SERIAL ORDER PERCEPTION OF PRESCHOOL CHILDREN IN THREE SENSORY MODES

by

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ABSTRACT

Clinical work with learning disabled children (Hardy, 1965; Boder, 1973) has suggested that these children have difficulty perceiving and producing items in correct sequential order. Previous research has not, however, indicated clearly whether deficits in serial order (sequential) perception are unitary and affect all sensory modes or are specific and affect sensory modes differentially. The following study tests serial order perception in three sensory modes; vision, audition, and touch, and provides evidence for specific independent serial order perception in different sensory modes. Twenty-seven preschool children were required to indicate the correct order of stimulus presentation for a series of trials in three sensory modes and their best scores were recorded. Most correlations between the scores in different sensory modes were nonsignificant lending support to the hypothesis that serial order perception is modality specific.

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DEDICATION

I wish to dedicate this work to my family, and especially to my wife, Margaret. Without their patience and encouragement this work would not have been possible.

INTRODUCTION

THE IMPORTANCE OF SERIAL ORDER/SEQUENTIAL BEHAVIOR

Lashley (1951) argued convincingly that temporal integration is a basic requirement for "the logical and orderly arrangement of thought and action". Temporal integration refers to the perception and organization of stimuli into a serial order based upon the dimension of time. Lashley stated further that not only is the perception of serial order of prime importance but that the translation of perceptions into behavior is dependent upon an ability to organize behavioral units into a serial order. Effective behavior more complex than reflexes depends upon temporal serial ordering.

Language, being either the behavior which allows thought to be expressed, or the behavior which allows thought to develop (Vygotsky, 1962), depending upon one's theoretical point of view, is dependent upon temporal integration. Both spoken and written language depend upon orderly, predetermined sequences of behavior. If verbalizations are produced without reference to the correct sequence of phonetic elements, understanding is impossible. In written language the orderly arrangement of graphemes is of primary importance, and in both verbal and written language the syntax, an order imposed upon the individual words, allows meaning to be carried by what would otherwise be only a random collection of either auditory patterns or visual images. Using writing as an example of a language behavior one can see that it requires serial organization in two ways. First, the internal production of language is dependent upon the production of orderly sequences, and second, the external motor behavior of writing requires the serial production of fine and gross motor movements.

The development of memories is also dependent upon ordering serially, and if the method and manner of reproducing material can be taken as evidence of the underlying storage processes, then it seems that memory is stored in a temporal, serial organizational framework. (Hilgard, Atkinson and Atkinson, 1979) By implication then most learning is based upon the ability to sequence events correctly.

Memory, language, and skilled behavior all presuppose an ability to order events effectively in a serial manner. Accepting this we must conclude that complex human behavior is dependent upon intact sequencing abilities.

Das, Kirby and Jarman (1975) have provided a survey of relevant empirical studies testing the pervasiveness of the successive mode of cognitive functioning. Based upon Luria's theory of simultaneous and successive synthesis, Das and his colleagues have demonstrated by factor analytic methods that across cultures, across ages, and across social classes the same cognitive structure exists in individuals. This cognitive structure consists of three factors. One factor is the speed of cognitive functioning. One is the mode of simultaneous processing and the other is a successive processing mode. Successive processing or synthesis is serial ordering. Other researchers (Bogen, 1969; Cohen, 1973; Taylor, 1976) have found the same basic cognitive structure (although the terms may vary eg. serial and parallel as opposed to successive and simultaneous). Processing in sequence is a basic function of the human cerebral hemispheres, and is orthogonal to, or independent of, both speed of processing and simultaneous processing.

LANGUAGE AS SERIAL ORDER BEHAVIOR

The Left Hemisphere: Language and Sequencing

The majority opinion since the observations of Dax, Broca, Wernicke, and others in the nineteenth century has been that the left hemisphere is responsible for receptive and expressive language. (Geschwind, 1974) This view has been subject to minor revisions since that time; Hughlings Jackson's observations that automatic and emotional language are also present in the right hemisphere, the observations of crossed aphasia, and most recently Gazzaniga and Sperry's (1967, 1970) observations of limited right hemisphere language in split brain patients. Irrespective of these dissensions from orthodoxy, we can still say that in the majority of people the major portion of language expression and understanding is a function of an intact left hemisphere.

Recent evidence has suggested that sequencing abilities are intimately bound up with language abilities. Bannatyne (quoted in Bakker, 1972) points this out when he states "...language is almost entirely an auditory sequencing process, and I would go so far as to say that a specific language disability could be redefined as a specific auditory sequencing disability". Arthur Benton (1961), in a discussion of the Gerstmann syndrome, concluded that in addition to the four behavioral deficits comprising the syndrome; right-left disorientation, acalculia, agraphia, and finger agnosia; aphasia and dyslexia are often accompanying symptoms. These symptoms can all be signs of left parietal lobe dysfunction and, in addition, all contain some component of sequencing. In a later paper, Benton (1964) discussed developmental aphasia and concluded that there exists a group of children who do not learn to express and/or understand language and whose disability cannot be explained without reference to abnormal brain development or functioning. Often the evidence points to bilateral damage/dysfunction but on occasion only the left hemisphere is implicated. Clinical reports (Monsees, 1961; De Quiros, 1964; Hardy, 1965; Boder, 1973; Tallal, Stark and Curtiss, 1976) emphasize that these same children suffer from poor sequencing abilities.

Robert Efron (1963a, b, c) has attempted to delineate the cerebral location for the perception of simultaneity and temporal order (receptive sequencing). In the first study of the series (1963a) Efron hypothesized that temporal discrimination is determined by comparing the input from one side of the body to the input from the other side. Further, it is only after the sensory information from the left side of the body (right hemisphere) is transferred to the left hemisphere (the hemisphere dominant for speech) that the comparison is made. In other words, the point where sequential events are perceived is in the hemisphere dominant for speech (the left hemisphere for most people, but the right hemisphere in a small percentage). The results of Efron's study are in accord with his hypothesis and Efron reviews earlier literature which reported similar findings: however, without Efron's hypothesis these findings had been overlooked. Another of Efron's studies (1963b) demonstrated that reducing the intensity of a stimulus delayed its conscious perception and that the nervous system does not take stimulus intensity into account when judging the temporal order of two events. The third study (1963c) used hospitalized patients as subjects rather than university students. The experimental group consisted of eleven patients with left hemisphere lesions and some degree of aphasia. The control group consisted of four patients with right hemisphere lesions and one patient with a left hemisphere lesion, none of whom were aphasic. Two tasks were used. The visual task required the reporting (verbally or nonverbally) of which of two lights flashed first. The auditory task used the same protocol. All aphasic patients were impaired to some degree on both tasks, however the expressive aphasics were more seriously impaired on the auditory sequence while the receptive aphasics were more seriously impaired on the visual sequence discrimination task. The patient without aphasia but with a left hemisphere lesion was unimpaired on both tasks. Efron concludes; 1) disturbances in the discrimination of a temporal sequence are correlated with lesions of the hemisphere dominant for speech, 2) disturbances in the discrimination of temporal sequences are correlated with some degree of aphasic disorder, 3) expressive aphasia, correlated with anterior lesions, is correlated with more severe auditory sequencing difficulties, and 4) receptive aphasia, correlated with posterior lesions, is correlated with more severe deficits in visual sequencing abilities. Swisher and Hirsh (1972) studied receptive aphasics and do not support Efron's findings. Their research indicates equally severe deficits in both visual and auditory sequencing. Tzortzis and Albert (1974) reported similar results with conduction aphasics. They found an impaired ability to reproduce the sequence of items even when all the items could be correctly recalled. "This was true whether the material was verbal or non-verbal, whether the modality of input was auditory or visual, and whether the response was oral or by pointing." (p. 357)

The subjects in Efron's, Swisher and Hirsh's, and Tzortzis and Albert's studies were adults. Bakker (1972) reports results obtained with children and his findings are not in total agreement with the results reported for adults. Fedio and Mirsky (1969, reported in Bakker, 1972) studied children with unilateral epileptiform discharges that were localized in either the right or left temporal lobe. The test battery used consisted of auditory- and visual-verbal and -nonverbal tasks. Their results suggest that dysfunction of the right temporal lobe interferes with nonverbal temporal sequencing whereas left temporal lobe dysfunction impairs ability more in verbal temporal discriminations. Bakker's studies with dyslexic children indicate that the perception of temporal order is not mediated exclusively by one or the other hemisphere, but instead depends on the nature of the task. He and his colleagues have determined that sequencing tasks of a verbal or meaningful (nameable) nature are primarily processed by the left hemisphere but that nonverbal or meaningless (unnameable figures) temporal ordering tasks are mediated by the right hemisphere. Furthermore, according to Bakker, it is only tasks which demand ordering of verbal and/or meaningful material which differentiate between above and below average readers.

Continuous Categorical Dichotomy in Speech Perception

In a series of experiments culminating in 1962, Fry and his colleagues (Fry, Abramson, Eimas and Liberman, 1962) found that the perception of vowels is different than the perception of consonants. Using computer synthesized variations of the stop consonants "b", "d", and "g" a range of stimuli were developed by systematically varying the second formant (F2) of the phoneme. The result was a series of stimuli, with equal interval changes, that ranged from "b" through "d" to "g". Subjects did not perceive a stimulus midway between two consonants as being a combination of the two but instead rigidly classified the stimulus as either "b", "d", or "g". Vowels, on the other hand, were found to be perceived on a continuous dimension. Using the same technique of systematically varying the stimuli, it was found that there was no evidence of discontinuities in the discrimination functions at the phoneme boundaries. In point of fact, subjects heard vowels continuously but consonants categorically. When the consonants and vowels were placed in context, differences in perception were also noticed. The perception of consonants was only slightly affected by the immediately preceeding or immediately following sound. If consonants are perceived in sharply marked categories, then it is reasonable to assume that the temporal sequence would have little effect on the perception of the sound. The data are in accord with this deduction. Vowels are affected to a much greater degree by context. It appears that the listener is strongly influenced in the perception of a vowel by the immediately preceeding phoneme. The vowel is compared to earlier sounds and if vowels are heard in a continuous manner, then this finding that contextual effects occur seems reasonable.

More recent work by Fujisaki and Kawashima (1970) indicates that the degree of categorical perception is directly related to the rate of formant transition. Their results show that it is the duration of presentation that, to a large degree, determines whether the stimulus is coded categorically or continuously. By artifically varying the duration of speech sounds it was found that isolated vowels are perceived in a more categorical manner as the duration is decreased, context increases categorical discrimination of vowels but not of fricatives, and voiced stops are perceived in a much more categorical manner than either vowels or fricatives. The distinguishing feature between these three classes of phonemes is that vowels and fricatives maintain a constant frequency over the total duration of the sound, whereas voiced stop consonants are characterized by their temporal variation. The duration of vowels can be varied arbitrarily but it is impossible to vary the duration of consonants arbitrarily. It is the very rate of change in voiced stops which characterizes their phonetic quality. What these researchers determined was that making a vowel more consonant like (increasing the temporal variation and shortening the duration) increased the categorical perception of that vowel.

Cutting and Rosner (1974) carried the exploration of temporal variation and duration in sound further. They synthesized both speech and music sounds and demonstrated that categorical perception is dependent upon the dimension of rise time. In other words, categorical perception is not limited to speech sounds, and the dimension of rise time cues perceptual categorization of sound.

Dichotic Listening

Dichotic listening occurs when different stimuli are presented simultaneously to the two ears. Doreen Kimura has used dichotic listening tasks extensively with both normal and brain damaged populations. Kimura (1967) has found that digits are more accurately reported from the right ear than from the left ear, and that damage to the left temporal lobe impairs performance on this task. The crossed auditory pathways are more effective than the uncrossed at transmitting sound to the brain for analysis and Kimura's results are further evidence pointing to left hemisphere dominance for speech decoding. Testing children, Kimura found the right ear advantage (REA) for digits was present in 5 year old girls but didn't appear in boys until 6 years of age. Kimura also found that melodies show a left ear advantage (LEA), indicating right hemisphere dominance for the perception of music.

A number of researchers concluded that encoding was the essential feature of speech which produced the REA.

However, as the research continued, it was found that stop consonants produced an REA but vowels did not. These results, combined with the findings on continuous and categorical perception of speech sounds, produced a number of hypotheses concerning the necessary conditions for the REA to occur. Haggard (1971) and Haggard and Parkinson (1971) constructed a number of experimental tasks designed to evaluate these different hypotheses. In one series of experiments these researchers produced an LEA for stop consonants and an REA for vowels, the reverse of the usual result, by varying the instructional set of the subject. In later experiments an LEA for the emotional tone of dichotically presented sentences was obtained. These results taken together would suggest that the total perceptual set is the important factor in producing ear advantages, not the purely acoustical attributes of the stimuli. By inducing a linguistic, sequential, analytic set an REA can be demonstrated for many different types of auditory material.

Haggard's results have been questioned. Day and Vigorito (1973) using a temporal ordering task, and Cutting (1973) using an identification task, both produced ear advantages paralleling the degree of encodedness of the phonemes. In both cases it was found that stop consonants, the most highly encoded speech sounds, produced the largest REA, while vowels, the least encoded speech sounds, produced either no ear advantage or a slight LEA. Liquids produced a slight right ear advantage and are midway on the continuum of encodedness. In other words, a linear relationship between the degree of encodedness and the direction and degree of ear advantage was demonstrated. It seems that certain aspects of the stimuli may be a powerful source for producing differential ear scores in the dichotic listening task, but in some situations the power of the stimulus can be overcome by the induced perceptual set. This finding is in accord with Kinsbourne's notions of priming and attentional set. (Kinsbourne and Smith, 1974)

However, Spellacy and Blumstein (1970) found that certain aspects of the stimulus are sufficiently powerful to overcome an induced attentional set. In a dichotic listening experiment these researchers created two groups; a language expectancy group and a nonlanguage expectancy group. Using a series of CVC syllables with either vowel or initial consonant differences they found a right ear advantage for consonants in both groups. It seems that the consonant aspects of the stimulus overcame an induced set (nonlanguage) shown in the past to favour a left ear advantage. As well, these researchers found that language expectancy improved right ear recognition of vowels but did not correspondingly diminish left ear performance. Citing other research, Spellacy and Blumstein argue for a left hemisphere mechanism, activated by language sounds and language expectancy, that is particularly sensitive to the higher speech frequencies more commonly found in consonants than vowels.

Halperin, Nachshon and Carmon (1973) followed up the studies showing categorical perception of sound for stimuli containing frequency or duration transitions, and the studies which showed an REA for stop consonants but not for vowels, by varying the complexity of temporal patterning of pure tones in a dichotic listening task. These researchers conducted two tests, one in which the number of frequency transitions was varied, and one in which intrastimulus duration was varied. In both cases, when no transitions within the stimuli took place a slight LEA occurred, but as the number of transitions increased there was a marked shift to an REA. The authors concluded that the left hemisphere is specialized for the perception of verbal stimuli, for the processing of temporal patterns of auditory stimuli, and therefore, for the sequential analysis of acoustic stimuli.

A series of experiments comparing relative ear advantages, using two different types of auditory stimuli, obtained results supporting the hypothesis of two separate mechanisms in the left hemisphere for speech and auditory perception. Cutting (1974) synthesized speech sounds and sine waves. The sine waves were of the same duration and frequency, and contained the same number of transitions as the speech sounds. He demonstrated an REA for the sine waves and a larger REA for the speech sounds. The REA for the sine waves suggests that the left hemisphere contains some mechanism which processes the complex acoustical aspects of the speech signal. This mechanism appears to be strictly auditory. It functions independently of speech perception. A second mechanism is postulated to account for the larger REA obtained with speech signals. This second mechanism, unlike the first, does differentiate between phonetic and non-phonetic transitions in sound, and is specialized for the detection of speech sound transitions.

These studies provide clear evidence that speech perception is dependent upon serial ordering but do not clearly indicate whether serial ordering is an aspect of speech perception or whether serial ordering is a function of the left hemisphere, involved in speech perception, but independent of it.

SERIAL ORDER BEHAVIOR IN ATYPICAL INDIVIDUALS (KNOWN OR PRESUMED BRAIN DYSFUNCTION)

Visual Sequencing

A number of studies have investigated the visual sequencing abilities of aphasics. Withrow (1964) tested aphasic, deaf and normal children on the recall of items presented visually. The items were presented either simultaneously, or sequentially at one of four different rates. All groups performed equally well when the items were presented simultaneously, but the deaf and aphasic groups performed significantly poorer than the normals when the items were presented sequentially. Tallal and Piercy (1973b) found, however, that aphasic children were not impaired in relation to normal children on a visual sequencing task. The task they used consisted of deciding which of two lights was flashed first, and then pressing a corresponding button to indicate the choice. Two studies of adult aphasics indicate that visual sequencing problems are correlates of traumatic aphasia. Efron (1963c) found that both receptive and expressive aphasics were impaired in the ability to determine which of two lights flashed first, and the receptive aphasics were more seriously impaired than were the expressive aphasics. Tzortzis and Albert (1974) studied the serial order disabilities of conduction aphasics. The performances of the conduction aphasics were compared to motor expressive aphasics, sensory receptive aphasics and to normal controls. A visual sequence was presented and the subjects were asked to indicate the order either orally or by pointing. When an oral report was requested the conduction aphasics were poorer than the control aphasics and the normal controls, but when the response demanded was pointing out the correct sequence all aphasic subjects performed more poorly than the normals.

The visual sequencing abilities of children with reading problems has also been investigated. Temporal sequences of letters, digits, meaningful figures, and meaningless figures were presented to two groups of poor readers. (Bakker, 1967) One group was two years behind the population norms in reading and the other group four years behind. The more severely reading retarded group performed significantly worse than the moderately reading retarded group when the stimuli were letters or meaningful figures (ie. easily nameable). No differences appeared with the meaningless figures and only a slight difference occurred with the digits. Weiner, Barnsley and Rabinovitch (1970) used a modified version of the Gaddes Dynamic Visual Retention Test (Gaddes, 1967) with Grade Four students. These researchers found no differences between poor and average readers in their ability to remember sequences of lights (meaningless figures). However, they suggest that faster stimulus presentation speeds may differentiate between average and poor readers. Zurif and Carson (1970) compared the performances of normal readers to the performances of dyslexic children on a task requiring the temporal analysis of flashing lights. A temporal sequence of lights was presented, then a second sequence was presented and the child was asked whether the two sequences were the same or different. Dyslexic children made significantly more errors than normal children. Corkin

(1974) also found that inferior readers performed poorly on a visual sequencing task. Five blocks were set on a table between the experimenter and the child. The experimenter touched each of the blocks, in a different order for each trial, and the child responded by touching each of the blocks in the same order (the Knox Cube Test). Gaddes and Spellacy (1977) found that reading ability in normal Grade Two and Grade Five children, as measured by the Wide Range Achievement Test and The Canada Test of Basic Skills, is correlated with visual sequential abilities.

Auditory Sequencing

Aphasic children have been found to be impaired in the perception of the temporal order of auditory stimuli. Lowe and Campbell (1965) presented two identical tones one after another and varied the time gap between the sounds in order to determine the minimum time separation needed to perceive the sound pulses as two sounds rather than one. Aphasic children performed this task as well as normal children, but when two different sounds were presented at varying intervals and the task was to determine which sound occurred first, the normal children performed significantly better than the aphasics. Stark

(1967) used the Illinois Test of Psycholinguistic Abilities (ITPA) to test aphasic children and found that they were most impaired on the Auditory-Vocal Sequencing subtest. The mean performance of the aphasics was more than two years below their chronological age. Tallal and Piercy (1973a, b) presented two different sounds sequentially and the subjects (aphasic and normal children) were then asked whether the pattern was the same as or different from a probe pattern presented immediately afterward. The aphasic children made more errors than the normal children. In another experiment the same two sounds were presented sequentially in patterns consisting of up to five elements. In this case, the response consisted of matching the presented pattern by pressing, in order, two buttons previously taught to correspond to the two sounds. The results indicated that as the duration of each sound element decreased, and as the interval between elements decreased, and as the number of elements in the sequence increased the aphasics' performance decreased. The control subjects, on the other hand, were not adversely affected by any of the above mentioned parameters. The most complex task, as determined by the aphasics' difficulties, was not sufficiently difficult to produce any increase in the error rate for the normals. In a later series of studies (Tallal and Piercy, 1974, 1975) synthetic vowels and consonants were presented to aphasic and normal children using the same protocol as used in their previous studies. Each phoneme was kept to a total duration of 250 milliseconds. Four types of phonemes were used; 1) steady state vowels with a duration of 250 msec., 2) stop consonant-vowel syllables in which the consonant duration was 43 msec. and the vowel duration was 207 msec. (this is as the C-V syllables are said in normal speech, e.g. "ba" and "da"), 3) vowel-vowel syllables in which the first vowel lasted 43 msec. and the second 207 msec., and 4) consonant-vowel syllables in which the duration of the stop consonant was artificially extended to 95 msec. while the complete utterance was maintained at 250 msec. (it is not possible to extend the consonant to 95 msec. in speech by speaking slowly). Aphasics were unimpaired in the perception of the steady state vowels and the C-V syllables with the consonant extended to 95 msec., however, on the other tasks the aphasic children were significantly impaired in relation to the control children. It was concluded that the aphasic children were impaired in the ability to discriminate rapid sequential auditory stimuli, but not in the detection of transitions, provided the transitions themselves were of a relatively long duration. A comparison between the aphasics' performance and the performance of younger normal children revealed that 8½ year old aphasic children made significantly more errors than 4½ year old normal children. (Tallal, 1976) An analysis of the speech of aphasic children showed that those phonemes which present the most difficulty in perception, the stop consonants, are also the phonemes which these children find most difficult to produce. (Tallal, Stark, and Curtiss, 1976)

The deficits of adult aphasics on auditory sequencing tasks have also been investigated. Efron (1963c) reported that expressive aphasics were more severly impaired on a task requiring the specification of which of two sounds occurred first than receptive aphasics although both groups were significantly impaired when compared to non-aphasic brain damaged control subjects. Tzortzis and Albert (1974) found that sensory, motor, and conduction aphasics were all impaired on auditory sequencing tasks. If the material, either verbal or meaningful nonverbal stimuli, was presented in the auditory modality and an oral response was required then all aphasic subjects were impaired. If the response required was pointing, then all aphasics were impaired, and to a greater extent than when the response was oral. An error analysis showed that often the individual elements were correctly identified but were reported in an incorrect order. Swisher and Hirsh (1972) also found auditory sequencing deficits present in sensory receptive aphasics.

Dyslexic children have also been reported to be deficient in auditory sequencing skills. The rhythm subtest of the Seashore Measures of Musical Talents was used by Zurif and Carson (1970) to assess the auditory sequencing abilities of poor and normal readers. The dyslexics were significantly inferior to the normal readers in dealing with the temporal aspects of patterned nonverbal auditory stimuli. However, Weiner et. al. (1970) found the tonal memory section of the Seashore Test did not differentiate between normal and poor Grade Four readers. Gaddes and Spellacy (1977) used a similar task and found that it correlated moderately well with reading and arithmetic skills in normal Grade Five students, but not very well at all, with either skill, in Grade Two students. Corkin (1974) assessed auditory sequencing using a modified version of the Digit Span subtest of the Wechsler Intelligence Scale for Children (WISC) and found that normal readers were able to reproduce significantly longer strings of digits than the inferior readers. Both groups of readers improved with age and at a parallel rate. Owen, Adams, Forrest, Stolz and Fisher (1971) found that educationally handicapped (learning disabled) children were deficient in their ability to recall the order of, or to place in sequence, auditory stimuli. A signal detection analysis of auditory sequency discrimination was carried out by Doehring and Libman (1974). Their results indicate that the observed differences in auditory sequencing abilities between normal and deficient readers are not due to different styles of responding. The patterns of responding for both normals and poor readers were virtually identical.

Auditory-Visual Sequencing

Gerald Senf (1969; Senf and Feshback, 1970; Senf and Freundl, 1971) investigated immediate memory for bisensory stimuli in normal children, children with learning disorders (dyslexic), and culturally deprived poor readers. The task Senf used consisted of three sets of auditory and visual cues presented simultaneously. An auditory and a visual stimulus were presented simultaneously, and were followed by two further sets of audiovisual pairs. The time interval between stimulus pairs, and the method of recall varied. It was found that during undirected recall all children generally recalled the items in modality specific sets (ie. three visual followed by three auditory). Normal readers increased the number of items recalled as intermodal sets as their age increased. Neither the learning disabled nor the culturally deprived deficient readers showed this trend. When the children were directed to recall in audiovisual pairs the normal children and the culturally deprived children increased the number of elements recalled as pairs. The dyslexic children did not seem to be sensitive to this induced set: they did not increase the number of elements recalled as pairs. In both conditions normal children showed no preference for recalling one modality before the other. In other words, they were just as likely to recall an auditory item first as a visual item. The dyslexic children however, in both conditions, showed a strong preference for recall of the auditory items first. In general, the culturally deprived children behave in a manner consistent with the normal developmental pattern; ie. as a younger normal child. The behavior of the learning disabled children was qualitatively different from the behavior patterns of the normal children, and this implies that the dyslexic child is not simply suffering from maturational lag.

Visual-Motor Sequencing

The Visual Decoding, Visual-Motor Association, and the Visual-Motor Sequencing subtests of the ITPA were administered by Stark (1966) to a group of aphasic children. He found that the mean for the Visual-Motor Association subtest was only slightly below the mean for the general population but that the performances of the aphasic children showed a great deal of scatter (ie. from +2.00 standard deviations to -3.00). The aphasic children were most impaired on the Visual-Motor Sequencing sub-test, being on average over 1.5 standard deviations below the population norm. In a later study (Stark, 1967), three sequencing tasks were used to assess the performance of aphasic children. Again, the performance on the Visual-Motor Sequencing subtest by the aphasic group was significantly poorer than the population norm.

Poppen, Stark, Eisenson, Forrest and Wertheim (1969) used visual motor sequencing tasks and determined that reproduction of a spatial-temporal pattern of light flashes is slightly better in aphasic children than their memory for a series of auditory stimuli. These researchers also determined that performance suffered if a delay was introduced between perception of the sequence and the initiation of the motor response. Delay produced a greater decrement in performance for the aphasic children than for the control children. Poppen et. al. (1969) compared their results with the results of other researchers using different sequencing tasks and concluded that aphasic children suffer from a general sequencing deficit. Aphasic children are deficient in this ability and the deficit manifests itself with auditory and visual stimuli regardless of whether the required response is to be made orally or with motor behavior.

Tactual Sequencing

A finger localization task, as a measure of tactual sequencing ability, has been used with dyslexic children. Kinsbourne and Warrington (1963) found that there is a subgroup of dyslexic children whose performance on the finger localization task simulates the difficulties experienced by adult patients with Gerstmann's syndrome. Spellacy and Peter (1978) studied dyscalculic children identified as Developmental Gerstmann syndrome and found that "the presence or absence of the four Gerstmann behavioral elements does not describe a behaviorally homogeneous group" (p. 202) and therefore the utility of the concept of Developmental Gerstmann syndrome is questioned, but the dsycalculic children studied were all impaired in finger localization. Bakker (1972) reports a study in which two or three fingers were stimulated in temporal succession by a slight touch. The subjects' fingers were stimulated out of sight and the subjects were told to point out the order of stimulation on pictures of the two hands. Performance was better for the left hand in all children but in the dsylexic group the performance for the two hands was more nearly equal. This indicated to Bakker that the dyslexic children were less well lateralized than the normal children. In a second study, the children were asked to name the figures stimulated, in order, rather than to point them out. This task was performed better for the right hand and Bakker concludes that verbal temporal ordering is a left hemisphere function whereas nonverbal temporal sequencing is mediated by the right hemisphere. Weiner et. al. (1970) using a different measure of tactual sequencing found no difference between normal and poor readers.

SUMMARY

As can be seen by the variety of results reported no clear consensus has appeared regarding serial order performances in either typical or atypical populations. It does seem clear that serial ordering is essential for language, and that dominant hemisphere damage or dysfunction which affects language functions also affects serial ordering. However, it is not at all clear whether the serial ordering deficits are unitary or are modality specific. Tallal found that aphasics were selectively impaired on auditory sequencing tasks while Efron, Swisher and Hirsh, and Tzortzis and Albert found evidence of impairment in both visual and auditory modalities. In addition, Efron concludes that all serial ordering is carried out by the dominant hemisphere whereas Bakker concludes that verbal serial ordering is a dominant hemisphere function while nonverbal sequencing is carried out by the minor hemisphere.

Three major reasons for the disagreements may be; 1) population differences ie. Efron dealt with aphasic adults, Tallal with aphasic children, and Bakker with dyslexic children. 2) task differences--A great variety of tasks have been used by different researchers to assess sequencing abilities. Most, if not all, of these tasks involve other abilities besides sequencing and this may be a source of confounding in the results. 3) the small number of subjects used in many of these studies ie. Efron reported results for 11 aphasic adults, Tallal for 12 aphasic children, Tzortzis and Albert for 5 aphasic adults.

Regardless of the disagreements one thing does stand out. We can conclude that, in individuals who have dysfunctions of reading and/or writing and/or expressive language, sequencing difficulties are present. Sequencing difficulties interfere with the normal learning processes, and may result in impaired ability to read, write, and/or speak. But, again it is unclear whether the reported sequencing difficulties are related to specific areas of functioning or whether the sequencing difficulties are felt through all modalities. In an effort to determine whether serial ordering is a unitary function or modality specific the following study was conducted.

METHOD

SUBJECTS

Twenty-seven children were tested over a four week period. All children were in attendance at a college demonstration school used for the training of pre-school workers and were well known to the researcher. The research project was explained to all parents and staff at an evening centre meeting and consent was obtained from all parents. Every child in attendance at the centre was tested.

Thirteen subjects were male and fourteen were female. The age range of the children was from two years eleven months to four years eleven months with a mean age of three years ten and one-half months. Three children were left-handed, three children were non-Caucasian (one Chinese, one East Indian and one Japanese) and although the range of development was wide none of the subjects were identified as having special needs.

All the children lived in two parent families though some had spent some time as a member of a single parent family. Every subject, except one, had at least one sibling. Family backgrounds were predominantly middle class and all but two of the children spoke English at home.

Appendix A provides details regarding subject sex, age and handedness.

MATERIALS

A panel with three lights was constructed for the visual sequencing task. Three red Christmas tree lights were mounted in an unpainted plywood panel. Each light was independently controlled by push buttons mounted behind the panel. The apparatus is described in Appendix B.

The auditory sequencing apparatus was a modified xylophone. All notes but three were removed. The retained notes were c, c' and c".

The tactual sequencing test made use of a thirty centimeter square piece of nontransparent black cloth.

PROCEDURE

For a one week period the experimenter attended the centre on a daily basis and tested visual sequencing abilities. Each child was approached independently, when they were in transition from one activity to another, and asked if they would like to come with the experimenter to play a game. The experimenter and the subject then went to the centre office where a child-sized table and chairs were set up. The office is a private room separated from the rest of the centre. It is 3.6 meters by 4.2 meters in size. The subject could not see into the other centre areas from the office and sound from the centre was minimal.

The child sat opposite the experimenter and the visual sequencing apparatus was set up on the table between the subject and the experimenter. It was explained to the child that the lights would turn on one at a time and that after they went out the child was to tell or show the experimenter which light went on first, second, third, etc. A training and practice session, lasting from one minute to four minutes, occurred before the test. The practice session was terminated when the experimenter was convinced that the subject understood the task.

The test then proceeded with one light being turned on for a one second duration, followed by a one second gap and a second light being turned on for one second. The control of the presentation time and the intervals was manual.

The order of the lights in sequence was varied randomly. Random number tables were generated in advance, and the same tables were used for each child and for the visual, auditory and tactual presentations. In other words, the order of lights flashed in the two light sequence was varied randomly. However, the subject was not presented with any three light sequences until success on the two light sequence was demonstrated.

Success was judged as the correct indication of a sequence on two consecutive trials. Lack of success was judged as two consecutive errors in determining the correct sequence of presentation. The number of lights in the sequence increased until the child was unsuccessful and at this point the test was terminated and the child was invited to explore the apparatus and play with the buttons.

The auditory sequencing tests were conducted the following week. As with the previous test, each child was tested independently in the centre office.

The xylophone was placed on a shelf under the table, in front of the researcher, and out of the child's line of sight. A same-different procedure was used and the child was first trained to respond appropriately. Once the researcher was satisfied that the child understood the task the test was conducted. Tones were sounded with one second gaps followed by a second presentation three seconds later. The order of the tones was varied randomly as in the visual test. The correctness of the second set of tones was also varied randomly. The number of tones in the sequence was increased until the child was unsuccessful. The criterion for success and failure used in the visual test was used here as well.

The tactual testing was conducted during the third week. Again, the child was invited to play and was tested independently. The child sat opposite the experimenter and placed his/her hand palm down on the table. A black cloth covered the subject's hand and the experimenter reached under the cloth and touched the child's fingers with his right index finger. The subjects' index, large and ring fingers were used and both hands were tested. The order of hands tested was varied from one child to another, but the test for one hand was completed before moving on to the other hand.

The experimenter touched one finger for one second, followed by a one second gap and a second finger was touched for one second. After touching the child's fingers the cloth was removed and the child indicated the order in which the fingers had been touched. The method of indication used by the subjects was to point to or touch the stimulated fingers in order. The order of fingers touched varied randomly in the same manner as in the previous tests and the test continued until the child was unsuccessful. The same judgement of success and failure was used in this test as in previous tests.

The fourth week was used to test those children who had been absent for the previous tests or had refused to participate in the first round.

Pilot studies conducted with other children, prior to the testing, had demonstrated that same-different tests of visual and tactual sequencing were more difficult for this age group than a straight motor response indicating the order of presentation. However, motor responses to the auditory sequencing tasks were difficult to elicit and therefore a same-different test was used.

Handedness was determined by reference to the centre files. Included in the files were parental statements regarding the handedness of the child as well as observations by centre staff of the child. The files included observations of the preferred hand for holding a spoon, and a pencil and the use of right or left handed scissors for cutting.

RESULTS AND DISCUSSION

The question being asked in this study is whether sequencing or serial order perception is an ability specific to each sensory modality or a single ability which crosses all modalities. In an effort to provide evidence one way or the other, young children's perception of serial order was measured (see Appendix C for subjects' scores). If this ability is unitary as opposed to modality specific then high significant correlations should exist between the different measures. However, if sequencing abilities are modality and hemispherically specific then the correlations between tests may be nonsignificant. Table 5 below gives the correlations between the different measures.

Table 5: Correlations between the dependent variables.

	Visual	Auditory	Tactual (left hand)
Auditory	.67 ($p<.05$)		
Tactual (left hand)	.49 ($p<.05$)	.10 n.s.	
Tactual (right hand)	.44 ($p<.05$)	.42 ($p<.05$)	.29 n.s.

As Table 5 shows there are significant correlations between the tests of serial order perception in the visual mode and both auditory and tactual modes. This would tend to indicate that serial order perception is a unitary function, however the nonsignificant correlations between auditory and tactual (left hand) and between tactual (left hand) and tactual (right hand) are difficult to account for with this hypothesis.

An alternate hypothesis, proposed by Fedio and Mirsky (1969, reported in Bakker, 1972) and supported by Bakker (1972), suggests that serial order perception is divided between the hemispheres with the left hemisphere responding to verbal stimuli and the right hemisphere responding to nonverbal stimuli. This hypothesis does not account for the obtained correlations. It predicts a correlation between serial tactual stimulation of the left hand (because of the crossed sensory pathways this stimulation is perceived first in the right hemisphere) and the serial order perception of nonverbal stimuli. Both the visual and auditory stimuli used in this experiment were nonverbal and a significant correlation exists only between tactual (left hand) stimulation and visual stimulation but not between auditory stimulation and tactual (left hand) stimulation. However, the nonsignificant correlation between right and left hands does provide support for the suggestion of hemispherically separate serial order perception.

Efron (1963a, b, c) argues against hemispheric separation of serial order perception. He suggests instead that the left hemisphere (the dominant language hemisphere) performs all serial order perception and that the anterior left hemisphere perceives auditory (verbal and nonverbal) serial order while the posterior left hemisphere perceives visual serial order. Again, this hypothesis does not account for the relationship of both right and left hand tactual perception to visual perception but only right hand perception to auditory perception.

If we hypothesize instead that serial order perception is modality specific as well as hemispherically specific then we may be closer to accounting for these correlations. This hypothesis accounts for the nonsignificant correlations but is not disproved by the significant correlations. The subjects in this experiment are children who are still developing and have not yet reached their maximum ability in serial order perception. Therefore, this hypothesis would suggest for these subjects that as age increases to some as yet unknown point, ability in all sensory modalities will improve, and as serial order perception in one modality improves, perception in other modalities may also be improving. However, it may also be the case that growth in different modalities may be uneven.

The table below looks at the prediction of increasing ability as age increases.

Table 6: Correlations between subjects' ages and the dependent variables.

	Age
Visual	.59 ($p<.05$)
Auditory	.50 ($p<.05$)
Tactual (left hand)	.27 n.s.
Tactual (right hand)	.48 ($p<.05$)

Table 6 indicates that for all dependent variables with the exception of tactual serial order perception in the left hand as age increases serial order perception improves. The nonsignificant correlation between age and tactual (left hand) is an anomaly, but in general, increasing age matches increasing ability.

It must therefore be recognized that because serial order perception improves with age, and because the age range in this study is from 35 months to 59 months, some correlations will exist between the dependent variables. These correlations due to increasing age may be statistically controlled using partial correlations between the measures (Edwards, 1976) i.e. the effect of age on sequencing abilities can be controlled by using a correlation procedure which has the effect of holding age constant. Therefore, the resulting correlations indicate the degree of relationships between serial order abilities only.

The table below reports the partial correlations (age held constant) between the different measures.

Table 7: Partial correlations, age held constant, between the dependent variables.

	Visual	Auditory	Tactual (left hand)
Auditory	.53 ($p<.05$)		
Tactual (left hand)	.42 ($p<.05$)	-.04 n.s.	
Tactual (right hand)	.22 n.s.	.23 n.s.	.19 n.s.

These results provide clear evidence that serial order perception is not unitary. The results indicate a significant relationship between visual sequencing and auditory sequencing and between visual sequencing and tactual sequencing in the left hand only, but no significant relationship between visual sequencing and tactual sequencing in the right hand, nor between auditory sequencing and tactual sequencing in either hand or between tactual sequencing in the left hand and the right hand.

The fact that only two of six correlations are significant is suggestive. If serial order perception were a unitary function then significant correlations should exist between all measures, and because this was not found to be the case, it may be, that, in fact, serial order perception is modality specific. The significant correlations between visual sequencing and auditory sequencing and left hand tactual sequencing may not indicate a single brain function but may indicate separate mechanisms developing and maturing at similar rates. If this is the case then the lack of significant relationships between the other measurements is understandable.

A further indication of independent mechanisms in the brain is the nonsignificant correlations between tactual sequencing in the left and right hands. This result may indicate independent perception of serial order in the left and right hemispheres. Further investigation of this observation is indicated.

In order to investigate more fully hemispheric differences in serial order perception it is suggested that older subjects be tested. Testing subjects more completely lateralized than three and four year old children may produce more easily interpretable results. It is also suggested that separate auditory tests be conducted for the right and left ears. These tests will help to determine if the differential performances are hemispheric and/or sensory modality in origin.

It is also recommended that further studies be confined to single sex groups of subjects. The different rates of overall maturation and especially brain maturation and lateralization shown for pre-pubescent children make mixed sex comparisons more complicated. (Yussen and Santrock, 1982) The following tables present the partial correlations (age held constant) for males and for females in this study separately.

Table 8: Partial correlations, age held constant, between the dependent variables for subjects 1 to 13. Males

	Visual	Auditory	Tactual (left hand)
Auditory	.44		
Tactual (left hand)	.49	-.03	

Tactual (right hand)	.09	-.22	-.09

Probability for all correlations is greater than .05

Table 9: Partial correlations, age held constant, between the dependent variables for subjects 14 to 27. Females

	Visual	Auditory	Tactual (left hand)
Auditory	.48		
Tactual (left hand)	.10	-.30	
Tactual (right hand)	.32	.34	.13

Probability for all correlations is greater than .05

These correlations are disparate enough to lend support to the recommendation that single sex subject groups be used in further research. In addition, the lack of any significant correlations between the dependent variables once age and sex are held constant strongly argues against the notion of unitary serial order perception or behavior. These results also provide no support for Bakker's (1972) hypothesis that all verbal sequencing is carried on in the left hemisphere and all nonverbal sequencing is a right hemisphere function.

Monsees (1961), Hardy (1965) and Popen et. al. (1969) suggest that aphasic children suffer from a general sequencing disorder; that is, deficient ability to place stimuli in all sensory modes in correct temporal order. If, as the present research indicates, sequential behavior is not unitary, then it is difficult to imagine the type of brain dysfunction usually associated with aphasia also producing a general sequencing deficit. Other researchers (Lowe and Campbell, 1965; Stark, 1967; Tallal and Piercy, 1973a, b; Tallal et. al., 1976) have found specific auditory sequencing deficits in aphasic children and although Poppen et. al. (1969) hypothesize a general sequencing deficit their data also show aphasic children to be especially deficient in auditory sequencing ability.

These observations of specific sequencing problems are predicted by an hypothesis of modality specific serial order perception. In addition, although this hypothesis does not absolutely rule out multiple areas of dysfunction, it would suggest that visual serial order perception would not necessarily be affected in aphasic children. Stark (1966) does report impaired visual motor sequencing in aphasic children, but Tallal and Piercy (1973b) found visual sequencing abilities in aphasic children to be on par with age matched normal children.

Withrow (1964), however did find impaired visual sequencing abilities in aphasic children, but when he tested deaf children he found them to be equally impaired in visual sequencing. It may be that in some way failure to understand and/or use spoken language inhibits the normal development of visual serial order perception.

Dyslexic children, whose difficulty is with written, visual language, could be expected, according to the modality specific hypothesis, to be selectively impaired on visual sequencing tasks. Bakker (1967) compared dyslexic children to nondyslexic poor readers and found the dyslexic children to be significantly poorer at visual sequencing tasks using letters or easily nameable pictures. Boder (1973) suggests that only some dyslexic children are impaired on sequencing tasks but does not specify sensory modes, and De Quiros (1964) reports auditory sequencing deficits in poor readers. However, his group of poor readers was comprised of a mixed group of both dyslexic and dysphasic children. Senf (1969; Senf and Feshback, 1970; Senf and Freundl, 1971), Zurif and Carson (1970) and Corkin (1974) all report visual sequencing deficits in dyslexic children. Corkin (1974) and Zurif and Carson (1970) also report auditory sequencing difficulties in their subjects but a review of their data indicates that the dyslexic children were more impaired on visual sequencing tasks when compared to the control children than they were on auditory sequencing tasks. Owen et. al. (1971) studied educationally handicapped children, identified primarily by reading scores well below predictions from grade level and I.Q., and found auditory sequencing difficulties. Unfortunately, they did not also test visual sequencing abilities.

Poor readers who have not been identified as dyslexic have also been studied. Gaddes and Spellacy (1977) did find evidence of poorer visual sequencing abilities in poor readers, as did Senf (1969) with culturally deprived poor readers. These children are assumed to be poor readers for reasons other than specific brain dysfunction, and therefore their sequencing difficulties may be of a different sort than dyslexic children. Senf (1969; Senf and Feshback, 1970; Senf and Freundl, 1971) did in fact find this to be the case. An error analysis showed the culturally deprived poor readers behaved as younger normal children: the dyslexic children did not. Doehring and Libman (1974) also found this true with poor readers. Finally, Weiner et. al. (1970) found no evidence of sequencing problems with a group of poor readers.

CONCLUSION

The importance of serial order perception and behavior for language, memory and cognitive development was summarized. Language was looked at as a special case of serial order/sequential perception and behavior and research was cited establishing the role of serial order perception in understanding spoken language. Individuals with specific language and thinking problems, specifically those with known or suspected brain damage or dysfunction, were shown to have difficulty with serial order perception. However, the research was unclear as to whether the problems were sensory mode specific or unitary in nature. An experiment with normal preschool children provided support for sensory mode specificity in serial order perception and a review of the literature supported this hypothesis.

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APPENDIX A: The tables below give the sex, ages and handedness of the 27 subjects tested.

Table 1: Age and handedness of male subjects.

Males

Subject Number	Age years: months	Age months	Handedness
S1	3:02	38	R
S2	3:03	39	R
S3	3:06	42	R
S4	3:07	43	L
S5	4:00	48	R
S6	4:01	49	R
S7	4:04	52	R
S8	4:07	55	R
S9	4:07	55	L
S10	4:08	56	R
S11	4:09	57	R
S12	4:10	58	R
S13	4:11	59	R

Table 2: Age and handedness of female subjects

Females

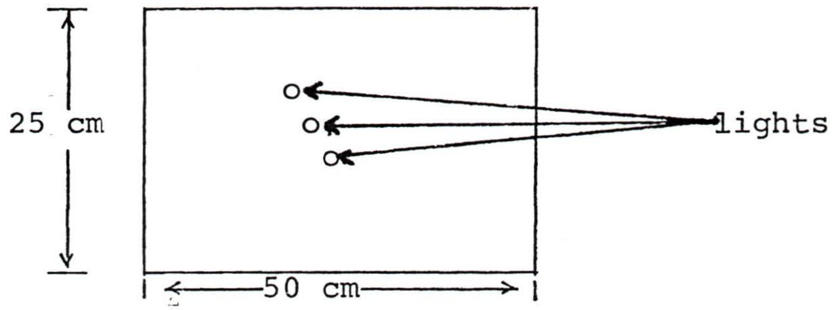
Subject Number	Age years: months	Age months	Handedness
S14	2:11	35	R
S15	3:00	36	R
S16	3:01	37	R
S17	3:04	40	R
S18	3:04	40	R
S19	3:05	41	R
S20	3:06	42	R
S21	3:07	43	R
S22	3:07	43	R
S23	3:11	47	R
S24	3:11	47	L
S25	4:00	48	R
S26	4:01	49	R
S27	4:07	55	R

Table 3: Subjects by age and sex.

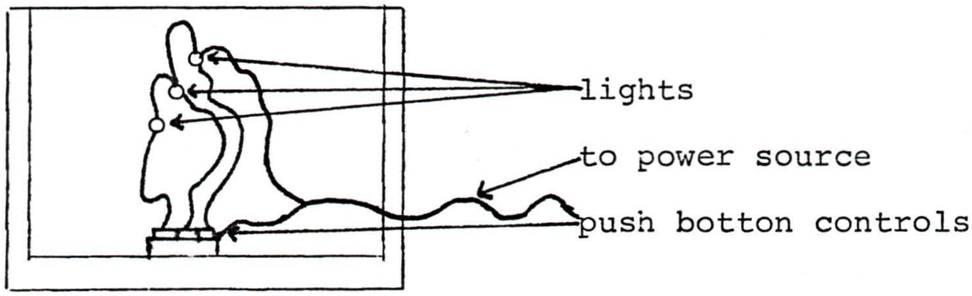
Ages of the Subjects (months)		Sex of the Subjects: Male	Female	
	35-43	4	9	13
	47-59	9	5	14
		13	14	

APPENDIX B: The apparatus used to test visual sequencing was constructed as diagrammed below.

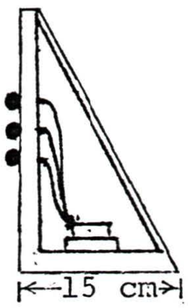
<u>Figure 1:</u> Subjects' view of the visual apparatus.



<u>Figure 2:</u> Experimenter's view of the visual apparatus.



<u>Figure 3:</u> Side view of the visual apparatus.



APPENDIX C: The table below gives the raw scores for each subject in the experiment

Table 4: Subjects' raw scores.

Subject Number	Visual*	Auditory*	Tactual Left*	Tactual Right*	Tactual Sum
1	2	2	1	1	2
2	2	0	2	1	3
3	4	3	2	1	3
4	0	1	0	1	1
5	3	2	1	1	2
6	3	3	1	1	2
7	3	3	1	1	2
8	4	2	2	2	4
9	3	3	1	2	3
10	3	3	3	1	4
11	3	3	1	2	3
12	3	2	2	2	4
13	4	3	2	2	4
14	1	1	1	1	2
15	1	2	1	1	2
16	2	2	1	2	3
17	3	1	2	2	4
18	2	2	2	1	3
19	2	3	2	1	3
20	3	3	1	2	3
21	4	3	2	2	4
22	3	3	1	1	2
23	3	2	2	1	3
24	2	1	2	2	4
25	3	3	1	1	2
26	3	4	2	2	4
27	4	5	2	3	5
Mean Scores	2.7	2.4	1.5	1.5	3

*number of items indicated in the correct sequence (see the Methods section, pages 32-36 for more detail regarding measurement of the dependent variables)

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Medical Research Council Studentship, 1977/78

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