reasoning is correct, then this may serve as an explanation for the lack of differential RT Stroop effects in the Tsao et al. (1979) study which used a verbal response. By the same account, however, Tsao et al.'s error rate findings become hard to explain. Also in this vein, subjects in Warren & Marsh (1978) responded by pressing keys with both hands. Assuming the reliability of Schmit & Davis' response hand effect, the two hand response in the Warren & Marsh study may contribute to the result of no differential interference in the visual fields. The response hand effect would also suggest that covert verbal mediation was not taking place in the Schmit & Davis study for the color response and, therefore, the interference occurs at input stages of processing.

One final study to be reported here did not evaluate hemispheric differences for Stroop stimuli directly, but its findings are interpreted in terms of differential hemispheric processing. Biederman & Tsao (1979) found greater interference using a traditional form of a Stroop task for Chinese Stroop stimuli and native Chinese speakers than for English stimuli and English speakers. The authors speculate that the greater interference for Chinese is attributable to greater input sources of interference caused by right hemisphere processing of the irrelevant ideograph and color. Color information has shown a right hemisphere processing advantage in hue discrimination tasks (Davidoff, 1976; Pennal, 1977; Hannay, 1979) and color identification tasks (Schmit & Davis, 1974; Pirot, Pulton & Sutker, 1977). A RHA for Chinese ideographs is inferred from the evidence for a RHA for Japanese Kanji discussed above.

In the Biederman & Tsao study, Chinese subjects experienced 196 msec per item greater interference than the English subjects. Compared with other studies demonstrating Stroop effects attributable to input sources of interference, this effect is quite large. Other studies using verbal responses Stroop input interference effects of 30-70 msec. So even if input interference for Chinese subjects were twice that of input interference for English subjects, the magnitude of the effect reported by Biederman & Tsao is still very large.

There is a possibility of relatively greater response competition sources of interference for the Chinese subjects. The subjects in the experiment scanned the stimulus card from top to bottom starting with the left most column (Biederman, Note 5). The vertical scanning required by the task more closely approximates normal reading for the Chinese than the English subjects and may put the Chinese subjects in more of a "reading mode" than the English subjects which may in turn lead to more response competition.

Bourg (1980) replicated the Biederman & Tsao (1979) study with congenitally, profoundly deaf native ASL signers in an ASL version of a traditional Stroop task. Deaf subjects were shown sign-pictures of ASL color signs where the outline of the hand was drawn in a conflicting ink color. With these stimuli, the deaf subjects experienced more interference to the ASL Stroop stimuli than monolingual English speakers did to a similarly constructed English Stroop task.

A weakness in both the Bourg (1980) and Biederman & Tsao (1979) papers is that each language group only performed the task in their preferred language (ASL, Chinese, or English). A better study would be one in which both language groups performed the Stroop task in both languages. This study, of course, assumes that subjects have used the nonpreferred language to some degree. This study would allow direct comparisons of the amounts of ASL and English Stroop interference in both deaf and hearing subjects. Previous studies of bilingual Stroop interference (Preston & Lambert, 1969) have shown that the dominant or preferred language produces more interference than the second or nonpreferred language in bilinguals. Also, bilinguals as a group show less interference overall than monolinguals.

The present study gave ASL and English Stroop tasks to congentially, profoundly deaf native signers whose first language was ASL and to English speakers with varying degrees of knowledge of total communication, but not ASL. The Stroop stimuli were presented to the right and left visual fields so that hemispheric processing effects could be assessed. One prediction is that the deaf subjects will experience more interference to the ASL Stroop task than the hearing subjects, while the hearing subjects will experience more interference to the English Stroop task than the deaf subjects. Moreover, subjects in each group should show more interference to the preferred language Stroop task than to the nonpreferred language task.

The hearing subjects also show a similar pattern of results in the English Stroop task as was reported in the Schmit & Davis (1974) study; that is, color naming should have an overall advantage when the color stimuli are presented to the LVF. Likewise, word naming should have an RVF advantage. Deaf subjects should also have an LVF advantage in the color naming task, and they should have an LVF advantage in the sign naming task if signs are processed with a right hemisphere advantage.

Method

Subjects

The Deaf group comprised 16 congenitally deaf adults, 3 males and 13 females ranging in age from 18 to 27 with a mean age of 21. All subjects learned ASL as their first language, had two deaf parents, attended residential (manual) schools for the deaf and used ASL as their preferred mode of communication. Hearing loss resulting from hereditary deafness is usually peripheral in nature (Fraser, 1970) and is not associated with other neurological impairment. All subjects were faculty, staff, or students at Gallaudet College.

The hearing group comprised 16 normally hearing, English monolingual adults, 7 males and 9 females, who ranged in age from

23 to 40 (mean age 32) and were not familiar with ASL. These subjects were all staff or faculty members at Gallaudet College who signed and comprehended various forms of total communication but yet did not sign or comprehend ASL. All subjects reported having normal eyesight in each eye (corrected in some cases) and normal color vision. All subjects were determined to be righthanded by self report and by responses to 10 questions extracted from the Edinburgh Handedness Inventory (Oldfield, 1971). Subjects performed at least 9 of the 10 queried motor activities with their right hand. Eighteen subjects were paid participants in the experiment; the remaining 14 were volunteers.

Stimuli

In the experiment, Stroop stimuli were constructed using the colors red and orange. Choice of colors was constrained by ASL color signs. In ASL there are three basic color terms: RED, BLACK and WHITE (ASL color signs and English color words will be typed in all caps). Other color signs are loan signs (Stokoe, Note 6) which consist of the handshape of the letter in the manual alphabet that corresponds to the first letter of the English color term. YELLOW, GREEN, BLUE, and PURPLE are signed with the appropriate manual alphabet handshape for the active hand (right hand for right handed signers) which is oscillated at the side of the body at shoulder height. PINK is distinguished from PURPLE by moving the location of the "P" hand from the side of the body to near the mouth at the midline of the body. ORANGE is signed with a repeated squeezed and relaxed fist near the mouth at the midline of the body. ~~It is~~ not a basic color term, but rather a polysemous sign whose first meaning is the fruit (Stokoe, Note 6). The basic color sign RED is made with an extended index finger moving downward at the lips.

The stimuli were 35mm slides of the words or sign pictures RED and ORANGE drawn in red and orange ink resulting in 4 possible stimulus combinations for the words (2 words by 2 colors) and 8 possible stimulus combinations for the signs (2 signs x 2 colors x left/right-handed signer). The sign pictures of the right-handed signs are shown in Figure 1. Only the outline of the hand was drawn in colored ink with the remainder of the drawing in black ink. Each sign and word was printed on white paper. The stimuli were then photographed in a black construction paper frame in order to reduce the total amount of light on the projection screen. Thus, a stimulus slide appeared to a subject as a dark field with the stimulus appearing within a smaller white field. This white field subtended 12.5 deg of horizontal visual angle and 4 deg of vertical visual angle.

RED

ORANGE

Figure 1. Two Experimental Sign Line Drawings

For the signs, the midline of the signer's face was centered 4.1 deg from central fixation with the sign itself (as measured from shoulder to shoulder) subtending 3.2 deg of visual angle. The words were also centered 4.1 deg from central fixation; the word RED was 1.4 deg wide and ORANGE was 3.2 deg wide. A slide of a black dot (.1 deg in diameter) centered in the white field served as the fixation point for the word and sign stimuli.

Design and Procedure

Each subject was administered 4 tasks: (1) color naming of the ink in which the color signs were drawn; (2) color naming of the ink in which the color words were drawn; (3) sign naming of the colored signs; and (4) word naming of the colored words.

Task 1 (the ASL color naming condition) consisted of 64 randomized trials. These trials were 4 repetitions of the 16 stimulus combinations (i.e., 2 colors x 2 lexical items x 2 left/right-handed signer x 2 visual fields). Thus, half the trials presented stimuli with consonant color and lexical information (non-Stroop stimuli) and half presented stimuli with conflicting color and lexical information (Stroop stimuli). Task 2 (the English color naming condition) also consisted of 64 trials; 8 repetitions of the 8 stimulus combinations (2 words x 2 colors x 2 visual fields). Half the trials presented Stroop stimuli and half presented nonStroop stimuli. Tasks 3 and 4 also consisted of 64 trials and used the same stimuli of tasks 1 and 2 respectively. In tasks 3 and 4, however, subjects ignored the ink color and named the sign or word.

In all tasks, stimuli were projected on a high luminance, daylight projection screen 7' from the subject who was seated in a 5' x 11' dimly lit anechoic chamber. The subject sat at a table in front of the screen with his head positioned on a chin rest. The subject maintained this position through each task. A trial consisted of the fixation dot (which served as a fixation dot and as a warning of the next trial) presented for 2 sec followed by a 190 msec duration stimulus slide. Slide as quickly as possible while minimizing errors. RT was measured to the nearest msec from the onset of the stimulus slide. Response feedback was provided immediately after the subject responded.

Task order was completely counterbalanced across subjects with the one constraint that tasks involving the same stimuli (either English or ASL) would always occur together. Thus, both tasks involving the ASL stimuli would always precede or follow the English stimuli tasks. Each subject performed each task once. Half the subjects in each group responded with their right hand, half with their left. The subject responded by pressing one of two buttons on an answer box placed in front of him with either the middle or index finger of the assigned hand. Response to finger assignment was fully counterbalanced across subjects. Deaf subjects viewed a videotape of the experimental instructions presented in ASL; hearing subjects read the instructions.

Slide projector and tachistoscopic shutter operation, and response feedback were controlled by a PDP-8 minicomputer. The subject's responses and RTs were stored on the computer's disk for later analysis. Before the first task, subjects were administered a block of 16 color naming practice trials consisting of 8 sign stimuli and 8 word stimuli so that they would be familiar with the color discrimination and the response apparatus.

Results

Reaction Time

Median RTs for correct trials were computed for each subject for each visual field/response combination for each task. The signer handedness variable was ignored in the computation of the median RTs in the ASL tasks. Color naming and sign/word naming tasks were analyzed separately.

Most subjects reported that the colors red and orange were difficult to distinguish, particularly in the context of the sign RED. The sign picture RED allowed for the least color content of all the stimuli. When Stroop interference is analyzed as the difference in RT between Stroop stimuli and nonStroop stimuli, the sign RED had no interfering effect for either the deaf or hearing groups. The deaf group's mean RT to the color red in the sign RED, a nonStroop stimulus, was 896 msec and the RT to orange in the sign RED, a Stroop stimulus, was 808 msec. The hearing group's mean RTs for those two stimuli were 863 msec and 846 msec respectively. Thus, color naming RTs to a Stroop stimulus whose sign was RED were shorter than RTs to a nonStroop stimulus whose sign was RED. It seems clear that this negative Stroop interference for stimuli with the sign RED is a result of subjects' inability to distinguish red and orange in the sign RED and not due to a cognitive variable of interest to this experiment. For the color naming tasks, RTs to Stroop and nonStroop stimuli with the sign and word ORANGE only were analyzed.

The color naming RTs were analyzed in a Group x Response Hand x Task x Stimulus Type (Stroop, nonStroop) x Visual Field ANOVA. As shown in Table 1, both groups experienced substantial amounts of Stroop interference in both tasks as indicated by an overall effect of Stimulus Type ($F(1,28)=69.17$, $p<.001$). More important, however, is the presence of a Group x Task x Stimulus Type interaction ($F(1,28)=6.40$, $p<.05$). As can be seen from Table 1, hearing subjects experienced more interference to English stimuli (Stroop-nonStroop = 270 msec)than did deaf subjects (184 msec). Deaf subjects, on the other hand, experienced more interference to the ASL stimuli (126 msec) than did hearing subjects (94 msec).

Table 1. Coloring Naming RTs (msecs)

	Hearing		Deaf	
	ASL	ENG	ASL	ENG
Stroop	776	972	822	823
NonStroop	682	702	696	639
Stroop - NonStroop	94	270	126	184

Both deaf and hearing groups experienced more interference to English stimuli than to ASL stimuli as indicated by a Task x Stimulus Type interaction ($F(1,28)=20.06$, $p<.001$). Table 2 shows the Response Hand x Stimulus Type interaction ($F(1,28)=6.18$, $p<.05$): the righthand responders suffered more interference than the lefthand responders.

Table 2. Response Hand x Stimulus Type RTs (msecs)

	Right	Left
Stroop	861	835
NonStroop	643	717

There was no main effect of visual field in this analysis. A Group x Visual Field interaction did obtain, however, ($F(1,28)=6.40$, $p<.05$). Table 3 shows that the deaf subjects had a 43 msec LVF advantage in color naming while the hearing subjects had a 33 msec RVF advantage. This interaction was not predicted in that it was expected that all subjects would show a LVF advantage for color identification. The only other effect in this ANOVA was a Response Hand x Task x Stimulus Type x Visual Field interaction ($F(1,28)=5.52$, $p<.05$). We have no ready explanation for this interaction.

Table 3. Group x Visual Field Color Naming RTs (msecs)

	LVF	RVF
Hearing	723	767
Deaf	799	766

A Group x Response Hand x Task x Stimulus Type x Response (red, orange) x Visual Field ANOVA was performed on the word and sign naming tasks. This analysis revealed a Stimulus Type main effect $(F1,28)=13.84$, $p<.01$) with nonStroop stimuli taking less time to identify (600 msec) than Stroop stimuli (619 msec). Notice that this reverse Stroop interference is much smaller in magnitude than the Stroop interference reported above. A Task main effect also obtained ($F(1,28)=39.04$, $p<.001$) with ASL sign naming (655 msec) taking about 90 msec longer per item than English word naming (565 msec).

Table 4. Group x Response Hand x Visual Vield RTs (msecs)

	LVF	RVF
Hearing-right	630	662
Hearing-left	631	621
Deaf-right	568	558
Deaf-left	607	601

Table 4 shows the Group x Response Hand x Visual Field interaction ($F(1,28)=4.35$, $p<4.35$). Notice from Table 4 that the hearing, righthand responders had a 32 msec LVF advantage while all other groups had a small RVF advantage. The only other significant effect in this analysis was a Response Hand x Task x Response x Visual Field interaction ($F(1,28)=7.95$, $p<.01$).

Percent Correct

Percent correct scores were computed for each visual field/response combination for each subject. As in the RT analyses, the signer handedness variable was ignored in the computations. Color naming and sign/word naming tasks were analyzed separately.

Table 5. Task x Stimulus Type Percent Correct Scores

	ENG	ASL	
Stroop	65	84	75
NonStroop	96	94	95
	82	89	

The color naming percent correct scores were analyzed in a Group x Response Hand x Task x Stimulus Type x Visual Field ANOVA. A Stroop effect was evidenced in the percent correct data in that subjects performed better (95%) on the nonStroop stimuli than on the Stroop stimuli (75%) ($F(1,28)=100.41$, $p<.001$). Table 5 shows that the English Stimuli caused more interference than the ASL stimuli as indicated by a Task x Stimulus Type interaction ($f(1,28)=14.20$, $p<.01$). This result parallels the RT data in that, overall, both groups of subjects suffered more interference to the English stimuli. There is no evidence in the percent correct data, however, that the deaf subjects showed more interference to the ASL stimuli than did the hearing subjects; the Group x Task x Stimulus Type interaction for the percent correct scores was not significant ($F(1,28)=1.07$, $p>.3$). The only other effect in this analysis was a Stimulus Type x Visual

Field interaction ($F(1,28)=7.35$, $p<.05$) which is shown in Table 6. As can be seen in Table 6, subjects experience more interference to stimuli presented to the LVF than to the RVF.

Table 6. Stimulus Type x Visual Field (% Correct)

	LVF	RVF
Stroop	71	79
NonStroop	98	93

The word and sign task percent correct data were analyzed in a Group x Response Hand x Task x Stimulus Type x Response x Visual Field ANOVA. The only reliable effect in this analysis is a Task x Response interaction ($F(1,28)=5.78$, $p<.05$) shown in Table 7. Subjects had the most difficulty in naming the sign RED compared to the other 3 lexical items in the task, although this is a small effect.

Table 7. Task x Response -- Word/Sign Naming (% Correct)

	ENG	ASL
RED	98	95
ORANGE	98	98

Discussion

The major finding of the experiment is that both deaf subjects whose first language is ASL and hearing subjects who are not ASL bilinguals, but who know signs to some degree, experienced Stroop interference for both English and ASL. More importantly, however, the deaf subjects experienced more interference to the ASL stimuli than did the hearing subjects in the experiment. This suggests that the deaf subjects have a different and more complex representation of sign meaning than the hearing subjects and that the deaf subjects have faster access to that meaning. Thus, the signs had a greater interfering effect in the color naming task. For the deaf subjects, the semantic analysis of the sign stimuli is more of an automatic process than for the hearing subjects. The fact that the hearing subjects suffered less interference to the sign stimuli suggests that they could suppress the meaning of the sign more easily than the deaf subjects.

The fact that normal-hearing subjects experienced significant interference to the ASL Stroop stimuli suggests that they were processing the meaning of the signs, however. The reduced interference for the ASL subjects with the ASL stimuli is consistent with other bilingual versions of the Stroop task. Preston & Lambert (1969) reported that for a Stroop task in a given language (e.g., French), native speakers experienced more interference than speakers who had learned that language as a second language.

One major area where the present study is inconsistent with other bilingual Stroop research is that the deaf subjects experienced more interference to the English Stroop stimuli than to ASL stimuli. Preston & Lambert (1969) showed that Stroop stimuli in a subect's native language porduce more interference than second language Stroop stimuli. For this reason, the deaf subjects had been expected to show more interference to the ASL stimuli than the English stimuli. A possible explanation of why the ASL subjects did not show more interference to the ASL stimuli than to the English stimuli is that signs do not naturally occur as static pictures (i.e., there is no natural ASL orthography). This is not the case for English. Thus, the signs had less interfering power for the deaf subjects than the words because of the relatively unnatural presentation mode of the signs. It is remarkable, in fact, that statically presented sign pictures had the consistent interfering effect they did.

The visual field variable had little effect on the color naming or word/sign naming times or the accuracy of identification for either the deaf or hearing subjects. Word naming did not show the typical right visual field (left hemisphere) processing advantage; nor did sign naming show a visual field processing advantage. In the case of word naming, the two stimuli (the words RED and ORANGE) could be distinguished by word length alone. Word recognition based on length alone requires visuospatial processing, a right hemishphere activity. Several subjects reported that they relied on the length information for the word naming task. Using colors of similar hue in the color naming tasks may have forced subjects into an analytical processing mode (i.e., left hemisphere processing) to distinguish the colors; this would account for the lack of a left visual field (right hemisphere) processing advantage for color naming.

The lack of clear visual field differences in the processing of signs, words, and colors does not detract from the study's basic finding, however. The demonstration of greater interference to ASL Stroop stimuli by native ASL signers than by hearing, native English speakers who learned to sign later in life is encouraging in itself. Further investigation of the precise locus of this effect is warranted.

References

Baker, C., & Padden, C.A. Focusing on the nonmanual components of American Sign Language. In P. Siple (Ed.), Understanding language through Sign Language research. New York: Academic Press, 1978.

Battison, R. Phonological deletion in American Sign Language. Sign Language Studies, 1974, 5, 1-19.

Battison, R. Lexical borrowing in American Sign Language. Silver Spring, Maryland: Linstok Press, 1978.

Bellugi, U., & Fischer, S. A comparison of Sign Language and spoken language. Cognition, 1972, 1, 173-200.

Bellugi, U., Klima, E.S., & Siple, P. Remembering in signs. Cognition, 1975, 3, 93-125.

Bellugi, U., & Siple, P. Remembering with and without words. In Current problems in psycholinguistics. Paris: Centre National de la Recherche Scientifique, 1974.

Bever, T.G., & Chiarello, R.J. Cerebral dominance in musicians and nonmusicians. Science, 1974, 185, 537-539.

Biederman, I., & Tsao, Y-C. On processing Chinese ideographs and English words: Some implications from Stroop-test results. Cognitive Psychology, 1979, 11, 125-132.

Bourg, J.W. Stroop interference and cerebral assymetry in native deaf signers of American Sign Language. Unpublished doctoral thesis, State University of New York at Buffalo, 1980.

Bryden, M.P. Tachistoscopic recognition, handedness, and cerebral dominance. Neuropsychologia, 1965, 3, 1-8.

Clark, H.H., & Brownell, H.H. Judging up and down. Journal of Experimental Psychology: Human Perception and Performance, 1975, 1, 339-352.

Clark, H.H., & Chase, W.G. On the process of comparing sentences against pictures. Cognitive Psychology, 1972, 3, 472-517.

Crowder, R.G. Principles of learning and memory. Hillsdale, New Jersey: Erlbaum, 1976.

Dalrymple-Alford, E.C., & Azkoul, J. The locus of interference in Stroop and related tasks. Perception & Psychophysics, 1972, 11, 385-388.

Davidoff, J. Hemispheric sensitivity differences in the perception of color. Quarterly Journal of Experimental Psychology, 1976, 28, 387-394.

Davis, R., & Schmit, V. Visual and verbal coding in the interhemispheric transfer of information. Acta Psychologica, 1973, 37, 229-240.

Donaldson, M., & Balfour, G. Less is more; a study of language comprehension in children. British Journal of Psychology, 1968, 59, 461-471.

Dyer, F.N. Interference and facilitation for color naming with separate bilateral presentations of the word and color. Journal of Experimental Psychology, 1973a, 99, 314-317.

Dyer, F.N. The Stroop phenomenon and its use in the study of perceptual, cognitive and response processes. Memory and Cognition, 1973b, 1, 106-120.

Fraisse, P. Why is naming longer than reading? Acta Psychologica 1969, 30, 96-103.

Fraser, G.R. The causes of profound deafness in childhood. In G.E.W. Wolstenholm & J. Knight (Eds.), Sensorineural hearing loss. London: Churchill, 1970.

Frishberg, N. Arbitrariness and iconicity: Historical change in American Sign Language. Language, 1975, 51, 696-719.

Gazzaniga, M.S. The bisected brain. New York: Appleton-Century-Crofts, 1970.

Geffen, G., Bradshaw, J.L., & Nettleton, N.C. Hemispheric asymmetry: Verbal and spatial encoding of visual stimuli. Journal of Experimental Psychology, 1972, 95, 25-31.

Geschwind, N. The organization of language and the brain. Science, 1970, 170, 940-944.

Grosjean, F. A study of timing in a manual and a spoken language: American Sign Language and English. Journal of Psycholinguistic Research, 1979, 8, 379-405.

Gumenik, W.E., & Glass, R. Effects of reducing the readability of the words in the Stroop color-word test. Psychonomic Science, 1970, 20, 247-248.

Hannay, H.J. Asymmetry in reception and retention of colors. Brain and Language, 1979, 8, 191-201.

Harrison, N.S., & Boese, E. The locus of semantic interference in the "Stroop" color-naming task. Perception & Psychophysics, 1976, 20, 408-412.

Hatta, T. Asynchrony of lateral onset as a factor in difference in visual field. Perceptual and Motor Skills, 1976, 42, 163-166.

Hatta, T. Recognition of Japanese Kanji in the left and right visual fields. Neuropsychologia, 1977, 15, 685-688.

Hellige, J.B., & Cox, R.J. Effects of concurrent verbal memory on recognition of stimuli from left and right visual fields. Journal of Experimental Psychology: Human Perception and Performance, 1976, 2, 210-221.

Hines, D. Recognition of verbs, abstract nouns and concrete nouns from the left and right visual half-fields. Neuropsychologia, 1976, 14, 211-216.

Hintzman, D.L., Carre, F.A., Eskridge, V.L., Owens, A.M., Shaff, S.S., & Sparks, M.E. "Stroop" effect: Input or output phenomenon? Journal of Experimental Psychology, 1972, 75, 458-459.

Hock, H.S., & Egeth, H.E. Verbal interference with encoding in a perceptual classification task. Journal of Experimental Psychology, 1970, 83, 299-303.

Jensen, A.R., & Rohwer, W.D., Jr. The Stroop color-word test: A review. Acta Psychologica, 1966, 25, 36-93.

Kimura, D. Left-right differences in the perception of melodies. Quarterly Journal of Experimental Psychology, 1964, 16, 355-358.

Kimura, D. Dual functional asymmetry of the brain in visual perception. Neurophychologia, 1966, 4, 275-285.

Kimura, D. The asymmetry of the human brain. Scientific American, 1973a, 228, 70-78.

Kimura, D. Manual activity during speaking - I. Right-handers. Neuropsychologia, 1973b, 11, 45-50.

Kimura, D. Manual activity during speaking - II. Left-handers. Neuropsychologia, 1973c, 11, 51-55.

Kimura, D. The neural basis of language qua gesture. In H. Whitaker and H.A. Whitaker (Eds.), Studies in neurolinguistics, Vol. 2. New York: Academic Press, 1976.

Klein, G.S. Semantic power measured through the interference of words with color-naming. American Journal of Psychology, 1964, 77, 576-588.

Klima, E., & Bellugi, U. The signs of language. Cambridge, Mass.: Harvard University Press, 1979.

Lansdell, H. Effect of extent of temporal lobe ablations on two lateralized deficits. Psychology and Behavior, 1968, 3, 271-273.

Manning, A.A., Goble, W., Markman, R., & LaBreche, T. Lateral cerebral differences in the deaf in response to linguistic and nonlinguistic stimuli. Brain and Language, 1976, 4, 309-321.

Mayberry, R.I. Manual communication. In H. Davis & S.R. Silverman (Eds.), Hearing and Deafness (4th ed.). New York: Holt, Rinehart and Winston, 1978.

McKeever, W.F., Hoemann, H.W., Florian, V.A., & VanDeventer, A.D. Evidence of minimal cerebral asymmetries for the processing of English words and American Sign Language stimuli in the congenitally deaf. Neuropsychologia, 1976, 6, 413-423.

Milner, B. Interhemispheric differences in the localization of psychological processes in man. British Medical Bulletin, 1971, 27, 272-277.

Milner, B. Hemispheric specialization: Scope and limits. In F.O. Schmitt & F.G. Warden (Eds.), The Neurosciences: Third study program. Boston: MIT Press, 1974.

Morton, J. Categories of interference: Verbal mediation and conflict in card sorting. British Journal of Psychology, 1969, 60, 329-346.

Nebes, R.D. Hemispheric specialization in commissurotomized man. Psychological Bulletin, 1974, 81, 1-14.

Neville, H.J., & Bellugi, U. Patterns of cerebral specialization in congenitally deaf adults: A preliminary report. In P. Siple (Ed.), Understanding language through Sign Language research. New York: Academic Press, 1978.

Oldfield, R.C. The assessment and analysis of handedness: The Edinburgh inventory. Neuropsychologia, 1971, 9, 97-117.

Palef, S.R., & Olson, D.R. Spatial and verbal rivalry in a Stroop-like task. _Canadian Journal of Psychology_, 1975, _29_, 201-209.

Pennal, B.E. Human cerebral asymmetry in color discrimination. _Neuropsychologia_, 1977, _15_, 563-568.

Phippard, D. Hemifield differences in visual perception in deaf and hearing subjects. _Neuropsychologia_, 1977, _15_, 555-561.

Pirot, M., Pulton, T.W., & Sutker, L.W. Hemispheric asymmetry in reaction time to color stimuli. _Perceptual and Motor Skills_, 1977, _45_, 1151-1155.

Poizner, H., & Battison, R. Cerebral asymmetry for Sign Language: Clinical and experimental evidence. In H. Lane & F. Grosjean (Eds.), _Recent Perspectives on American Sign Language_. Hillsdale, New Jersey: Erlbaum, 1980.

Poizner, H., Battison, R., & Lane, H. Cerebral asymmetry for American Sign Language: The effects of moving stimuli. _Brain and Language_, 1979, _7_, 351-362.

Poizner, H., & Lane, H. Cerebral asymmetry in the perception of American Sign Language. _Brain and Language_, 1979, _7_, 210-226.

Posner, M.I. Abstraction and the process of recognition. In G. Bower & K. Spence (Eds.), _Psychology of Learning and Motivation_, Vol. 3. New York: Academic Press, 1969.

Preston, M.S., & Lambert, W.E. Interlingual interference in a bilingual version of the Stroop color-word task. _Journal of Verbal Learning and Verbal Behavior_, 1969, _8_, 295-301.

Prichatt, D. An investigation in some of the underlying associative verbal processes of the Stroop colour effect. Quarterly Journal of Experimental Psychology, 1968, 20, 351-359.

Rizzolatti, G., Umilta, C., & Berlucchi, G. Opposite superiorities of the left and right cerebral hemispheres in discriminative reaction time to physiognomical and alphabetic material. Brain, 1971, 94, 431-442.

Sasanuma, S., Itoh, M., Mori, K., & Kobayashi, Y. Tachistoscopic recognition of Kana and Kanji Words. Neuropsychologia, 1977, 15, 547-553.

Schmit, V., & Davis, R. The role of hemispheric specialization in the analysis of Stroop stimuli. Acta Psychologica, 1974, 38, 149-158.

Schwam, E. "MORE" is "LESS": Sign Language comprehension in deaf and hearing children. Journal of Experimental Child Psychology, 1980, 29, 249-263.

Schwartz, J., & Tallal, P. Rate of acoustic change may underlie hemispheric specialization for speech perception. Science, 1980, 207, 1380-1381.

Seymour, P.H.K. A model for reading, naming and comparison. British Journal of Psychology, 1973, 64, 35-49.

Seymour, P.H.K. Conceptual encoding and locus of the Stroop effect. Quarterly Journal of Experimental Psychology, 1977, 29, 245-265.

Simion, F., Bagnara, S., Bisiacchi, P., Roncato, S., & Umiltà, C. Laterality effects, levels of processing and stimulus properties. Journal of Experimental Psychology: Human Perception and Performance, 1980, 6, 184-195.

Simon, J.R., & Sudalaimuthu, P. Effects of S-R mapping and response modality on performance in a Stroop task. Journal of Experimental Psychology: Human Perception and Performance, 1979, 5, 176-187.

Siple, P. Linguistic and psychological properties of American Sign Language: An overview. In P. Siple (Ed.), Understanding language through Sign Language research. New York: Academic Press, 1978.

Siple, P., Fischer, S., & Bellugi, U. Memory for nonsemantic attributes of American Sign Language signs and English words. Journal of Verbal Learning and Verbal Behavior, 1977, 16, 561-574.

Sternberg, S. The discovery of processing stages: Extensions of Donders' method. Acta Psychologica, 1969, 30, 276-315.

Stirling, N. Stroop interference: An input and an output phenomenon. Quarterly Journal of Experimental Psychology, 1979, 31, 121-132.

Stokoe, W.C., Jr. Sign Language structure: An outline of the visual communication systems of the American deaf. Studies in Linguistics, Occasional Papers: No. 8. Buffalo, New York: University of Buffalo Press, 1960 (revised edition, Silver Spring, Maryland: Linstok Press, 1978).

Stokoe, W.C., Jr., Casterline, D.C., & Croneberg, C.G. A dictionary of American Sign Language on linguistic principles. Washington, D.C.: Gallaudet College Press, 1965 (2nd edition, Silver Spring, Maryland: Linstok Press, 1976).

Stroop, J. Studies of interference in serial verbal reactions. Journal of Experimental Psychology, 1935, 18, 643-662.

Studdert-Kennedy, M., & Shankweiler, D. Hemispheric specialization for speech perception. Journal of the Acoustical Society of America, 1970, 48, 579-594.

Triesman, A.M., & Fearnley, S. The Stroop test: Selective attention to colors and words. Nature, 1969, 222, 437-439.

Tsao, Y-C., Feustel, T., & Soseos, C. Stroop interference in the left and right visual fields. Brain and Language, 1979, 8, 367-379.

Umilta, C., Sava, D., & Salmaso, D. Hemispheric asymmetries in a letter classification task with different typefaces. Brain and Language, 1980, 9, 171-181.

Virostek, S., & Cutting, J.E. Asymmetries for Ameslan handshapes and other forms in signers and nonsigners. Perception and Psychophysics, 1979, 26, 505-508.

Warren, L.R., & Marsh, G.R. Hemispheric asymmetry in the processing of Stroop stimuli. Bulletin of the Psychonomic Society, 1978, 12, 214-216.

Zangwill, O.L. Cerebral dominance and its relation to psychological function. Edinburgh: Oliver and Boyd, 1960.

Reference Notes

1. Liddell, S.K. An investigation into the syntactic structure of American Sign Language. Unpublished doctoral thesis, University of California, San Diego, 1977.
2. Brown, R. Why are signed languages easier to learn than spoken languages? Address to the National Association of the Deaf, 1977.
3. St. John, R.C. Lateral asymmetry in face perception. (Research Bulletin #495) London, Ontario: Department of Psychology, University of Western Ontario, 1979.
4. Vargha-Khadem, Faraneh. Hemispheric specialization in congenitally deaf and hearing children and adolescents. Unpublished doctoral thesis, University of Massachusetts, 1979.
5. Biederman, I. Personal communication, January, 1980.
6. Stokoe, W.C., Jr. Social correlates of Sign color terms. Unpublished manuscript, 1975.

SECTION C

TEST RESPONSE VARIATIONS BETWEEN HEARING IMPAIRED AND HEARING STUDENTS

Introduction

Educators of hearing impaired students have strongly urged the development of achievement tests which accommodate the students' special needs and, simultaneously, provide scores which can be compared to those obtained by hearing students. Comparability has been most frequently achieved through the use of norm-referenced standardized tests. For example, a special edition for hearing impaired students of the Stanford Achievement Test (SAT-HI) is in widespread use. Since it has been standardized with groups of hearing and hearing impaired students, the SAT-HI enables educators to compare the overall achievement patterns of their students with those shown by hearing students (Trybus & Karchmer, 1977). Additionally, much of the research that has been published pertaining to the achievement levels of hearing impaired students has used data from large-scale administrations of the SAT-HI (Allen & Karchmer, 1981; Jensema, 1975; Ries, Trybus, Sepielli, & Buchanan, 1973; Trybus & Jensema, 1976; Trybus & Karchmer, 1977). The use of norm-referenced test materials, however, is not the only way to achieve comparability. Tests developed using latent trait models of assessment provide educators with alternatives. Such tests purport to be sample-free; with the tests, item score information is used to estimate student ability directly (Rasch, 1960; Wright & Stone, 1979).

The use of latent trait models offers possibilities to educators of hearing impaired students who desire test score information about which unambiguous statements can be made regarding the achievement levels of their students. Additionally, the methods used to study item responses and to assemble tests which yield response patterns that fit latent trait models offer test developers the means by which they can determine whether or not skills do indeed develop similarly with hearing and hearing impaired populations.

The current study examines the item responses of hearing impaired students to a small set of items selected from a specific skill continuum. The items have been calibrated with a Rasch procedure and have been selected to represent a wide range of abilities. Rasch calibration involves placing student ability estimates and item difficulty estimates on the same scale. The calibration previously had been carried out on large samples of hearing children. This study assesses the validity of the resulting Rasch difficulty parameters when they are applied to the test results of hearing impaired students.

The analysis focuses on two issues. The first pertains to the order of difficulty of the items. To assure comparability, it must be shown that any skill continuum which has been defined for hearing students is also appropriate for hearing impaired students. That is, it must be demonstrated that the item difficulty-student ability calibration for hearing impaired students produces the same Rasch scale as does the calibration for hearing students. Evidence related to this issue will be explored.

The second issue pertains to item format. The manner in which a test item is presented to and comprehended by the students is a significant issue in all test development. This is especially crucial for hearing impaired students who, as a group, are well known to have limited English language and reading abilities. A test format which requires hearing impaired students to read, understand, and answer test items on their own, as opposed to one in which the test items are dictated to the students, may introduce a factor in the assessment process that is not present for hearing students. This study explores whether such a factor is indeed present when the set of items are administered.

Method

Description of the sample

The sample was comprised of 1542 students from 39 different special educational programs for hearing impaired students in six different states. Students in the sample ranged in age from 7 to 18, with 24% of the sample in the 6 to 9 year old age group, 29% in the 10 to 13 year old age group, and 47% in the 14 to 18 year old age group. The larger percentage in the older group reflects the fact that this group is larger in the U.S. population of deaf students due to an epidemic of rubella in 1964-65. This epidemic resulted in a dramatic increase in the number of deaf students born during that year. The students in the sample attended different types of educational programs, including integrated public school programs (76%) and residential and day school programs for the hearing impaired (24%). The students came from various ethnic backgrounds, including whites (53%), blacks (18%), and Spanish-Americans (29%). Forty-nine percent of the sample had profound losses (>90 dB in the better ear), 25% had severe losses (between 70 and 90 dB) and 26% had less than severe losses (<70dB).

The programs from which the students were drawn participated in a large pilot test project in which four levels of a comprehensive Rasch-based language arts test were administered to hearing impaired students.

<u>Description of the instrument</u>

The instrument was designed to serve as a screening test in conjunction with the four levels of the actual tests given. The tests were published by the Los Angeles County Test Development Center (LACTDC)[1]. In the procedures typically used with this test, hearing students are assigned to the appropriate test level on the basis of their grade in school; kindergartners receive Level 1, first and second graders receive Level 2, etc. With hearing impaired students, such a procedure is not advisable, since the relationship between their grade and skill levels is not the same as it is with hearing students (Trybus & Karchmer, 1977). Thus, a nine-item screening test was developed specifically for this project by LACTDC with items drawn from the same item domain used to create the published tests. Rasch item difficulty parameters for seven of the nine items were established through their prior administration to hearing students. Due to item bank deficiencies in the extremely low ability range, however, the two easiest items in the test were taken from a different item bank and thus the parameters provided for these items were estimates and their standard errors were unavailable. The nine items appear as an appendix.

Testing procedures

The tests were administered in the students' normal classroom environments. Test booklets and teacher instruction sheets were distributed to all of the classroom teachers whose classes participated in the study. The instructions urged that the testing be carried out in the manner that was customary for that program, using the communication mode that was typically employed in daily instruction. The tests were administered ordinarily by the students' classroom teachers. In some programs, however, school psychologists, diagnosticians, or itinerant teachers administered the tests.

The screening tests themselves contained items administered in two different formats. Items 1 through 6 on the test were dictated to the students in the students' typical communication mode. Items 7 through 9 required the students to read and comprehend them on their own. These different formats were representative of formats used in the larger test battery, in which the higher levels require students to read and comprehend the items on their own, while the lower levels do not.

Analysis

Item Difficulties

Table 1 presents both the Rasch item difficulty parameters based on samples of hearing students in grades K through 4 and the proportions of correct responses on each item for the hearing impaired students in the current sample. The standard errors for the Rasch parameters and the ranks of the item difficulties for the hearing impaired sample are also given.

For hearing impaired students, Item 2 is not the second easiest item. Even though the Rasch parameters for Items 1 and 2 are estimates, it is clear that these items are similar in difficulty, with item difficulty parameters of -7.56 and -7.52, respectively. Item 3 is much more difficult with an item difficulty parameter of -4.47. For hearing impaired students, a different pattern can be noted: 80% of the students in the hearing impaired sample answered Item 3 correctly, while only 62% answered Item 2 correctly. In fact, Item 2 is the fourth most difficult item for hearing impaired students.

Item 8 is another highly discrepant item, showing a proportion correct at chance level for hearing impaired students. Twenty-five percent fewer hearing impaired students answered Item 8 correctly than answered any other item correctly, indicating that it was, by far, the most difficult item.

Table 2 displays the correlations between the items and total score. While Items 1 through 6 (the teacher-dictated items) show fairly high correlations with the total score, Items 7 through 9 (the student-read items) do not. Item 8 has an especially low correlation with the total raw score. To the extent that the total score represents a more valid measure of student ability in this area than do the individual item scores, the dictated items are more valid than are the student-read items.

<u>Factor Analysis</u>

An important assumption of the Rasch model is that a set of items, in order to be considered a valid measure of a certain skill or trait level, should be explainable in terms of a single factor. To explore whether this assumption was satisfied, the data were factor analyzed. Table 3 presents the results of this analysis using a principal components solution. This table reveals that the communalities for some of the items are quite low, i.e., a large proportion of variance of these items is unexplainable by either of the two factors that were generated. This is especially true for Items 2, 8, and 9. For Item 2 over 70% of the variance is unique to the item. For Items 8 and 9, over 80% of the variances are unique.

There is some evidence that the second factor might be important. The eigenvalues show that 20% of the total item variance accounted for by the first two factors can be attributed to the second factor. (Twenty percent is the ratio of .57, the eigenvalue for the second factor, to 2.85, the sum of both eigenvalues.)

To interpret the second factor, the principal components solution was rotated using Varimax rotation. This rotational procedure was selected to maximize each item's loading on only one of the two factors (Nie, Hull, Jenkins, Steinbrenner, & Bent, 1975). The results of this rotation appear in Table 4.

Items 7 and 8 showed the highest correlations with the second factor. Indeed, the rotation yielded, for Item 8, a .00 loading on the first factor. Item 8 requires student to select the response waited, as opposed to in the theater, movie, and chuckling when asked to choose the best word or group of words to complete the sentence, "The audience ________________." The pattern of errors for Item 8 reveals that 46% of the students responded in the theater to this item. Additionally, the data showed that only 38% of the students who scored 8 out of 9 on the test got Item 8 correct. These students, who were able to answer all other items correctly, were misled by the foil in which there was an obvious association between audience and theater. Item 7 is also highly representative of Factor 2 with a .63 loading. For Item 7, students were required to respond august, as opposed to dinner, holiday, or church when asked which of the set of words should be capitalized.

Items 7 and 8 measure different skills (Capitalization and Sentence Completion), yet they both have high loadings on the second factor. Items 1 through 6 were dictated to the students while Items 7 through 9 required students to read and respond on their own. Perhaps the reading requirement constitutes the second factor. If so, then it is a bit perplexing why Item 9 (which tests alphabetization skills) does not have a high loading on the second factor since it, along with Items 7 and 8, required that students respond without teacher assistance.

It is possible that Item 9 does not require the same degree of reading skill as do Items 7 and 8; Item 9 requires students to respond fact, as opposed to feet, fear, or fable when asked which of the four words would come immediately after the word face in alphabetical order. For hearing impaired students, Item 9 was the easiest of the three student-read items. Perhaps some students selected the correct answer without reading and understanding the intent of the question simply because fact bears the closest graphemic similarity to face which appears in quotation marks in the item string. This explanation is speculative, but would account for the low communality of Item 9 and the unexpected higher proportion of students answering Item 9 correctly.

It is interesting also to note that Item 2, which requires no reading, had a .33 loading on the second factor. Students are required to respond by marking a picture of a shoe as opposed to pictures of a box of popcorn, a candy cane, or a lollipop when asked which picture does not belong with a picture of an ice cream cone. This item, which is very easy for hearing students, is the fourth most difficult item for hearing impaired students. Reading ability is therefore not the only underlying component which describes the second factor. The data suggest that the ability to place objects into categories and make judgments regarding category membership is also a component.

Discussion

In situations where tests, which have been developed through Rasch modelling procedures with hearing students, are given to hearing impaired students, much attention needs to be directed at both the specification of the skill and the format of the items. The analyses performed in this study show that the items, when ordered by difficulty level for hearing impaired students, imply a different sequence of skill development than do the Rasch difficulty parameters for hearing students. Other evidence shows that a factor can be extracted which may relate significantly to item format.

One of the major advantages of the Rasch model is that inferences can be made about a student's ability to perform certain tasks without assessing those tasks directly. For example, it can be assumed that students who can perform 2-digit multiplication can also perform 1-digit addition and subtraction. Such inferences are only valid in cases where there is confidence related to the sequencing of the skill development. The current study has sown that such confidence is questionable when skills and traits defined for hearing students are assessed for hearing impaired students using Rasch item difficulty parameters developed for the hearing group.

Hearing impaired students had a difficult time with the categorization task in Item 2. Likewise, high scorers on the test were as easily misled as low scorers into choosing <u>in the theater</u> as the best response for "The audience ----" in a sentence completion task (Item 8). It is not the purpose of this paper to propose theoretical statements about the cognitive development of hearing impaired students which would lead to the pattern of responses evidenced by the current data set. However, it seems clear that the effective testing of hearing impaired students in various achievement areas is dependent upon a better understanding the development of their cognitive abilities.

The second issue addressed by the study, that of item format, is also crucial. Two different item formats were used in the current set of items. In one format students were required to read and answer the items without teacher assistance. In the other format, the test administrators dictated the item instructions to the students, who then selected the correct answer. In typical standardized testing situations, teachers do not dictate item instructions to students. Thus there may be a paradox with respect to the comparability of the test results between hearing and hearing impaired students. To maintain comparability testing procedures often insist that hearing impaired students read and interpret on their own those items which their hearing counterparts have had to read and interpret. The current data show that this requirement may undermine rather than facilitate comparability. If the development of reading skill lags behind the development of the skill that is being assessed, then it is possible that students will be unfairly assessed when required to read items on their own.

The data did not conclusively indicate a reading format factor, however. Item 9 posed less of a problem for hearing impaired students and correlated with the second factor to a much less degree than did the other student-read items. It was suggested above that some hearing impaired students may have overcome a lack of reading skill in this item by focusing on the formal similarities between <u>fact</u> and <u>face</u>. Much research is needed which explores the possible strategies that individuals use in responding to test items. When lack of reading skill precludes the full understanding of an item, it is probable that students adopt strategies which systematically influence their chances of getting the item correct.

Item format and skill sequence have been discussed as if they had independent effects on the observed pattern of test results. Of course they interact, and it is not totally clear from the data when item formatting problems have produced the observed results and when skill specification problems have. Item 2, for example, may have been the fourth most difficult item because of its format and not because hearing impaired students have problems with categorization tasks *per se*. Indeed, item formatting itself could explain the discrepancy between the order of Rasch item difficulty parameters and the observed problems. However, the need for extreme care in defining appropriate skill hierarchies for hearing impaired students is not negated by that possibility.

Comparability of test results is obviously desirable from an educator's point of view. The current study has explored a set of test data and has identified factors which can mitigate against comparability. Vast amounts of research are needed in both areas discussed: skill specification and item format. Ironically, "comparable" item formats may not prove to be "same" formats, and skill continuums may need to be redefined for hearing impaired students.

References

Allen, T.E. and Karchmer, M.A. Influences on academic achievement of hearing impaired students born during the 1964-65 rubella epidemic. Directions, 1981 (in press).

Jensema, C. The relationship between academic achievement and the demographic characteristics of hearing impaired children and youth. Washington, D.C.: Gallaudet College, Office of Demographic Studies, 1975.

Nie, N.H., Hull, C.H., Jenkins, J.G., Steinbrenner, K., and Bent, D.H. Statistical package for the social sciences. New York: McGraw Hill, 1975.

Rasch, G. Probabilistic models for some intelligence and attainment tests. Copenhagen: Denmarks Paedagogiske Institut, 1960.

Ries, P., Trybus, R., Siepelli, P., and Buchanan, C. Further studies in achievement testing, hearing impaired students, United States: Spring, 1971. Series D, Number 13. Washington, D.C.: Office of Demographic Studies, Gallaudet College, 1973.

Trybus, R. and Jensema, C. The development, use, and interpretation of the 1973 Stanford Achievement Test, Special Edition for Hearing Impaired Students. Report of the Proceedings of the Forty-Seventh Meeting of the Convention of American Instructors of the Deaf. Greensboro, N.C., June 22-27, 1975, 73-78.

Trybus, R. and Karchmer, M. School achievement scores of hearing impaired children: National data on achievement status and growth patterns. American Annals of the Deaf Directory of programs and Services, 1977, 122, 62-69.

Wright, B.D. and Stone, M.H. Best Test Design. Chicago: MESA Press, 1979.

Footnotes

1. The tests are now part of a battery of tests known as the System for Comprehensive Assessment of Learning Experiences (SCALE), published by Intran Corporation, Minneapolis, Minnesota.

2. Not all programs for the hearing impaired use the same communication mode. Some programs emphasize the use of speech reading and speech production in the instructional setting. Other programs use sign language methods in conjunction with speech.

TABLE 1

Comparison of Rasch Item Difficulty Parameters Determined for Hearing Students and Proportion Correct for Hearing Impaired Students

Item	Rasch Difficulty Parameters	S.E.	Prop. Correct for HI N=1447	Item diff. rank for HI
Dictated items				
1. Letter Recognition	-7.56	*	.96	1
2. Compare/Contrast	-7.52	*	.62	
3. Sentence Completion	-4.47	.147	.80	3
4. Plural Forms	-3.91	.249	.82	2
5. Punctuation	-3.04	.033	.79	4
6. Apostrophe	-2.00	.029	.67	5
Student Read Items				
7. Capitalization	-1.87	.059	.43	8
8. Sentence Completion	-0.78	.098	.24	9
9. Alphabetizing	-0.23	.078	.50	7

*Parameters for Items 1 and 2 are estiamtes; they wre drawn from a different item bank from which the other items were drawn. Standard errors are not available.

TABLE 2

Item to Total Score Correlations

	Item	r
1.	Letter Recognition	.73
2.	Compare/Contrast	.57
3.	Sentence Completion	.71
4.	Plural Forms	.61
5.	Punctuation	.72
6.	Apostrophe	.64
7.	Capitalization	.51
8.	Sentence Completion	.29
9.	Alphabetization	.37

TABLE 3

Factor Matrix-Using Principal Components Solution

Item	Factor 1	Factor 2	Communality
1. Letter Recognition	.45	-.40	.36
2. Compare/Contrast	.52	.08	.28
3. Sentence Completion	.63	-.08	.40
4. Pural Forms	.53	-.16	.30
5. Punctuation	.64	-.11	.42
6. Apostrophe	.59	.03	.35
7. Capitalization	.46	.46	.42
8. Sentence Completion	.22	.37	.19
9. Alphabetization	.33	.11	.12
Eigenvalues	2.28	.57	

TABLE 4

Factor Matrix-Using Varimax Rotation

Item	Factor 1	Factor 2
1. Letter Recognition	.56	-.12
2. Compare/Contrast	.41	.33
3. Sentence Completion	.59	.24
4. Pural Forms	.54	.12
5. Punctuation	.61	.22
6. Apostrophe	.50	.32
7. Capitalization	.17	.63
8. Sentence Completion	.00	.43
9. Alphabetization	.23	.26

Appendix

Locator Test of Language Arts

(Note: Teacher-read directions appear in italics.)

Open your test. Look at the box with a star in the corner. Put your pencil on the circle under the picture of a book. Fill in the circle. Mark all your answers this way. (Check that this is understood.)

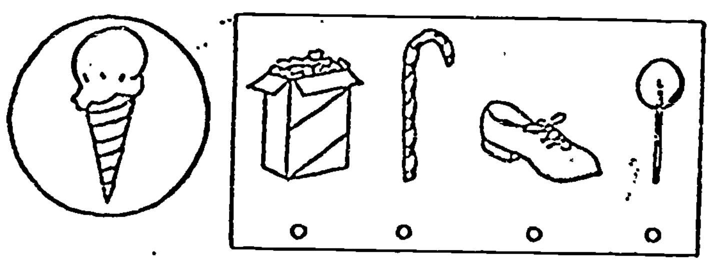
Find number 1. Look at the letters. Find "r".

1

r	s	l	o
o	o	o	o

Find number 2. Look at the picture in the circle. Now look at the pictures in the box. Which one is different from the picture in the circle? (If the student does not understand, say: "Which one does not go with the picture in the circle?")

2



Find number 3. Read the sentence and find the right word.

3

Please place ______ books here.

- o your
- o grow
- o far
- o yes

Find number 4: Read the words in the box. Which word means many things? (If the student does not understand, say..."Which word means more than one thing?").

4

bed	book	ball	birds
o	o	o	o

Find number 5: Read the sentence. Look at the box with the pictures. Which one goes at the end of the sentence?

5

Mother went to the store

?	.	,	!
o	o	o	o

Find number 6: Read the sentence. Look at the words under the sentence. Which word is right?

6

The umpire ________ want to postpone the game because of rain.

- o did'nt
- o didn't
- o didnt'
- o didnt

Turn the page. For numbers 7, 8, and 9, read the directions to yourself and find the right answer. Turn the test booklet over when you finish. If you do not know a word, skip it and go on. I cannot help you. Are there any questions? You may begin.

THE NEXT THREE ITEMS ARE TO BE READ BY THE STUDENT AND ANSWERED WITHOUT TEACHER ASSISTANCE.

7 Which word should be capitalized?

- O dinner
- O holiday
- O church
- O august

8 Choose the best word or group of words for this sentence.

The audience ________.

- O in the theater
- O waited
- O movie
- O chuckling

9 Which word would come immediately after the word "face" in alphabetical order?

- O feet
- O fact
- O fear
- O fable

ACKNOWLEDGEMENTS

Work of this scope would not have been possible without the hard work and cooperation of many individuals and organizations. The investigators would like to acknowledge these varied contributions.

The memory experiment was the result of collaboration of many people. D. Wayne Mitchell did much of the software development for the equipment, designed the computer artwork, and conducted several of the experimental sessions. Don Gilliland made modifications of the hardware and did much of the machine-language programming. Peter Belmont provided program design consultation. Tamara Osborne conducted the experimental sessions with the deaf children. Linda Petersen and Robert Mulcahy were involved in the pilot projects that led to the reported experiment. The professional staff at the Kansas State School for the Deaf (particularly audiologist Tom Porter), at the Department of Research at the Shawnee Mission, (Kansas) Public Schools, and at the Model Secondary School for the Deaf in Washington, D.C., are to be thanked for their cooperation.

The "Stroop" experiment was made possible by the use of equipment and facilities of Gallaudet College Research Institute's Sensory Communication Laboratory, James Pickett, Director. Fred Brandt and Gene Herbert provided both software and hardware support. Tamara Osborne conducted many of the experimental sessions. Thanks are also due to many Gallaudet students, staff, and faculty who participated as subjects.

The "Test Response Variation" study was also made possible by the contributions of many people and organizations. The contributions of Dr. Mardel Kolls of the Los Angeles County Test Development Center are gratefully acknowledged. Dr. Kolls developed the materials and helped modify them for hearing impaired students. She also provided comments on the manuscript, as did Arthur Schildroth. The Services for the Deaf, Texas Education Agency, provided invaluable support and encouragement. Finally, we recognize the efforts of the personnel at 39 participating programs.

Finally, the investigators wish to thank Sally O'Rourke for the administrative support services she provided during the term of the project. To Sue Hotto, Gail Ries, Vivian Stevens, and Hank Young go sincere thanks for their hard work in the preparation of this manuscript.