SPATIAL-TEMPORAL PROCESSING AND CEREBRAL DOMINANCE: A DEVELOPMENTAL STUDY WITH NORMAL READERS

by

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ABSTRACT

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The development of spatial-temporal processing abilities and their relationship to hemisphere specialization was studied in 45 dextral boys (ages 7.6, 10.7 and 13.7 years), classified as normal readers. All subjects were administered four forms of a spatial-temporal test and a dichotic digits task. In addition, each child was administered an IQ and a reading test. While significant differences were found in overall performance between the youngest and the two older groups on the spatial-temporal test, the order of difficulty remained identical for each group; the only significant difference was between the temporal-temporal and spatial-temporal tasks, the former being less difficult. Further analysis, controlling for intelligence, revealed that children in the low IQ group found spatial-spatial, spatial-temporal and temporal-spatial tasks significantly more difficult than temporal-temporal tasks. Children in the high IQ group performed equally well on all tasks. A significant right ear advantage was found at 7.6 and 10.7 years; however, no significant correlations were found between performances on the temporal-temporal task and ear difference or reading scores. Results are discussed in terms of the intellectual level and performance of the subjects. Recommendations for further research are made.

ABSTRAIT

M.A. Diane McLean

Le développement de capacités spatiale-temporelles et le rapport entre ce développement et la spécialisation hémisphérique a été étudié dans 45 garçons droitiers (agé de 7.6, 10.7 et 13.7 ans) ayant été classifié comme lecteurs normaux. Chaque candidat a subi quatre formes d'une tâche spatiale-temporelle et une tâche d'écoute dichotique (chiffres comme stimulus). En plus, chaque candidat a subi un test de quotient intellectuel et un test de lecture. Quoique des différences significatives ont été trouvées entre la performance du groupe age de 7.6 ans et des deux autres groupes dans la tâche spatiale-temporelle; l'ordre de difficulté est resté identique pour chacun des groupes; la seule différence significative étant entre les tâches temporelle-temporelles et spatiale-temporelles, ces dernières étant les plus difficiles.

Une analyse plus approfondie, en contrôlant la variante d'intelligence, a révélé que pour le groupe ayant un quotient intellectuel inférieur la performance des tâches spatiale-spatiales, spatiale-temporelles et temporelle-spatiales était significativement plus difficile que celle des tâches temporelle-temporelles.

Le groupe ayant un quotient élevé n'a pas montré de différences significatives dans la performance des quatre tâches.

Un avantage significatif d'oreille droite a été trouvé dans les groupes 7.6 et 10.7 mais aucun rapport significatif n'a été trouvé entre les performances des tâches temporelles-temporelles et les différences d'oreilles ou les résultats du test de lecture.

Les résultats sont analysé en fonction du niveau intellectuel et de la performance des candidats. Des recommendations pour d'autres recherches possibles sont faites.

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I. INTRODUCTION

Over time psychologists and educators have been willing to conceive of some model by which the brain (or brain and central nervous system) was believed to operate thereby allowing a resolution of many intractable problems.

The notions advanced at different times have emphasized sensory imagery, handedness, eyedness, crossed dominance especially in relation to a major and continuing educational problem, that of enabling children to read and to comprehend what they have read.

Approaches have developed from that of general mental hygiene in the 1940's to direct sensory training (visual, auditory, psychomotor) in the 1950's, where physiological, medical or educational treatment followed diagnosis. More recently the emphasis has shifted from various forms of straight sensory training to overcome 'diagnosed weaknesses', to a re-examination of the problems in terms of sensory processing and sensory integration, along with investigation in terms of hemispheric specialization.

The continuing presence in our schools of children who cannot read, or do so with great difficulty, has provided a population where sensory deficits, failure of sensory integrations, problems of laterality, even of possible cerebral dysfunctions, appear to abound. Perhaps it is now time to examine, in a population of normal children who do not present such problems, and who are reported by their teachers to read satisfactorily, some of the tentative conclusions reached by study of their more a-normal age mates. The research which will be subsequently described attempts to make such an enquiry with respect to sensory integration, especially of the spatial and temporal modes, and in relation to aspects of hemispheric specialization.

II. REVIEW OF RELATED RESEARCH

A. SPATIAL-TEMPORAL PROCESSING

The studies of spatial-temporal processing have evolved from investigations of sensory integration.

1. Sensory Integration: A Developmental Perspective

Research into sensory integration has its origin in comparative psychology (Maier & Scheira, 1935) and comparative neurophysiology (Sherrington, 1940), the basic premise being that with the ascent of the phylogenetic scale, behavior becomes increasingly controlled by multi-modal as compared to modal functioning (the integration of the sensory modalities). The complex behavior of the organism is possible through the development of intersensory liaison, where in infancy, proximoceptive input (via a receptor which can only be stimulated through contact with it) is increasingly replaced by input via teleceptor systems (receptors which are adapted to receive stimuli from a distance) (Birch & Lefford, 1967). Behavior is subserved by the integration of information which arrives through different sensory channels.

The importance of integration of information from all sensory modalities has been comprehensively reviewed in studies of perception (Gibson, 1969; Wohwill, 1960), reading achievement (Derevensky, 1977), learning (Birch & Bitterman, 1949, 1951) and information processing (Freides, 1974; Ryan, 1940).

Sensory integration has been studied by investigating the perception of intersensory equivalences (the equating of stimuli presented in one modality with stimuli presented in another; i.e. the perception of a letter through vision and touch). This was studied mainly by a matching to sample method. The equivalences examined have included the use of both the visual haptic modalities (eg. Abravanel, 1968; Derevensky, 1976; Ford, 1967; Milner & Bryant, 1970) and auditory visual modalities (eg. Beery, 1967; Bryden, 1972; Ford, 1967; Jorgensen & Hyde, 1974; Kahn & Birch, 1968; MacKinnon & McCarthy, 1973; Reilly, 1971, 1972; Sterritt & Rudnick, 1966). The current review will focus upon the integration of auditory and visual modalities.

Birch (1962) reported a relationship between reading ability and intersensory integration, and indicated that poor readers showed inadequacy in the integration of auditory and visual stimuli. This integrative organization between modalities was believed to be essential for in its early stages reading requires visually presented stimuli to be equated with auditorily presented stimulus patterns. Ability to shift from the use of one modality to another has also been investigated by Raab, Deutsch & Freedman (1960) and Katz & Deutsch (1963), by testing reaction times to visual colored stimuli and to pure auditory tone stimuli. It was found that poor readers had more difficulty than good readers in rapidly shifting from one sensory modality to another. To some specific investigations of these kinds of integration we now turn.

a. Birch Studies

Birch investigated the development of intermodal equivalence (equivalence between sensory modalities) in normal children (Birch & Lefford, 1963) and the disturbances of intersensory integration in the neurologically damaged (Birch & Belmont, 1964; Birch & Belmont, 1965a; Birch, Belmont, Reilly & Belmont, 1961; Birch, Belmont, Reilly & Belmont, 1962) finding that neurointegrative development(intersensory integration) was significantly poorer in these children. Studies of cerebral palsied and schizophrenic children, then followed (Belmont, Birch & Karp, 1965; Walker & Birch, 1970). Here also, there was marked difficulty in intersensory processing. The particular studies, Birch & Belmont (1964) and Birch & Belmont (1965b) are often regarded as the seminal studies in this entire area.

The first investigation (Birch & Belmont, 1964) was carried out within a general framework of handedness and laterality and was an epidemiological study of Scottish school children (boys 9 and 10 years of age) who had significant degrees of reading retardation compared with normal boys of the same age. Integration was studied by a method of equivalence where a visual dot pattern which corresponded to the pattern of a rhythmic auditory stimulus had to be identified in an auditory-visual (A-V) matching task. Retarded readers were found to be significantly less efficient integrators than normals, and within the two groups, those children having lower auditory-visual scores tended to have lower reading scores. This difference in favour of normal readers as opposed to retarded readers persisted even when subjects of a low intellectual level were removed from the comparison.

The following year, Birch & Belmont (1965b) studied the developmental course of auditory-visual equivalence in children between the ages of 5 and 12. The development of this skill in equating the two sets of stimuli was also considered in relation to measures of IQ and reading skill. The performance of 5 year olds was only slightly better than chance expectancy, with improvement occurring in successive stages until age 10 where an asymptote was reached. The most rapid growth was found to be between the ages of 5 and 7. Except for the oldest and youngest subjects there was a significant positive relationship between IQ test score and auditory-visual integration.

There appeared to be opposite age trends in the relationship between auditory-visual integration and reading ability and between reading ability and IQ.[6] From this it was suggested that primary perceptual factors may be most important for initial acquisition of reading skill but that factors more closely related to IQ are more important in its elaboration as shown in the reading skills of a more mature kind.

b. Modification of Studies in Birch Tradition

Subsequent studies using a variety of populations and tasks have provided additional support for the developmental perspective of auditory-visual integration as well as for the relationship between auditory-visual integration and reading ability. However, it appears that the relationship is a complex one; while there are inconsistencies in the results, there is evidence to suggest that the relationship depends upon such factors as the sex, socio-economic status, intellectual ability and developmental level of the individual.

Within this general conclusion it must be pointed out that the preponderance of boys amongst children with reading difficulties has resulted in more single sex (boys) studies, so that sex differences in A-V sensory integration are, perhaps, not so clearly delineated (Birch & Belmont, 1964; Ford, 1967; Kahn & Birch, 1968; Sterritt & Rudnick, 1966). While Muehl &

Kremenak (1966) failed to find sex differences in integration skills, other studies have found girls to develop integration skills at an earlier age than boys (Reilly, 1971,1972).

The Birch studies as well as those of Beery (1967), Muehl & Kremenak (1966), and Sterritt & Rudnick (1966) with middle class subjects and Jorgenson & Hyde (1974) with subjects from a low socio-economic background, did not find auditory-visual integration skill to be dependent upon intelligence; however, Ford (1967) found the relationship between auditory-visual integration and reading achievement was weakened when IQ was controlled. Using both boys and girls, Reilly (1972) found sensory integration skills to be poorer in boys and girls from a lower socio-economic background than in middle class girls.

Investigations questioning the assumption of symmetry in cross-modal sequences found significant asymmetries between auditory-visual and visual-auditory matches. While the performance of poor readers on both forms (A-V and V-A) was significantly less than that of normal readers (Beery, 1967; Bryden, 1972; Jones, 1974; Muehl & Kremenak, 1966; Rudel & Teuber, 1971; Sterritt & Rudnick, 1966) and the performance of good readers significantly less than that of excellent readers (Bartholomeus & Doehring, 1972), there was evidence to suggest that the task having a visual standard from which to match was easier for both groups.

Bryant (1968) stated that errors in cross-modal matching may be due to failures of processing in one or both of the modalities involved, instead of, or in addition to failures in sensory integration. Studies employing intra- as well as inter-sensory matching procedures (pattern matching both within and between modalities, A-A, A-V, V-V, V-A) found similar developmental patterns and differences in all of the matches between good and poor readers, suggesting that the effects may not simply be due to the hypothesized integration process between auditory and visual stimuli (Alworth, 1974; Bryden, 1972; Gould, 1977; Kulman & Wolking, 1972; Muehl & Kremenak, 1966; Rudel & Teuber, 1971; Rudnick, Martin & Sterritt, 1972; Sterritt, Martin & Rudnick, 1971; Sterritt & Rudnick, 1966; Vande Voort, Senf & Benton, 1972; Vande Voort & Senf, 1973; Zurif & Carson, 1970).

2. <u>Spatial-Temporal Aspects of Intersensory Integration</u>

The equating of auditory with temporal qualities and visual with spatial ones, did not allow the individual roles of audition, vision, temporality and spatiality to be assessed. It was noted that not only did the stimuli in the Birch studies differ in modality, but they differed on the spatial-temporal dimension as well (Blank & Bridger, 1964). Visual stimuli were presented spatially and auditory stimuli were presented temporally. Goodnow (1971) suggested that the major change with age in matching auditory to visual patterns lies in the individual's realization that a spatial interval can represent a time limit. Studies utilizing visual-temporal stimuli (flashes of light) and visual-spatial stimuli (printed dots) as well as auditory-visual materials, found the temporal-spatial and the auditory-visual tasks to be of equal difficulty (Bryden, 1972; Rudnick, Sterritt & Flax, 1967; Sterritt, Martin & Rudnick, 1971; Sterritt & Rudnick, 1966). Here, however, instead of matching to sample, a method of paired comparisons was used.

It has been shown that the level of difficulty in spatial-temporal matching tasks depends upon the combination of the spatial and temporal aspects. Bryden (1972) working with 9 to 10 year old, good and poor readers, reported that assessment of the overall performance indicated that intramodal matches (temporal to a temporal or spatial to a spatial) were of less difficulty than cross-modal matches (temporal to a spatial or spatial to a temporal) regardless of sensory modality. The most difficult of the cross modal matches was the one in which a temporal standard was presented first. It was suggested that the strategies involved in coding sequential (temporal) material are different from those involved in coding spatial material and that this explained the performance difference in the various tasks. It was suggested that an entire spatial pattern can be rehearsed prior to presentation of the second pattern, but when a temporal pattern is processed, the code must be modified as the items are presented.

While Bryden (1972) found tests involving the integration of temporal-spatial aspects to be more difficult than those not involving integration, other studies investigating spatial-temporal matching only within the visual modality, have not obtained similar results. Sterritt, Martin & Rudnick (1971) in a study of preschoolers, Rudnick, Martin & Sterritt (1972) in a study of first graders and Rudel & Denckla (1976) in a study of learning disabled and normal readers, ranging in age from 7 to 12 years, reported the following results:- purely spatial matching tasks were simplest (spatial to spatial, S-S); tasks involving temporal and spatial patterns (spatial to temporal, S-T, or temporal to spatial, T-S) were of intermediate difficulty; and purely temporal matching tasks (temporal to temporal, T-T) were most difficult. Rudel & Denckla (1976) reported differences between learning disabled and normal readers, except on an S-S task, the only one which did not differentiate the groups. Of the two tasks requiring spatial and temporal integration, both groups, learning disabled and normal readers, performed better when matching from a spatial to a temporal standard (S-T) than when matching from a temporal standard (T-S). Developmental differences were noted within the normal readers for the youngest children (7 to 8 years) made significantly more errors than the 9 to 10 and 11 to 12 year old children on the S-T and T-S tasks.

While studies reviewed thus far, suggest that tasks involving temporal perception, whether purely temporal matches or matches requiring the equating of temporal and spatial stimuli, are more difficult than tasks involving only spatially presented stimuli, some investigations have directed their attention to the difficulties with temporal order perception. Bridger (1970), for example, states that the temporal spatial matching test can only be solved by means of verbal coding of the stimuli, indicating that verbal labelling is a factor affecting performance on the auditory-visual matching tasks. Blank & Bridger (1964) suggest that when analogous stimuli (sounds and patterns) are presented in different modalities as opposed to the same stimuli presented in different modalities (i.e. a ball matched through touch and vision), verbal labelling is necessary. Further, it was suggested that the auditory-visual defect reported in retarded readers is not due to a perceptual problem but rather due to a problem involving complex conceptualization. What appeared to be a cross modal deficiency was instead a failure to accurately code temporally presented components of the task.

Subsequent studies with first and fourth graders (Blank & Bridger, 1966; Blank, Weider & Bridger, 1968), of spatial and temporal matches within the visual modality found retarded readers to have significantly more difficulty than normal readers in establishing equivalences between spatial and temporal stimuli. More importantly, this difficulty was found to be dependent on verbal coding. When the need to code was eliminated, there was no difference in performance between normal and retarded readers. Blank, Weider & Bridger (1968) further emphasized that temporal components are not unique in their dependence on verbal stimuli; complex spatial stimuli may also be facilitated by verbalization.

Rhythm deficiencies in retarded readers reported by De Hirsch, Jansky & Langford (1966) and Stambak (1951) can also be explained by Blank & Bridger's theory. While these studies required non-verbal imitation, rhythms involve the presentation of temporal sequences, the perception of which necessitates the application of a code which may demand a high level of cognitive skill. Therefore, the deficiency may not be in perception of the rhythm but rather in the symbolic process of translation. In their work, De Hirsch, Jansky & Langford (1966) required their subjects to imitate a pattern which had been tapped out to them. They found that temporal order perception (T-O-P) correlated positively with reading ability at younger ages. The T-O-P and reading relation was found to be stronger in 5 to 8 year old girls than in boys of the same age. Sapir (1966) and

Keogh & Smith (1967) also report that first grade boys scored lower than first grade girls on perception of temporal order. It appeared that T-O-P conditioned reading and not the reverse since many children in these studies had little or no reading instruction.

Additional studies provide supporting evidence that retarded readers experience difficulty in T-O-P. While these studies did not explicitly examine the perception of temporal order, temporal perception was inherent to the task. Profiles of normal and disabled readers provided by the Wechsler Intelligence Scale for Children (WISC) showed that the Digit Span subtest discriminated between the groups (Belmont & Birch, 1966; Lyle & Goyen, 1969; Kinsbourne & Warrington, 1966). In this subtest, the subject hears a series of digits and is asked to reproduce them in the sequence of presentation.

Memory for bisensory stimuli has been examined in normal and reading disturbed boys (Senf, 1969; Senf & Feshback, 1970; Senf & Freundl, 1972). In their work an analogue of a dichotic listening test was used. Here, pairs of digits are presented simultaneously to subjects, one digit being visual and the other auditory. Subjects are required to reproduce the digits in the sequence of presentation; some subjects reproduce by pairs (auditory, visual; auditory, visual...) and other subjects reproduce according to modality (all auditory and then all visual). More errors of reproduction are found among children with reading difficulties than among those without such difficulty, especially when reproduction of pairs was required. Senf (1969) states that the LDC's (Learning Disturbed Children) failures were generally specific to the ordering of the stimuli, not to their accuracy of recall.

There is evidence, too, to suggest that strategies involved in ordering become more efficient with age. Ross & Youniss (1969) studied the memory for temporal order in 6 to 10 year old children, using series of both meaningful and meaningless (nonsense) figures. Performance with meaningful figures was higher than with meaningless ones, and memory for temporal order increased with age. The younger child ordered less spontaneously than older children with both sets of figures.

Bakker (1972) who has stated that temporal order is an essential moment in the reading process, has conducted studies which parallel those of Birch and others but which differ in two respects. There is a greater variability in materials in their studies: verbal stimuli (letters and digits), verbally codifiable stimuli (meaningful figures) and nonverbal stimuli (meaningless figures) are utilized. The sequence factor is emphasized and serial location of items is obtained by a reconstruction method. The studies are of both a verbal explication type (using verbal and verbally codifiable material) and a non-verbal explication type (using meaningless figures without a label, and hence incapable of direct vocalization).

Bakker and his co-workers have found that in children, aged 7 to 10 years, the perception of meaningful but not of meaningless figures correlated with the learning-to-read process in both normal and reading distrubed childrem, with T-O-P found to be better in older than in younger children (Bakker, 1967a; Groenendaal & Bakker, 1971). Subsequent studies (Bakker, 1972) reported that T-O-P was correlated with age in a sample of normal readers, correlated positively with reading ability in boys, and differentiated between boys and girls at younger ages. With pre-school and primary children T-O-P was not only age related, but significant increases in performance were found to take place in a period as short as six months. Girls were better than boys prior to age 7 in both auditory and visual modalities, but this superiority later disappeared and boys then performed as well as girls in auditory-temporal perception. T-O-P seems at this age to correlate with reading ability measured at a later age. With normal readers, boys and girls of 7 to 11 years of age, older children perceive temporal series better than younger children, and among the younger age groups girls are superior to boys. The T-O-P reading relation applied only to the boys in this group.

By way of explanation Bakker postulates a critical period in temporal order perception which affects the process of learning to read. Girls pass through this period between the ages of 4 and 6, boys between 5 and 8. Neurophysiological changes in the organism are held to be responsible.

Reading as a verbal activity is presumed to be primarily dependent upon left hemisphere functioning, and by extension temporal order perception of verbal material is dependent upon the same left hemisphere functioning. Correspondingly temporal order perception of nonverbal material must pertain to the right hemisphere. Earlier successes in the T-O-P task with verbal material among girls would indicate an earlier neurophysiological development of the left hemisphere in girls.

Thus, studies of sensory processing and sensory integration, from the seminal research of Birch and Belmont, conducted first with emphasis upon laterality and dominance, which had always had an implicit reference to brain activity, comes full circle to suggestions of hemisphere specialization as the important aspect of brain activity in studies of sensory processing in relation to reading. Fortunately, neurophysiological studies of hemisphere specialization have now provided a firmer foundation for the speculations of psychologists interested in sensory processing as pre-requisite to the development of measurable educational achievement. It is to some of this neurophysiological evidence that we now turn.

B. TEMPORAL PERCEPTION AND HEMISPHERE SPECIALIZATION

The notion of homologous areas of the brain seemed to exist prior to the conduct of experiments on brain activity _in situ_. Early progress came from studies necessitated by head wounds sustained in war, in industrial accidents, and later, in automobile accidents. The study of epileptic patients was also relevant. Experimental animal physiology, while not being capable of examining the area of the brain affecting speech, did allow for examination of the conditions under which contralateral hemiplegia (loss of motor movements in the side of the body opposite to that of brain injury) could occur. More recently, electrophysiological evidence from animal studies has shown that crossed auditory pathways are stronger than uncrossed (Rosenzweig, 1951; Tunturi, 1946). This has been shown for human subjects as well in that while each ear has connecting pathways with both hemispheres, the contralateral connections are more effective than the ipsilateral ones (Kimura, 1961a). Kimura, 1967; Wada & Rasmussen).

The interconnecting fibers (corpus callosum) which join the left and right hemispheres, were considered an enigma to neurologists in the 1940's and 1950's. The now classic split brain experiments carried out on cats and later monkeys (originating with Myers & Sperry in the early '50's) allowed blocking of interhemispheric transfer of visual information by surgically sectioning the corpus callosum.

Neurosurgical evidence from patients who had split brain surgery for controlling interhemispheric spread of epilepsy found that interhemispheric exchange of information was totally disrupted (Gazzaniga, Bogen & Sperry, 1963,1965; Gazzaniga & Sperry, 1967). The effect was such that information presented to one hemisphere could be processed and dealt with in that half brain, but the other half cerebrum was not aware of these activities. All processes occurring in the left hemisphere could be verbally described by the patients; information presented to the right hemisphere went undescribed.

Having established that there were two distinct hemispheres, research then focussed on the function that each performed.

1. <u>Asymmetry of Function</u>

a. Direct Evidence

The elucidation of the hemisphere specializations has depended primarily on the observations of behavior changes resulting from localizable brain damage either naturally occurring (Geschwind, 1970; Mountcastle, 1962), or surgically induced (eg. Gazzaniga & Hillyard, 1971; Milner, 1962). Methods such as electrical stimulation of the cerebral surface through an opening in the skull (Penfield & Roberts, 1959), the Wada test (an injection of sodium amytal into the carotid artery on one side of the neck, which produces temporary aphasia or loss of speech; Wada & Rasmussen, 1960), neurosurgical evidence from epileptic patients (Ornstein, 1978; Sperry, Gazzaniga & Bogen, 1969), and electroencephalographic (EEG) recordings of electrical currents of the brain from electrodes placed at various positions on the scalp, have provided more direct evidence of hemisphere specialization; each hemisphere is dominant for some functions and nondominant for others. Although split brain techniques provided evidence that the right hemisphere has a life of its own and is capable of experiencing most of the activities that the left brain is able to experience, the prevailing view of cerebral functions is that the left hemisphere is predominantly involved with receptive and expressive language and analytical reasoning, while the right hemisphere is specialized for holistic processing, perception of music and other non-linguistic sounds.

b. Indirect Evidence

Functional asymmetry of the hemispheres has been examined with experimental techniques requiring perception of lateralized stimuli. One example of this kind of research is the visual-half-field technique where tachistoscopic stimulation can only be seen in either the left or the right visual field.

A more widely used technique, known as dichotic listening, modelled after Broadbent (1954) has different stimuli presented simultaneously to both ears through stereophonic earphones, one digit to the left ear, the other digit to the right ear. Six digits are usually presented. The subject is then required to recall all the digits he heard (usually in any order). Since the right side of the body is served by the left hemisphere, which is predominantly involved with language, a right ear advantage (R.E.A.) would be expected for verbal stimuli. There is considerable evidence that the asymmetrical functioning of the two hemispheres for speech is reflected in unequal perception of verbal stimuli (letters, digits, numbers, words) presented dichotically to left and right ears.

In the majority of right handed individuals, the left hemisphere mediates speech. It has been found in both a clinical population (Branch, Milner & Rasmussen, 1964) and in a normal population (Bryden, 1965; Satz, Achenbach, Pattishall & Fennell, 1965) that over 90% of right handed individuals and over 60% of left handed individuals have left hemisphere representation for speech. There is also evidence to suggest that sinistrals (left handers) have greater hemispheric equipotentiality than dextrals (right handers) (Curry, 1967; Lishman & McMeekan, 1977; Luria, 1947; Subirina, 1958; Witelson, 1977), i.e., there is a tendency for the left and right hemispheres of sinistrals to be equally capable of processing information, regardless of the type. Further, it has been suggested that sinistrals may need to be reclassified as mixed or ambidextrous (Annett, 1970a, 1970b; Hecaen & de Ajuriaguerra, 1964; Kimura & Vanderwolf, 1970). Bryden (1970) and Zurif & Bryden (1969) suggested that sinistrals should be classified into two groups, familial and nonfamilial, depending upon the presence of sinistrality in one or more parents or siblings. When this is done it is seen that nonfamilial sinistrals perform exactly like dextrals in terms of cerebral dominance.

In a brain damaged population, damage to the left temporal lobe caused a greater decrease in overall performance on a dichotic digits task (Kimura, 1961b; Meyer & Yates, 1955; Milner, 1958), while performance on some subtests of the Seashore Measures of Musical Talents (Milner, 1962) and on a multiple choice recognition test of melodies (Shankweiler, 1966) was affected by right temporal lobectomy. Within a normal population there is evidence for a significant R.E.A. for verbal stimuli (Broadbent & Gregory, 1964; Bryden, 1963; Carr, 1969; Curry, 1967; Dirks, 1964; Inglis, 1965; Kimura, 1961a, 1963; Kimura & Folb, 1968; Satz, 1968; Satz, Levy & Tyson, 1970;

Studdert-Kennedy & Shankweiler, 1970; Zangwill, 1960), and a L.E.A. (left ear advantage) for melodies (Kimura, 1964). When meaningfulness of material (both with verbal stimuli and melodies) was considered, the same results were obtained (Kimura, 1966,1967).

Efron (1963a,1963b,1963c,1967), by presenting a series of two stimuli and requiring subjects to indicate which stimulus was presented first, found the perception of temporal order to be mediated by the left hemisphere. These results have been corroborated by other studies using this procedure (Edwards & Auger, 1965; Halliday & Mingay, 1961; Hirsch & Sherrick, 1961; Lowe & Campbell, 1965; Van Allen, Benton & Gordon, 1966). However, Masland (1967) states that these findings appear to be contradictory to those of Milner (1962). It will be recalled that Milner was concerned with hemisphere specialization in relation to the nature of the stimuli, verbal or non-verbal. Her non-verbal stimuli though temporal in nature were mediated by the right hemisphere. Efron's studies leading to the conclusion that temporal order perception was mediated by the left hemisphere used flashes of light and figures. This discrepancy could be resolved, in the opinion of Bakker, by postulating that the identification of a temporally presented stimulus requires a verbal label, and thus is predisposed to left hemisphere processing.

Apparently, it is not the temporal or non-temporal aspect of the material which determines the hemisphere involved but the verbal or non-verbal qualities. Studies requiring temporal perception of verbal and non-verbal material found that the left hemisphere is dominant for the processing of temporally presented verbal stimuli while the right hemisphere is more appropriate for the processing of temporally ordered non-verbal stimuli (Bakker, 1967b,1968,1969,1970; Bakker & Boeijenga, 1970; Doehring, 1972; Frankfurter & Honeck, 1973).

One final point might be made on monaural and dichotic tasks. Bakker and his associates, Doehring (1972) and Frankfurter & Honeck (1973) used monaural stimulation (presentation of stimuli to one ear at a time). It is therefore not necessary to have the presence of competing stimuli as is the case with dichotic listening tasks, as used by Kimura (1967) to produce ear asymmetry.

2. Development of Functional Asymmetry

The age at which the hemispheres become specialized for functions has generated a great deal of research. It appears that if one tests children early enough, a sex difference in the development of cerebral dominance may be detected. Kimura (1963), using dichotic stimulation, found a significant R.E.A. for verbal stimuli in boys and girls, of above average intelligence, as early as five years of age. Subsequent studies reported by Kimura (1967) found a R.E.A. as early as four years of age in children from an upper-middle socio-economic area but only as early as five years of age with children from a low to middle class socioeconomic area. In the latter group, only girls displayed a R.E.A.; this led Kimura to hypothesize that these children appeared to be at an early stage of cognitive development.

Much of the evidence concerning the development of hemisphere specialization has been provided by research investigating the relationship between cerebral dominance and reading ability. Since the superiority of the right ear is due to the dominance of the left hemisphere in processing verbal information, a relationship between right ear dominance and reading ability has been postulated. Sparrow & Satz (1970) and Satz & Van Nostrand (1973) argued for a developmental lag in hemisphere specialization for reading disabled children. While some studies found a definite lack of R.E.A. in disabled readers (Ozbrut, 1979; Satz & Friel, 1974; Satz, Friel & Rudegeair, 1976; Witelson & Rabinovitch, 1972; Zurif & Carson, 1970) others have shown the magnitude of the R.E.A. to be comparable to that found in young children (Satz, Rardin & Ross, 1971; Sparrow & Satz, 1970). Similar studies, while not finding a significant right-left difference, found a trend toward left ear advantage (Leong, 1976; Sparrow, 1969; Sparrow & Satz, 1970).

Studies using extremes reading groups have found a positive correlation between ear-difference scores and reading ability in children of ages 9 to 12 (Bakker, 1969; Leong, 1976; Satz, Rardin & Ross, 1971; Sparrow & Satz, 1970; Witelson & Rabinovitch, 1972; Zurif & Carson, 1970). However, in younger subjects (7 to 8 years) the best readers exhibited a smaller between ear-difference score (Bakker, Smink & Reitsma, 1973).

Smith (1971) states that perceptual analyses are as prominent a part of early reading as are syntactic and semantic operations, while with fluent reading the emphasis is placed on syntax and meaning. Therefore, it has been postulated that efficient reading is associated with low ear dominance (slightly left or slightly right) at younger ages and with high ear dominance at older ages, a notion supported by Bakker, Teunissen & Bosch (1976).

This particular research offered confirmatory evidence to that provided by Bryden (1970) that girls and boys of the same age differ in their cerebral dominance-reading relations; girls establish the adult pattern of left hemisphere dominance for speech much earlier than boys. This was also supported by Bakker _et al._ (1976).

C. SUMMARY AND IMPLICATIONS FOR PRESENT STUDY

The review of theory and research which has been presented has dealt with background studies leading to those involving spatial and temporal processing, as well as the relationship between hemisphere specialization and temporal order perception.

Spatial-temporal processing has its origin in research into sensory integration. Initial studies were concerned with the equating of auditory and visual stimuli, where auditory was synonomous with temporal and visual was synonomous with spatial presentation. It was found that sensory integration was developmental in nature and that a relationship existed between sensory integration skill and reading ability; however, the relationship appeared to be a complex one, found to be dependent upon sex, developmental level, IQ and socio-economic background of the individual. Studies which have examined abilities for matching auditory with auditory stimuli and visual with visual stimuli (intra as well as intersensory matches)have found that both types of matches differentiated good from poor readers and that the task having a visual standard from which to match, was the easier for both groups.

It was noted that not only did the material in the original intersensory studies differ in modality of presentation but differed also along the spatial-temporal dimension. Studies utilizing tests of spatial and temporal stimuli within the visual modality eliminated the confounding effect of equating modality with type of presentation (spatial or temporal). However, studies of spatial and temporal processing have produced conflicting results. There is evidence to suggest that matches which require a transformation from spatial to temporal or from temporal to spatial stimuli are the most difficult (Bryden, 1972) while other studies (Martin & Sterritt, 1972; Rudel & Denckla, 1976; Sterritt, Martin & Rudnick, 1971) report that of any matches involving temporal perception purely temporal matches are the most difficult.

However, it is difficult to ascertain whether the problem is one of translation between spatial and temporal stimuli or one of perception of temporal order, since the previous research has used different stimuli in their spatial and temporal presentations (patterns of dots vs. flashes of light). This in itself requires a translation of material. Additionally, there are inconsistencies in reported research as to the order of difficulty of the spatial-temporal tasks for various age groups.

The particular cerebral hemisphere involved in temporal order perception appears to be dependent upon the verbal or nonverbal nature of the stimuli. Studies using nonverbal material (musical sequences) found temporal perception to be mediated by the right hemisphere, whereas studies using verbal material (flashes of light and figures, which required labelling in order to report the sequence of presentation) found temporal perception to be mediated by the left hemisphere. Bakker (1972) has suggested that the temporal perception of meaningful but not of meaningless figures is mediated left cerebrally because the latter do not have a label and therefore are not verbal in nature.

In the majority of right handed individuals, temporal order perception of verbal material is mediated by the left hemisphere. This specialization of function is dependent upon the age and sex of the individual. Studies of upper middle class subjects have reported hemisphere specialization to be present as early as age four, whereas other studies have reported equipotentiality of function as late as ages 6 and 7. Differences have also been reported between boys and girls, with girls revealing hemisphere specialization at an earlier age. Therefore, it appears that in the majority of cases the development of specialization for certain functions within the appropriate cerebral hemisphere depends upon the sex, handedness, and age of the individual.

Emphasis in recent research has been with individual differences in learning patterns, and because of current interest and availability of large numbers of learning disabled children, much research has been reported on them. There is correspondingly a dearth of parallel studies with normal children. The research which will be subsequently outlined should serve to clarify the controversy regarding spatial-temporal processing as well as to investigate the development of these abilities in normal children. The development of hemisphere specialization will be investigated as well as the relationship between hemisphere specialization and temporal order perception and between temporal order perception and reading ability.

III. THE EXPERIMENT

It has been shown that sensory integration is developmentally patterned and is in some manner related to the growth of reading skills, at least in the earliest stages, however, a controversy exists as to whether certain processing difficulties encountered by children are due to the form of the material presented, or are occasioned by the necessity of changing from one form of presentation to another (i.e. the transformation from spatial to temporal). There are also reported differences as to the age at which the cerebral hemispheres become specialized for certain functions, and the age at which a relationship between temporal order perception and reading ability and between temporal order perception and cerebral dominance exists.

To date, much of the interest in studies related to these topics have used subjects, known to have or suspected of having reading difficulties. It becomes important, therefore, to examine these processes with children who are classified as 'normal' readers; are not seen as experiencing reading difficulties in the eyes of their teachers. In particular, because of work, with a learning disabled population, currently in progress within the Department of Educational Psychology at McGill University, a developmental study of 'normal' readers from the same population was desirable to provide some base data for comparison purposes.

A newly developed test, the MacKenzie Spatial-Temporal Test (see Appendix A) is being used in the investigation currently taking place. This test consists of meaningless figures given in both spatial and temporal presentations; there are four standard to target matches: spatial to spatial, spatial to temporal, temporal to temporal, and temporal to spatial. This test eliminates the confounding effect of translation of material since the same figures are used for both spatial and temporal presentations, and minimizes the memory load for item recall since the subject is given the figures and is only required to reconstruct the spatial or temporal presentation. Also being used in the investigation currently underway is the Dichotic Digits Test (see Appendix B). This test, modelled upon the work of Broadbent (1954) which has two different digits presented simultaneously to the two ears through stereophonic earphones, one digit to the left ear, the other to the right ear, infers left hemisphere representation for verbal material if a right ear advantage is found. Through this test the development of ear asymmetry can be studied.

Differences in the development of processing skills in boys and girls and in hemisphere specialization in sinistrals and dextrals, caused this study to be limited to dextral boys.

Subjects were selected as closely as possible to the ages of 7.6, 10.7 and 13.7 years to coincide with the ages at which the 'learning disabled' population receive assessments within the School Board; statutory procedures require formal 'recognition' of the state of being 'learning disabled' to be determined or confirmed, or amended at these ages. The selection of right handed male subjects, of the appropriate age, classified as normal readers required several steps.

A. SELECTION OF SUBJECTS

Fifteen children at each of the three age levels 7.6, 10.7 and 13.7 years, taken from grades two, five and eight participated in this study. All children were obtained from four fairly large elementary schools and one larger secondary school of the Lakeshore School Board, the cooperating school board. All children were believed to come from a middle class socio-economic background. While the School Board gave general permission for the research, it does not require that schools participate, so that consent of the schools must first be secured, then parental consent obtained, after being given an explanation of the nature and purpose of the study. Thus, for administrative reasons the number of participating schools was limited, but nevertheless schools from different areas of the Boards' jurisdiction were included to widen slightly the socio-economic class variable. Teachers were then asked to indicate which children, of those for whom permission had been obtained, would in their opinion be classified as normal readers. All left handers (according to the Harris Test of Lateral Dominance) were eliminated and a random selection of the remaining 'volunteers' was made to produce fifteen children at each of the three age levels of 7.6, 10.7 and 13.7 years. It is recognized that such a sample departs from what is theoretically desirable, however, considering the limitations imposed on such a study by the present situation within schools, it may well be the only kind of sample which will become readily available.

B. SELECTION OF TESTS

General cognitive evidence about this group of teacher-declared 'normal' readers was secured by the individual administration of the Wechsler Intelligence Scale for Children - Revised (WISC-R) and group administration of the Speed and Accuracy subtests of the Gates-MacGinitie Reading Tests, Primary CS - Form 2, Survey D - Form 2M and Survey E - Form 1M, respectively. There was individual testing with the MacKenzie Spatial-Temporal Test as well as with the Dichotic Digits Test. The series of digits of the Dichotic Digits Test were presented by means of a Realistic Portable Stereo Cassette System, Model # MD-200. The tape was made available by the courtesy of Mr. Laughlin Taylor and is a replica of the original Kimura (1961a) tape, made in the Department of Psychology, Montreal Neurological Institute.

C. THE PROCEDURE

All testing was carried out personally between January and March, 1979, during regular school hours in a private area made available by the school for this purpose. At the first testing session, the examiner spoke briefly with the subjects to explain the purpose of the experiment. Subjects were informed that the study involved a series of tests, designed to show the development of processes involved in learning activities in boys at three different ages. The WISC-R was then administered according to the standardized procedures for the test. This was followed by each of the four forms of the MacKenzie Spatial-Temporal Test, administered in a counter-balanced order, seven days apart (Appendix C). In another session the Dichotic Digits Test was given (Appendix D). Finally, there was a group administration of the required forms of the Speed and Accuracy Subtests of the Gates-MacGinitie Reading Tests. The approximate testing time for each child was two hours (including the time for group testing).

When the testing with the MacKenzie Spatial-Temporal Test was completed, each child was asked about the method adopted in the solution and performance of the various portions of the test. Scoring of the test (described in Appendix C) was independent of the replies given by the children. Maximum possible scores on each subtest was 12. Maximum possible score on the Dichotic Digits Test was 144.

IV. RESULTS

Raw scores for all variables are included in computer printout form, as Appendix E.

The characteristics of the sample as measured by the WISC-R and the Gates MacGinitie Reading Test are presented in Table 1.

Table 1. WISC-R and reading scores for the three age groups.

Age	WISC-R		Reading (z score)	
	X	sd	X	sd
7.6	119.9	8.433	54.8	6.36
10.7	118.4	6.978	59.3	6.41
13.7	121.3	9.758	60.8	7.06

An analysis of variance was performed on the performance scores of the MacKenzie Spatial-Temporal Test with the four forms of the test treated as repeated measures. Results of these analyses are found in Table 2.

As indicated in Table 2, significant main effects were found for age as they were for test. However, there was no significant interaction between the ~~two~~.

Table 2. Analysis of variance - MacKenzie Test.

Source	df	Sum of Squares	Mean Square	F	p
A (Age)	2	790.30	395.15	29.02	0.00001*
S (A)	42	571.90	13.62		
B (Tests)	3	62.67	20.88	5.33	0.0017*
AB	6	36.90	6.15	1.57	0.1611
BS (A)	126	493.43	3.92		

Multiple comparisons of the means of the age groups were performed using the Scheffé procedure (Kirk, 1968). Results of this analysis are presented in Table 3.

Table 3. Multiple comparisons of age groups on all forms of MacKenzie Test - Scheffé Procedure. Group means in ascending order.

Group	A1 - 7.6 Years 4.07	A2 - 10.7 Years 7.72	A3 - 13.7 Years 9.02
A1	-	29.35*	53.98*
A2		-	3.72
A3			-

*differences are significant at the .05 level.

critical F 6.444

As indicated in Table 3, the 7.6 year old children differed significantly from the 10.7 and 13.7 year old groups. No significant difference was found between the 10.7 and 13.7 year olds.

The means of the four forms of the MacKenzie Test were subjected to multiple comparisons using the Scheffé Procedure. These results are presented in Table 4.

Table 4. Multiple comparisons of means of MacKenzie Tests - Scheffé Procedure. Test means in ascending order.

MacKenzie Test	B2 S-T 6.00	B4 T-S 7.00	B1 S-S 7.18	B3 T-T 7.58
B2	—	5.7547	8.0115	14.3636*
B4		—	0.1864	1.9355
B1			—	0.9205
B3				—

*differences are significant at the .05 level.

critical F 8.0325

As indicated in Table 4, the only significant difference found between the tests was between the spatial to temporal and the temporal to temporal forms.

Following the results presented in Table 2, post hoc analysis was performed on the MacKenzie Test with IQ as a factor. Subjects were divided into two groups, IQ of 116 and above and 115 and below. Results of this analysis are presented in Table 5.

Table 5. Analysis of variance - MacKenzie Test (including IQ as a factor).

Source	df	Sum of Squares	Mean Square	F	p
A (Age)	2	441.94	220.97	19.25	0.0000*
C (IQ)	1	83.62	83.62	7.28	0.0102*
AC	2	36.29	18.14	1.58	0.2188
S (AC)	39	447.71	11.47		
B (Tests)	3	77.07	25.69	7.05	0.0002*
AB	6	24.68	4.11	1.13	0.3495
BC	3	48.56	16.19	4.45	0.0054*
ABC	6	19.93	3.32	0.91	0.4888
BS (AC)	117	426.06	3.64		

As indicated in Table 5, the results which were previously presented (Table 2) still remain. In addition a significant interaction was found between test and IQ.

The means of the test by IQ interaction were subjected to multiple comparisons using the Scheffé Procedure. Results of the analyses for the High IQ group are presented in Table 6. No significant differences were found between the four forms of the test.

Table 6. Multiple comparisons of means of MacKenzie Test for High IQ group-Scheffé Procedure.

MacKenzie Test $\bar{X}$	S-T 6.97	T-S 7.51	S-S 7.56	T-T 7.85
S-T	-	1.16	1.39	3.08
T-S		-	0.010	0.460
S-S			-	0.335
T-T				-

critical F 8.04
*differences are significant at the .05 level

Results of the analyses for the Low IQ group are presented in Table 7. Significant differences were found between the temporal to temporal test and the other three forms: spatial to temporal, spatial to spatial and temporal to spatial.

Table 7. Multiple comparisons of means of MacKenzie Test for Low IQ group-Scheffé Procedure.

MacKenzie Test	S-T 4.19	S-S 5.50	T-S 5.77	T-T 7.98
S-T	-	3.77	5.48	31.55*
S-S		-	0.043	13.51*
T-S			-	10.73*
T-T				-

critical F 8.04
*differences are significant at the .05 level

The scores of the dichotic listening test were subjected to analysis of variance with the right and left ear scores treated as repeated measures. The results of these analyses are presented in Table 8.

Table 8. Analysis of variance - dichotic digits test.

Source	df	Sum of Squares	Mean Square	F	p
A (Age)	2	4420.27	2210.13	19.72	0.0000*
S (A)	42	4706.13	112.05		
B (Tests)	1	1646.94	1646.94	30.49	0.0000*
AB	2	392.62	196.31	3.63	0.0350*
BS (A)	42	2268.93	54.02		

As indicated in Table 8 significant differences were found between the age groups and between the left and right ear scores. A significant interaction was found between age and ear scores.

Multiple comparisons using the Scheffé Procedure were performed on the means of the dichotic scores for each age group. Results of these analyses are presented in Table 9.

Table 9. Comparison of right and left ear scores of the dichotic digits test for three age groups - Scheffé Procedure.

Age	$\bar{X}$ left ear	$\bar{X}$ right ear	F
7.6	38.93	53.27	28.52*
10.7	55.00	61.73	6.29*
13.7	60.33	64.93	2.94

*differences are significant at .05 level.

critical F 4.08

These analyses reveal a significant right ear advantage for the 7.6 and 10.7 year old groups. No right ear advantage was found in the 13.7 year olds.

Pearson product-moment correlations were computed for the ear-difference scores (difference between left and right ears) and the scores of the temporal to temporal form of the MacKenzie Spatial-Temporal Test. The results of the analyses are presented in Table 10. No significant correlations were found.

Table 10. Correlations - ear difference scores with temporal to temporal scores.

Age	Correlation	p
7.6 year olds	-0.18	0.25
10.7 year olds	0.16	0.28
13.7 year olds	-0.761	0.39

Pearson product-moment correlations were computed for the Accuracy Score of the Gates MacGinitie Reading Tests and the performance on the temporal to temporal form of the MacKenzie Test. The results of these analyses are presented in Table 11. As indicated by the results, the only significant correlation was found in the 10.7 year old group, at the .02 level of significance.

Table 11. Correlations - reading scores with temporal to temporal scores.

Age	Correlation	p
7.6 year olds	0.00	0.50
10.7 year olds	0.52	0.02
13.7 year olds	0.10	0.36

V. DISCUSSION OF THE RESULTS

This experiment was designed to examine the developmental abilities in spatial-temporal processing in normal readers as well as to explore the relationship between hemisphere specialization and performance on purely temporal tests and the relationship between reading ability and temporal order perception. It was also expected that the MacKenzie Spatial-Temporal Test being used in this study would assist in the clarification of controversies which exist in past research into spatial-temporal processing.

The overall performance of the oldest and middle aged groups (13.7 and 10.7 years, respectively) was found to be significantly greater than the performance of the youngest group (7.6 years) on the MacKenzie Test. There was no significant difference between the two older groups. The results are in agreement with the developmental study by Birch and Belmont (1965b) of auditory and visual integration where an asympote was reached at age ten. However, it is felt that a ceiling effect could be responsible for the present results, since the oldest subjects often obtained perfect scores without a great deal of challenge.

The order of difficulty of the tests did not vary with age. Initial comparisons of the individual test means revealed that for all age groups the only significant difference was between the S-T (spatial to temporal) and T-T (temporal to temporal) tests; the S-T being more difficult. This data would appear to support Bryden's (1972) results since the transformation from spatial to temporal stimuli was significantly more difficult than the purely temporal to temporal tests. These results plus the fact that there was a considerable range in the IQ's of these subjects led to further analysis. The mean IQ of these three groups of declared 'normal' readers was nearly equal (119.9, 118.4 and 121.3, respectively) but the IQ's ranged from 96 to 138. When the groups were further divided into two IQ sub groups, 115 and below and 116 and above, a significant interaction between test and IQ was found. Comparison of the means in the High IQ group revealed different results from the comparisons of the means in the Low IQ group. The analyses seemed to indicate, as many have thought that subjects of high intelligence have the facility to adopt efficient and flexible strategies for handling the various tasks; there were no significant differences found between the forms of the test for these subjects. However, for the low IQ group significant differences were found between the temporal to temporal test and the other three forms: spatial to temporal (S-T), spatial to spatial (S-S) and temporal to spatial (T-S), the temporal to temporal

(T-T) being the least difficult. Once again it would appear that the results of Bryden (1972) are supported.

An explanation of the differences in test difficulty is offered through observations made while the children performed the tasks and interviews conducted with them upon completion of the four forms of the test. All subjects indicated that when the spatial presentation exceeded three figures, an attempt was made to process the pattern temporally. This would explain the temporal to temporal task being significantly easier since its presentation and response coincided with the strategies being used and explain why the spatial to spatial task, which does not imply a transformation from spatial to temporal stimuli was more difficult; it was not processed as a spatial test, therefore, a transformation did take place. All subjects processed the tasks temporally but those in the Low IQ group did not appear to be as capable as the High IQ group in rapidly adopting flexible strategies.

All children indicated that they labelled the figures (even though they were meaningless) and rehearsed the labels during the five second delay between presentation and response.

The results of the Dichotic Digits Test indicated that the youngest and middle aged groups displayed a significant right ear advantage. It appears that asymmetry of cerebral function was present as early as age 7.6 years which corroborates the results of Kimura (1963,1967). It appeared once again that the ear difference scores in the oldest group were masked by a ceiling effect of the test.

No significant correlations were found between the temporal to temporal and ear difference scores. These results appear to support those of Bakker (1967b) in that a relationship between the temporal perception of meaningless figures and left hemisphere specialization was not found. However, it has been shown that these figures were labelled, making them verbal in nature. The only age at which a relationship between reading ability and temporal order perception was found was in the 10.7 year old group and this was significant only at the .02 level. It appeared that the children in this sample had passed the critical stage at which a temporal order perception and reading relationship exists.

Overall Implications and Suggestions for Future Research

The results of this study did not find developmental differences with respect to spatial temporal processing; while the overall performance increased significantly between the youngest and oldest and between the youngest and middle aged groups, the order of difficulty of the tests did not vary with age. For all groups the temporal to temporal task was the easiest. However, while all subjects indicated that they processed all forms of the test temporally and facilitated this process by attaching a label, those of 115 IQ and below were not able to do this as successfully as those of higher IQ. Developmental differences between the 10.7 and 13.7 year olds were masked on the MacKenzie Spatial-Temporal Test and on the Dichotic Digits Task. Also, a relationship between the latter test and temporal order perception was not found.

These findings present several suggestions for future research, in respect to the population tested and the tests used. While it is believed that this sample is representative of 'normal' readers from the cooperating School Board, it is not believed that one can easily extrapolate from this group to other populations. It is therefore suggested that the intellectual level of the subjects be a factor for consideration in future studies. It is felt that a sample at such an advanced stage does not reveal developmental differences typical in other populations.

It is desirable that the upper levels of both the Dichotic Digits and MacKenzie Spatial-Temporal Test be increased to avoid ceiling effects. Further it is suggested that the time allowed for spatial presentations on the MacKenzie Test be reduced; this would not allow the pattern to be processed temporally and would therefore provide a better comparison between abilities in spatial and temporal processing.

VI. SUMMARY

This investigation of spatial-temporal processing and the relationship between temporal perception and hemisphere specialization developed from previous research in the area of sensory integration. The early work of Birch and Belmont reported correlations between deficiencies in the ability to integrate auditory and visual information and reading difficulty. Further research examining the spatial and temporal aspects of auditory visual integration has produced conflicting results. Studies such as Bryden (1972) report that difficulties lie in the tasks requiring a transfer between spatial and temporal stimuli, while other studies (e.g. Rudel & Denckla, 1976) report that temporal order perception is the problem. Few studies have dealt with the development of these abilities in children classified as normal readers.

The present study attempted to clarify the issues arriving from conflicting results and to investigate the developmental patterns in normal readers as well as to investigate the relationships between hemisphere specialization and temporal order perception and between reading ability and hemisphere specialization.

The MacKenzie Spatial-Temporal Test offers improvements over those used in past research in that it utilizes the same figures (meaningless symbols) in both spatial and temporal presentations, eliminating the need for transfer between stimuli necessary when flashes of light and patterns of dots were used. Additionally, this test reduces the memory load since only order recall, as opposed to both order and item recall, is required.

The subjects were three groups of right handed males, aged 7.6, 10.7 and 13.7 years, classified as 'normal' readers by their teachers. All subjects were believed to be from a middle-class socio-economic background. Characteristics of the sample were obtained by the WISC-R and the Speed and Accuracy Subtests of the Gates MacGinitie Reading Tests. All subjects were administered the four forms of the MacKenzie Spatial-Temporal Test and the Dichotic Digits Test.

Results of the MacKenzie Spatial-Temporal Test showed that while there was an increase in overall performance with age, the order of difficulty of the four forms of the test remained the same. Subjects of 116 and above IQ found the four forms to be of equal difficulty, while subjects of 115 and below IQ found the forms, S-S, S-T and T-S to be significantly more difficult than the T-T. All subjects indicated in interviews conducted upon completion of the testing, that they processed all forms of the test temporally and that this was facilitated by the application of a label to each symbol. Results of the Dichotic Digits Test revealed a significant right ear advantage at ages 7.6 and 10.7 years but not at age 13.7 years. Evidence of a relationship between hemisphere specialization and temporal order perception or between temporal order perception and reading ability was not obtained.

Recommendations for future research include suggestions regarding the selection of a sample of normal readers as well as recommendations for changes in the MacKenzie and Dichotic Digits Test.

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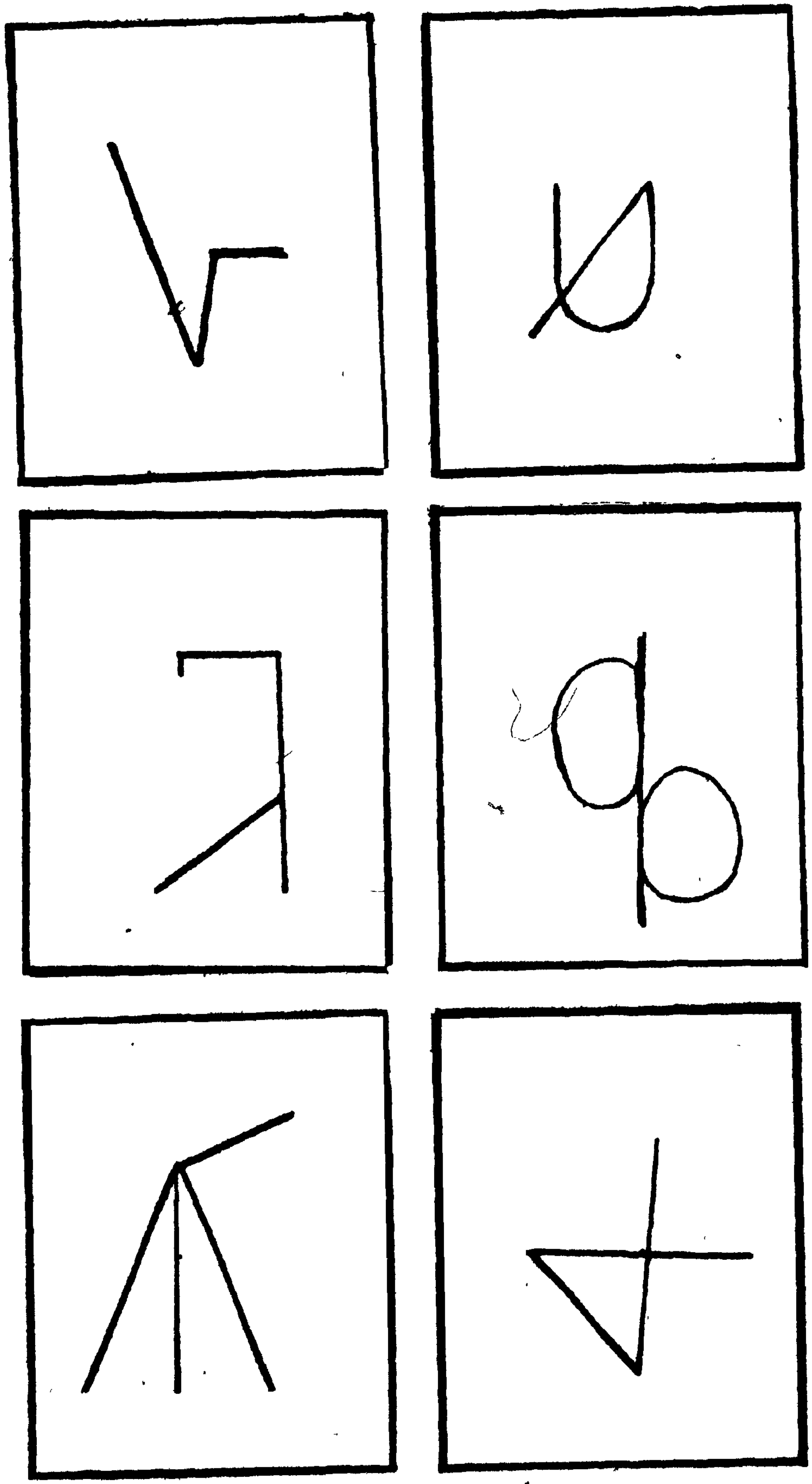
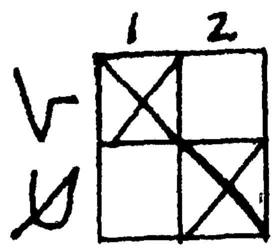
APPENDIX A

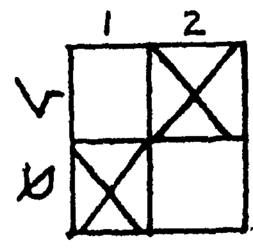
MACKENZIE SPATIAL-TEMPORAL TEST

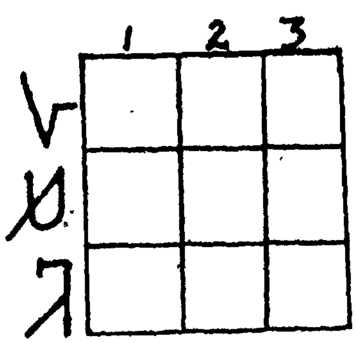
Symbols for Temporal Presentation

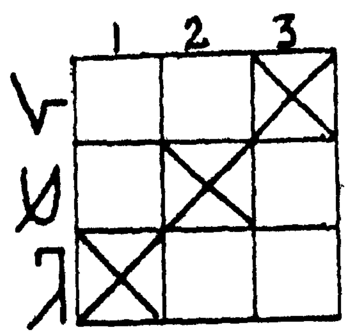


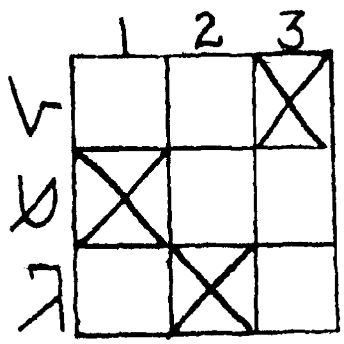
Spatial Presentations. The first three grids are practice trials.







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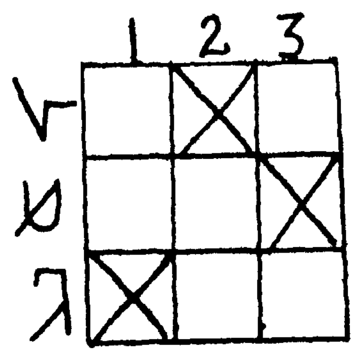
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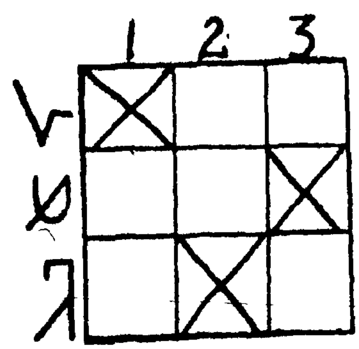
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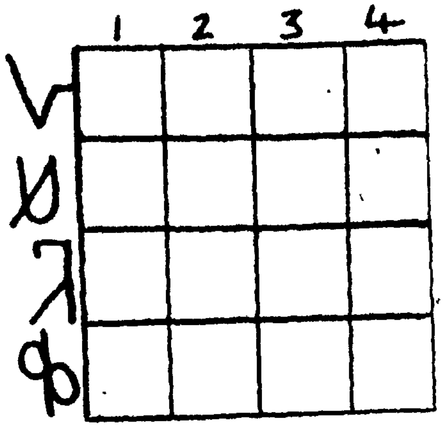
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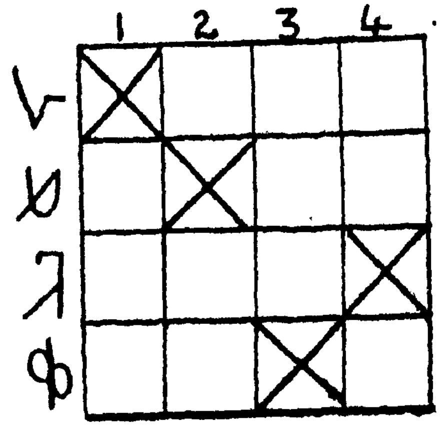
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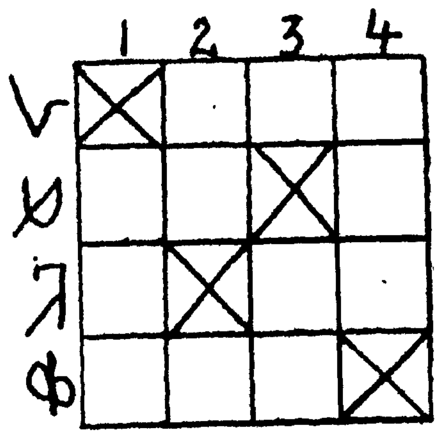
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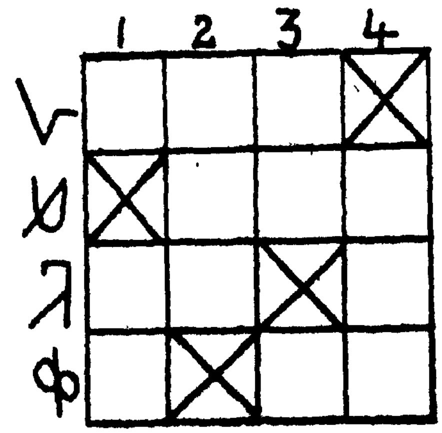
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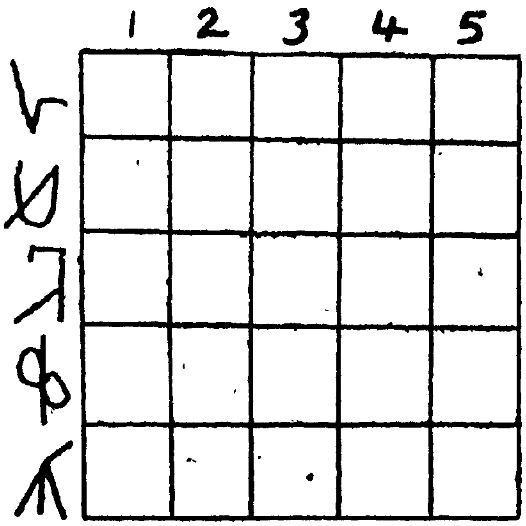
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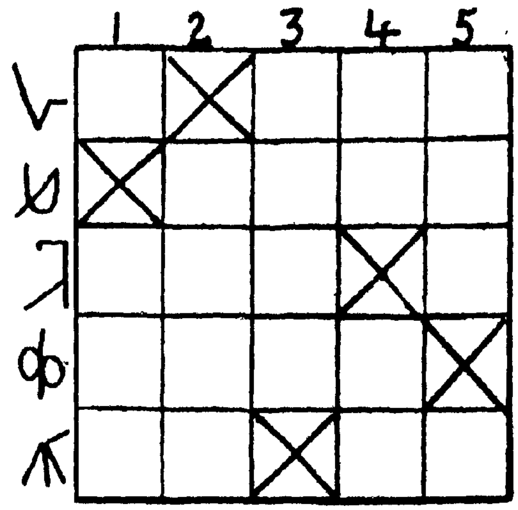
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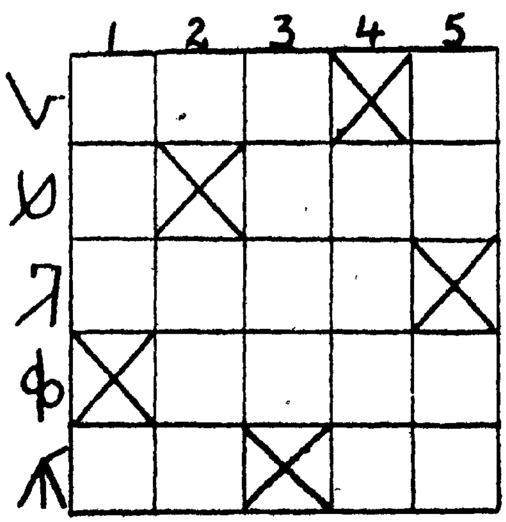
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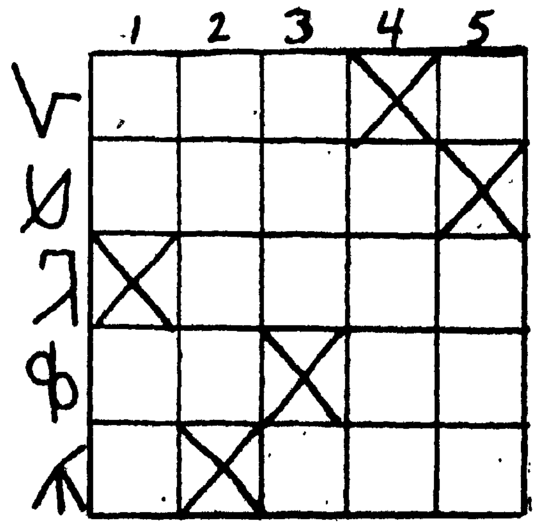
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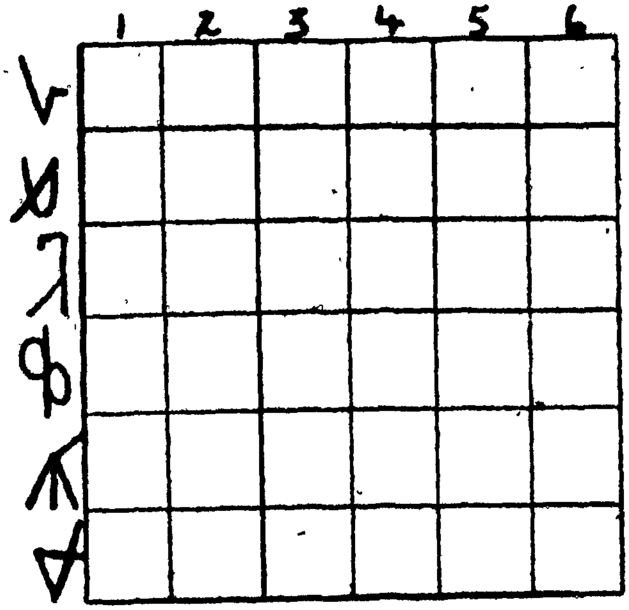
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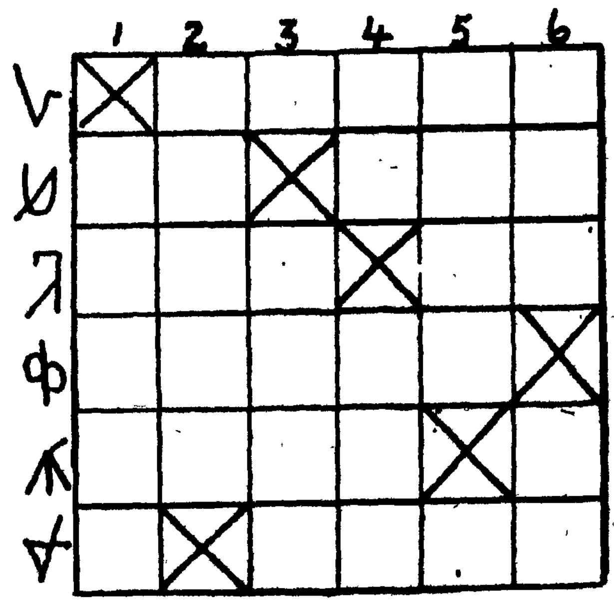
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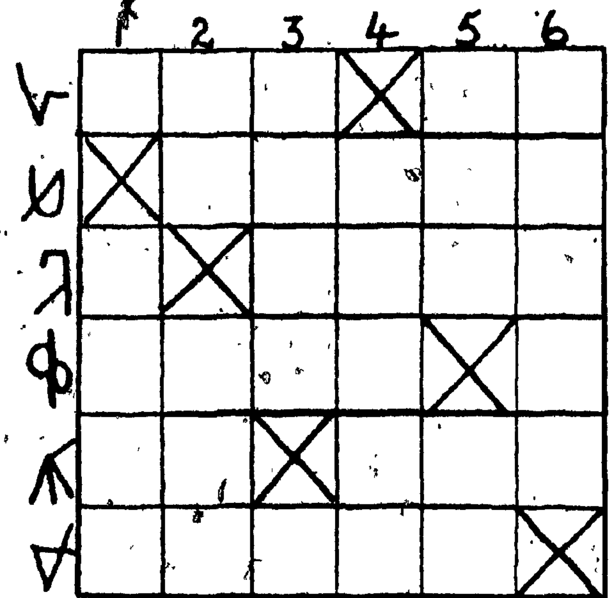
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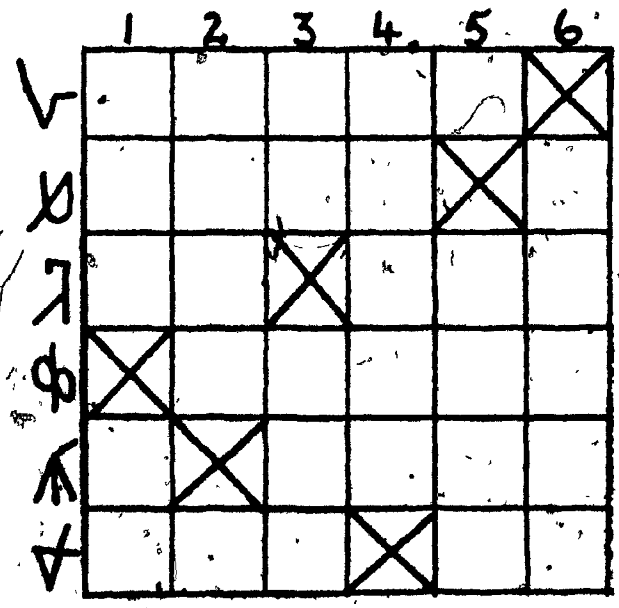
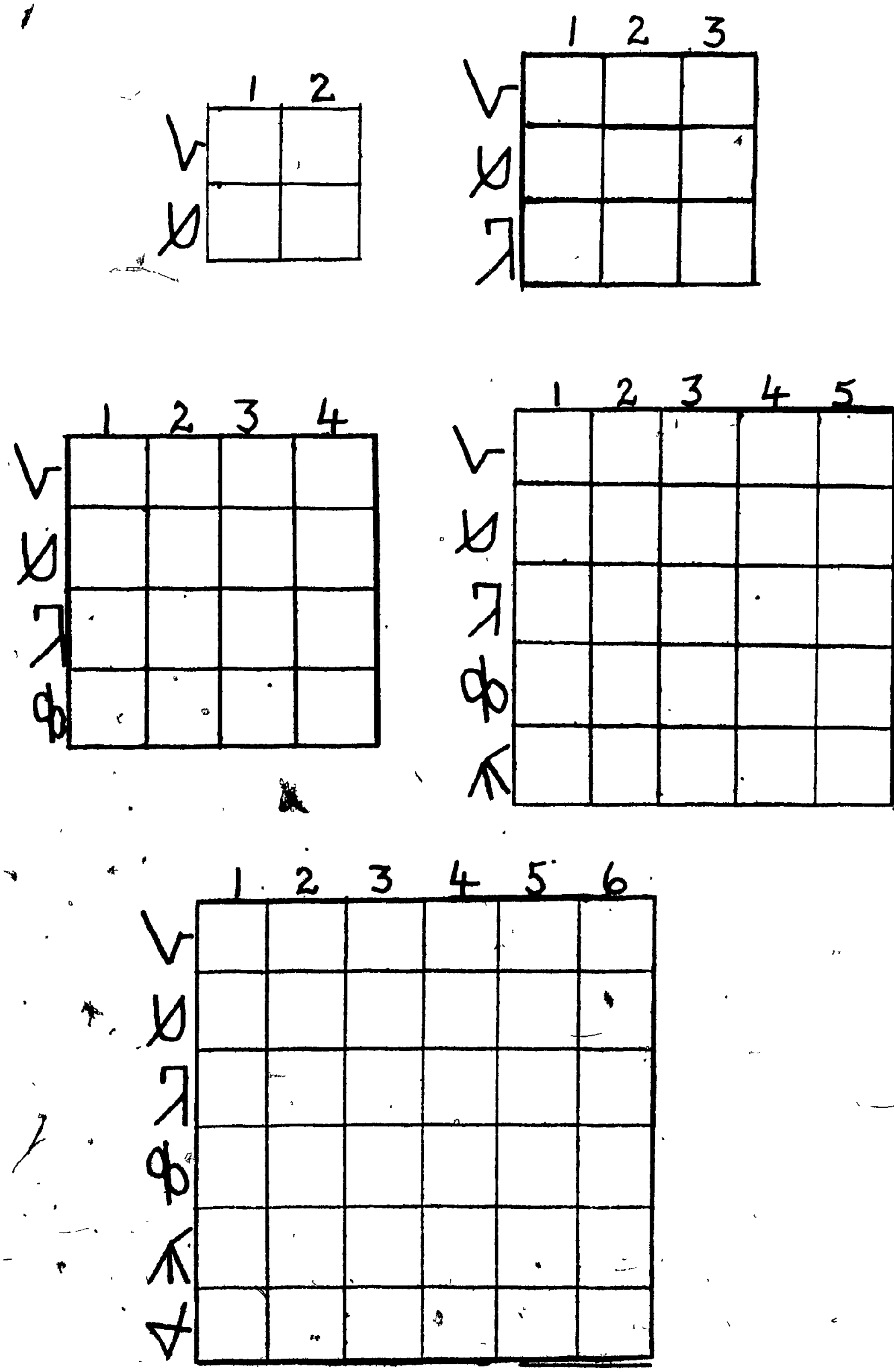

1 2 3 4 5 6

Examples of grids for spatial response.



APPENDIX B

DICHOTIC DIGITS TEST

Earphone -----	No.-----		Right	Left	Both
Test 1					
395	680				
750	293				
284	107				
132	584				
461	579				
023	748				
		total test 1			
Test 2					
587	649				
417	832				
069	257				
504	196				
265	380				
431	976				
		total test 2			
Change earphones No. -----					
Test 1					
680	395				
293	750				
107	284				
584	132				
579	461				
748	023				
		total test 1			
Test 2					
649	587				
832	417				
257	069				
196	504				
380	265				
976	431				
		total test 2			
		Grand Total			

APPENDIX C

DIRECTIONS FOR ADMINISTERING AND SCORING THE MACKENZIE SPATIAL-TEMPORAL TEST

The time allowed for viewing the symbols varies according to the number of symbols in each presentation. One second is allowed for each symbol, therefore, the spatial and temporal presentations range from two to six seconds. There is an interval of five seconds between presentation and response. No time limit is placed on the response. Testing ceases when three consecutive errors are made. One score is given for each correct presentation. Maximum possible score on each subtest is 12.

The test has four forms: spatial to spatial, spatial to temporal, temporal to temporal and temporal to spatial. The subject is shown the spatial or temporal presentation and asked to reconstruct it spatially or temporally. Three practice trials are given for each condition. Unless the first test is a purely temporal one (temporal to temporal) the subject is shown a sample spatial representation and instructed as to its interpretation:

"I'll show you how to read this pattern of x's (show pattern #1). See, we have signs here and numbers here. The x's tell us about the order the signs are in. See, this sign is first because the x across from it is under number 1. This sign is second because the x across from it is under number 2."

"Now look at this pattern." (show pattern 2). "Look at the x's. Put your finger on the sign that the x says is first." (if the subject cannot do this, then say, "It is this sign because the x across from it is under number 1.") "Put your finger on the sign that the x says is second."

Go back to card number 1 and say, "Is this sign first or second?" "Is this sign first or second?" Go to card number 2 and say, "Put your finger on the first sign." "Put your finger on the second sign." Proceed to either the spatial to spatial, spatial to temporal, temporal to temporal or temporal to spatial condition.

Since it was felt that directions for administering should be the same across age groups, very explicit language was used to ensure understanding in the youngest group.

Spatial to Spatial

Experimenter has grids displaying spatial patterns of symbols. Subject has empty grids.

"I am going to show you some patterns. After you look at a pattern and have waited for five seconds, I will say 'ready' and you may begin to make the pattern with your pencil on this paper by putting the x's in the right spaces." For practice trials, show patterns #1 and #2 (for 2 seconds each), wait five seconds and say, "Ready now make the pattern on your paper."

Show card #3 and say, "Look at this pattern. See, now we have one more sign and one more number." Proceed to card #4 (also a practice trial), display it (for 3 seconds), wait five seconds and say, "Ready, now make the pattern on your paper." Each time a new sign is introduced, show the blank grid first and say, "See, now we have one more sign and one more number." Proceed with successive patterns until three consecutive errors are made.

Spatial to Temporal

Experimenter has grids displaying spatial patterns of symbols. Subject has symbols on individual cards. Initially, the subject has only two cards and is given an additional one each time a new symbol is introduced.

"Now I am going to give you some cards with the signs on them. I will show you a pattern and after five seconds I will say 'ready' and you may put the signs on your cards in the same order they are shown in the pattern." For practice trials, show cards #1 and #2 (for two seconds each), wait five seconds and say, "Ready, place your cards so that the signs are in the same order they are shown in the pattern."

Show card #3 and say, "See now we have one more sign and one more number." Show card #4 (also a practice trial) for three seconds, wait five seconds and say, "Ready, place your cards so that the signs are in the same order as they are shown in the pattern." Each time a new sign is introduced, show the blank grid first and say, "See now we have one more sign and one more number." Proceed with successive patterns until three consecutive errors are made.

Temporal to Temporal

Experimenter and subjects have individual cards with symbols on them. Initially the subject has only the first two cards and is given an additional one each time a new symbol is introduced.

"I have some cards for you and some cards for me. Each card has a different sign on it. I am going to show you my cards in a special order and after five seconds, I will say, 'ready' and you may place your cards on the table in the same order. Let's start with these." Show sequence 1 and 2 (practice trials). Then say, "Now we are going to use one more sign." Give subject sign 3, and display the third sequence (also a practice trial). Proceed with the remaining sequences until three consecutive errors are made.

Temporal to Spatial

Experimenter has individual cards with symbols on them and subject has empty grids.

"I have some cards with signs on them. I am going to show them to you one at a time in a special order. After I have shown them to you, we will wait for five seconds, I will say 'ready', and you may put the x's in the pattern so that they are in the same order in which I showed them to you. The sign which you see first should have an x across from it, under number 1. The sign which you see second should have an x across from it, under number 2. Here are the first ones." Show sequence 1 and 2 (practice trials). Then say, "Now we are going to use one more sign." Show the new sign and pattern (grid) #3. Each time a new sign is introduced, the new grid should be shown as well. Proceed to #4 (a practice trial) and the remaining sequences, until three consecutive errors are made.

APPENDIX D

INSTRUCTIONS FOR DICHOTIC DIGITS TEST

Twenty-six series of three digit pairs were presented; the first 14 series, of which two were practice trials, at the rate of two pairs per half second and the next twelve series at the rate of two pairs per one and a half seconds. The earphones were exchanged interindividually in order to counterbalance possible channel effects.

Instructions were as follows: "Different numerals will be presented to each ear at the same time, followed by a pause. When you hear this pause I would like you to repeat, in any order, as many numerals as you can remember hearing."

Digits reported from the right and left ears were totalled separately. A grand total for both ears and for all series was also obtained. Maximum possible score was 144.

APPENDIX E

RAW DATA

ID | AGE | IQ | READING | SPATIAL TEMPORAL | DICHOTIC | HARRIS

Y. M. | V | P | F | F1 | F2 | F3 | SPEED | ACCURACY | SORT | SS ST TT TS | L R B

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010204[illegible]
020 [illegible]
030209[illegible]09100
040 [illegible]04080[illegible]05100
050[illegible]04050[illegible]079100
060200[illegible]04030[illegible]3071100
070207[illegible]04000401585[illegible]13100
080709109[illegible]590126102000901473708409[illegible]
090 [illegible]420201040630660960090
100[illegible]0403333506809[illegible]
110708[illegible]7609647[illegible]4404010602350009[illegible]100
120200[illegible]2020[illegible]00
1[illegible]0908384808609[illegible]0
140205[illegible]60934403480[illegible]0040504334208009[illegible]0
150[illegible]040[illegible]05667115100
160[illegible]3560735607[illegible]1[illegible]0610[illegible]39113[illegible]9100
170[illegible]812121011636412[illegible]7100
180[illegible]40521206[illegible]209002101[illegible]261601[illegible]6100
190[illegible]0703080745601[illegible]5100
200[illegible]2[illegible]3[illegible]1041008506511[illegible]5100
21[illegible]0[illegible]40650710407080756631[illegible]3090
22[illegible]0[illegible]0906560660466691351[illegible]00
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241[illegible]00129114133100116420404604583060607075161113100
2510061271127125116153103520585205931050803065767124100
26100711912312312012316069120741209012121212451[illegible]106100
2710101121081111031360935708061090900603060965[illegible]131100
28100510712011413310312359097620967206030508545410810Ö
29100510711711211011312659097620967106020807350408910Ö
301008114108112103133106530635406570090805055856114100
311305102091096083103106541005108690060011075868126100
321309112105109103116100591256312680071109056658124100
331307133129134140153133601256412690084006116169130100
341308123129128140133606012563126841111111057661231000
351306122115121116126146641257012690120910126970139100
361309115115118126126130611256312690120709066266128100
371306109131122136103130541005509990120912096969138100
381305122120123130153100541005309229007080607435810110Ö
391310115131126160126093591256312690090909105255107100
401308118118121113126140621257012688120810095948137100
411306112132124150130123520925609990121109117071141100
421307120114120123136100621257012690120910054451095100
431309106128118126113130520924607390111212096869137100
441309123143138176143110591256312690070506077067137100
451305130105121096143106591256312690120510095769126100
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