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MULTIMODAL SENSORY INTEGRATION AS A FUNCTION OF AGE AND
READING ABILITY

by Darla Lyn Drader

Thesis presented to the Faculty of
Graduate Studies of Carleton University
in partial fulfillment of the requirements
for the degree of Doctor of Philosophy

Ottawa, June, 1973

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of Graduate Studies acceptance of the thesis
"Multimodal Sensory Integration as a Function
of Age and Reading Ability"
submitted by Darla Lyn Drader
in partial fulfilment of the requirements for
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Abstract

The sensory integration abilities of good and poor readers were examined in two studies of intramodal, bimodal and trimodal integration. The effect of redundant information presented simultaneously in two sensory modalities on the ability to perform cross-modal equivalence tasks was of particular interest. In order to control for possible variation attributable to differences in within-modal functioning or to differences in the ability to perform a cross-modal task irrespective of redundancy, two control conditions were included. Thus in addition to studying trimodal integration, the present investigation examined intramodal and bimodal functioning. As well as serving as control conditions, the inclusion of the intramodal and bimodal tasks allowed examination of issues resulting from previous studies of sensory integration.

The 120 ten-to twelve-year-old boys included in the two studies were of average intelligence and had reading comprehension scores at or above their appropriate grade level (good readers) or two or more years below the appropriate grade level (poor readers). The children in the two age groups in the two studies (ten-and twelve-year-old boys in study 1 and ten-and eleven-year-old boys in study 2) were assigned to one of three conditions which required intramodal, bimodal or trimodal integration. Each main condition was comprised of three subtests. The intrasensory subtests required auditory-auditory (A-A),

visual-visual (V-V), and tactual-tactual (T-T) integration. The bimodal subtests required auditory-visual (A-V), visual-tactual (V-T), and tactual-auditory (T-A) integration. The trimodal subtests required auditory plus tactual-visual (A+T-V), visual plus tactual-auditory (V+T-A), and visual plus auditory-tactual (V+A-T) integration. Thus each child performed three of the nine subtests.

Each subtest involved "same different" judgements regarding the perceived equivalence of a standard and a comparison pattern which were randomly generated by the apparatus. The patterns ranged in length from four to nine pulses with five trials of each length. The positioning of two 1.0-second intervals distinguished the patterns. The usual interstimulus interval was 0.5 seconds and stimuli had a 0.2-second duration. The interpattern interval was 5.0 seconds and the intertrial interval was 10 seconds. The auditory stimuli were beeps presented over a set of headphones, the visual stimuli were flashes of light, and the tactual stimuli were taps on the index finger of the dominant hand.

Since there was a reliable correlation between reading scores and IQ scores, the data were analyzed using analyses of covariance. The results of study 1 revealed a development between ten and twelve years of age in the auditory intrasensory abilities of poor readers. There were no other age differences in the performance of the intrasensory subtests. The main effect of age was reliable in the analysis of the bimodal data. However, comparisons of the bimodal subtests to the appropriate intrasensory subtests indicated that this age change was not independent of intrasensory abilities. The analysis of the trimodal data did not reveal differences attributable to age.

Finally, the analyses of covariance did not reveal any differences between good and poor readers.

Study 2 was designed to overcome two difficulties in study 1. First of all, the task was difficult for all children and the possibility exists that a floor effect masked differences. Secondly, it could be argued that the younger children had greater difficulty understanding the instructions. Thus a preliminary training session was added to the study 1 procedure.

The results of study 2 indicated a general overall improvement in performance. On the intrasensory subtests the good readers performed better on the auditory intrasensory subtest than on the visual or tactual intrasensory subtests. The poor readers performed the intrasensory subtests as well as the good readers, but did not demonstrate a favored modality. There were no differences between the age or reading groups on the bimodal subtests. Performance of the trimodal subtests, however, favored the good readers.

The results of the two studies were discussed in relation to a number of issues concerning the importance of the format of presentation, the question of temporal-spatial translation, and issues concerning the appropriateness of the various remedial reading techniques.

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Glossary

bimodal integration - bisensory or cross-modal integration.

Birch-Belmont technique - The auditory pattern is tapped out in subjects view and is followed by the presentation of a card with three different visual patterns of spatially arranged dots. The subject is required to select the one visual pattern which he judges to be the same as the pattern he heard tapped.

bisensory integration - cross-modal integration involving two sensory modalities.

comparison pattern - the second pattern presented. The subject compares the comparison pattern to the standard pattern and judges to two patterns to be the same or different.

dyslexic children - children of average intelligence whose reading ability is two or more years below the normal grade placement.

haptic - active exploration of objects with the hands.

intersensory integration - the central synthesis of sensory information from different sensory modalities.

intramodal integration - intrasensory or within-modal integration.

intrasensory integration - the integration of information being received in one sensory modality (intramodal or within-modal integration).

sensory integration - the central synthesis of sensory information received in one or more modalities.

standard pattern - the first pattern presented against which the comparison pattern is judged as same or different. In some cases, more

than one comparison pattern was presented.

subtests - the three tests in each of the main conditions.

trimodal integration - cross-modal integration involving three sensory modalities.

trisenory integration - trimodal integration.

within-modal integration - intrasensory integration, intramodal integration.

Introduction

The present research was undertaken to examine the sensory integration abilities of good and poor readers. Sensory or perceptual integration is the central synthesis of sensory information received in one or more sensory modalities. When multiple stimuli are received in one modality, intrasensory integration is assumed to occur. When stimulation is received in different modalities, the process by which the stimuli are synthesized involves intersensory or cross-modal integration. There are several methods of studying sensory integration in humans.

The most commonly used technique is the method of equivalence (Kluver, 1933) in which stimuli are judged as same or different. Other available techniques include conditioning procedures, cross-modality learning and transfer, reaction time methods, and conditional learning. Since there are several types of test situations from which an operational definition of sensory integration can be obtained, a number of definitions could be arrived at depending on the type of test used. As Thom (1970) points out, such a possible diversity of definitions is one serious limitation of previous intersensory research.

One possible resolution, especially in research concerned with reading, is to use the test which most closely approximates the skill being investigated. Thus in a study of the relation of intersensory integration to reading ability, the test which most closely approximates the reading process should be the method used to operationally define

the construct. Basically, reading is the progression from spoken language to written language, the ability to communicate effectively using visual symbols (Gibson, 1965). The ability to read involves the differentiation of the visual symbols, the decoding of letters to sounds, and the ability to sequence the decoded letters to form higher-order units (Gibson, 1965). Reading also involves the temporal ordering of phonemes to correspond to sequences of visual symbols (Muehl & Kremenak, 1966). The importance of the central integration of information in different modalities and the ability to perceive temporal order correctly is evident. A task requiring equivalence judgements of temporally ordered patterns presented in different modalities could be said to approximate the reading task.

The Importance of Sensory Integration

At a theoretical level, the ability to recognize the equivalence of stimuli transmitted in different sensory modalities is thought to be an important aspect of the complex process of gaining and processing information about the world. A number of theories of intellectual development have stressed the importance of sensory integration skills. Piaget (1952), for instance, argues that cognitive growth is based on the continued formation of new, higher order interco-ordinated sensory-motor systems. The basic units of cognitive development in Piaget's theory are the hypothetical schemata which develop as a result

of two simultaneous processes, assimilation and accomodation.

Accomodation involves the incorporation of new information into the existing mental structures through modification of the schemata.

Assimilation is the corresponding process of perceptually altering the structure of new stimuli in such a way as to make the incongruent information more similar to the existing schemata. These two processes occur simultaneously and are said to be in equilibrium. Intelligence, according to Piaget (1952), is this process of mobile equilibration which is involved in adaptation to the environment. Intersensorial co-ordinations are of fundamental importance to the development of the mental structures.

In support of Piaget's notion that the quality and quantity of interaction with the environment determine the flexibility of central processes, Hunt (1961) points out that the complex operations characteristic of adult thought are not predetermined, fixed or heriditarily set down, but that such cognitive structures are the product of a long course of development in which each level of achievement is incorporated heirarchically into the next. One of Piaget's principles concerning the importance of organism-environment interaction deals with the internalization of actions into central processes. Piaget proposes that intelligence increases as central processes become more and more autonomous of perception and action. Accordingly Hunt (1961) stresses the importance of the integration of stimuli as a fundamental prerequisite to the operation of these higher-order autonomous

central processes.

Hebb's (1949, 1958) neurophysiological theory of intelligence stresses the importance of early experience in the development of perception. Perception, according to Hebb is a mediating link between sensation and response. In other words, perception is the central process governing the acquisition of new knowledge and the use of existing knowledge in the interpretation of new information. Hebb proposes a physiological mechanism, the cell assembly, as representing this perceptual process. Cell assemblies are neural mechanisms formed in response to external stimulation. Thus, they are central representations of external events.

As well as the theoretical emphasis on sensory integration in relation to cognitive development, Sabatino (1968) and Osgoode (1959) stress the importance of the integration of perceptual information in learning. According to Sabatino (1968), stimulation begins as sensory input which is coded neurally and transmitted to perceptual centers. Once perception or the integration of information into correct categories has occurred, information is relayed to higher cortical centers where language is formed into symbolic conceptual units. These language concepts provide for the formation of additional language symbols within the framework of the original conceptual categories. If the language concepts created additional language categories, language conceptual mediation has occurred. Of fundamental importance according to Sabatino is the integration of perceptual

information from more than one source and the memory storage of this information. Sabatino's model of learning stresses the necessity of higher centers receiving, associating and mediating symbolic units in a systematic manner. A breakdown in any one of these three processes could result in inaccurate information processing. Thus inadequate integration or association of sensory information would result in the transmission to the higher centers of inaccurate information.

Similarly, Osgoode's (1959) two-stage learning theory assumes that decoding and encoding involve three interactive levels of organization. These three levels are a projective level, an integrative level, and a representation or cognitive level. The emphasis again is on the necessity of a stage of integration in which afferent and efferent neural events are sequenced and ordered.

In all of the theories discussed, intersensory integration is implied or suggested as being one necessary foundation or basis for higher cognitive functioning. Comparative analyses of behavior systems (Birch, 1954; Maier & Schneirla, 1935) suggest that organized behaviour is the result of the development of organized patterns of functional relationships both within and between sense systems. The results of comparative neurophysiological studies led to Sherrington's (1951) classical statement: "Not new senses, but better liason between old senses is what the developing nervous system has in this respect stood for [p. 287]." Support for this doctrine is evident in comparative psychology. As one ascends the vertebrate series from fish to man, the

unimodal sensory control of behaviour is superceded by multimodal and intersensory control mechanisms (Birch, 1954; Maier & Schneirla, 1935). London's (1954) review of intersensory research points out the considerable evidence available to suggest that even for relatively simple sensory functions in man, the effects produced by the application of a stimulus to a given sensory organ are modified by ongoing activity in other sensory modalities.

Although the nature of the reading task suggests that the development of integrative organization between sensory systems is of fundamental importance to the ability to read (Gibson, 1965; Muehl & Kremenak, 1966), most research has concentrated on the functioning of the separate sensory systems. Several studies have suggested that auditory discrimination skills are related to reading ability (Bond, 1935; Dykstra, 1966; Durrell & Murphy, 1953; Goetzinger, Dirks & Baer, 1960; Harrington & Durrell, 1965; Silver & Hagin, 1966; Thompson, 1963). However, as Doehring and Rabinovitch (1969) point out, most of these studies have involved speech sounds or words, and some have used verbal tests such as the Wepman Auditory Discrimination Test (1958) to assess auditory perceptual functioning. According to Doehring and Rabinovitch (1969), deficits on these tests could be the result of verbal-symbolic deficiencies as well as auditory perception defects. In order to minimize the verbal requirements, Doehring and Rabinovitch (1969) used an oddity response and presented separate tests for the discrimination of pitch, loudness, simultaneous tones,

successive tones, and speech sounds. The results of the study suggested that children with learning problems were normal in their responses to verbal stimuli and to the simplest of nonverbal stimuli. However, the group with learning problems were less accurate in responding to more complex nonverbal stimuli. Doehring and Rabinovitch (1969) suggest that further research is required since the precise nature of auditory deficit was unclear. Silver and Hagin (1967) have suggested that temporal sequencing of auditory sounds may be an important aspect of the retarded readers perceptual deficiency. Since the sounds were presented temporally in the Doehring and Rabinovitch (1969) study, it could be the case that temporal sequencing rather than auditory discrimination is deficient.

The various investigations of visual perceptual abilities in relation to reading skill have also produced conflicting evidence. Goins (1958) and Lyle and Goyen (1968) for instance reported differences between good and poor readers on a variety of tests of visual perception favoring the good readers. On the other hand, Nielson and Ringe (1969) administered the Frostig Test of Visual Perception, the Bender Visual Motor Gestalt Test and the Goodenough Draw-a-Person Test to groups of normal and retarded readers and found that visual perception did not appear to be an important correlate of reading ability. Similarly, Benton (1962) suggest that defects in visual perception are not the causative factor in reading problems.

Following the Birch and Belmont (1964) conceptual framework, the reading process can be viewed as involving several different categories of auditory and visual sensory integrations: the auditory intrasensory integration of sound patterns, the visual intrasensory integration of graphic patterns, and the cross-modal integration of auditory patterns and visual patterns in which the appropriate sound sequences are produced in response to the visual sequences and visa versa. Thus, the importance of any single modality, aside from gross defects in the functioning of a modality, should probably be considered secondary to the ability to integrate information from two or more sensory systems since reading instruction involves the presentation of visual and auditory as well as perhaps tactile stimulation.

Ontogenetic Trends in Sensory Integration

A number of studies have examined age changes in the ability to match geometric forms cross-modally. For instance, Birch and Lefford (1963) required children aged five to eleven years to judge the equivalence of shapes in three integration tasks: visual to haptic, visual to kinesthetic, and haptic to kinesthetic. The ability to make various intersensory judgements improved with age. By age eleven there were almost no errors, with most rapid growth taking place between six and eight years of age. Blank and Bridger (1964) found

an improvement in haptic to visual equivalence judgements of shape at an even earlier age. Three-year-old children performed at a below chance level, the four- and five-year-old children performed at a level some what better than chance, and the six-year-old children had an average of 95 percent correct (Blank & Bridger, 1964).

A similar developmental study of intersensory abilities (Connors, Shuette & Goldman, 1967) required kindergarten, first-, third- and sixth-grade children to point to the geometric form which looked the same as the form the child was examining haptically. The results indicated ontogenetic changes in haptic to visual integration. The greatest development in haptic-visual abilities appeared to have occurred before the age of five years which is in agreement with Birch and Lefford's (1963) position that the most rapid period of visual-haptic growth is before the age of 5 years. Blank and Bridger (1964) as well report results in accord with this early development hypothesis.

A change in the method of tactual examination of the forms was employed by Kinsbourne and Warrington (1963) to examine the development of passive haptic shape perception in 4 1/2- to 7 1/2-year old children. The wooden shapes were molded into the hand's grip and a visual recognition match was required. The developmental improvements reported are consistent with those reported by Birch and Lefford (1963). At 4 1/2 years old, 32 per cent of the children were able to perform the

task. At 5 1/2 years of age the percentage of subjects passing had risen to 55. By 6 1/2 years of age 78 percent matched the forms correctly.

Using a considerably different task which required children to construct or to recognize a stimulus of an equivalent magnitude in a different sensory modality, Abravanel (1968) confirmed the age trends in integration of visual and haptic stimulation. In this study, the greatest increase in accuracy occurred between the ages of three and seven years.

Taken together, these studies of visual and haptic integration suggest age trends in the ability to match cross-modally. A number of unanswered questions remain however. Possibly the developmental trend in cross-modal matching is attributable to developments in the ability to integrate information within one modality. Thus, an age change in visual to haptic judgements could reflect a development in the ability to discriminate and process visual information rather than an improvement in the ability to integrate cross-modally. Bryant (1968) argues that the results of developmental studies of sensory integration across modalities are not valid in the absence of a within-modal (intrasensory) control condition. Thus, he suggests that it is reasonable to conclude that subjects cannot integrate across modalities only if more errors are made in the cross-modal condition than in the within-modal condition.

Very few studies of sensory integration abilities have included this important control. Rudel and Teuber (1964) studied shape discrimination in two cross-modal tasks (visual to tactual and tactual visual) and in two intrasensory tasks (tactual to tactual and visual to visual). Four-year-old children made consistently more errors than five-year-old children in all four conditions. At both age levels more errors were made in the tactual to tactual condition than in either of the cross modal tasks. Thus the difficulty apparent in the cross-modal situation could be attributable to tactual discrimination difficulties rather than integration difficulties. Unfortunately Rudel and Teuber (1964) did not statistically evaluate their data. Another study of shape discrimination confirmed these findings however. Milner and Bryant (1970) studied the ability of five-, six- and seven-year-old children to match two-dimensional shapes between and within the modalities of vision and touch. The rate of improvement with age was not different for the cross-modal than for the within-modal condition. Age changes in cross-modal integration were quite possibly based on changes in intramodal discriminatory abilities.

Recently, Rose, Blank and Bridger (1972) reported that intramodal tactual matching of form and texture by three-year-old children is neither better nor worse than intramodal visual or cross-modal matching when memory demands were eliminated from the task. However, with delayed presentation of the comparison patterns, there was a sharp

decline in accuracy for all conditions involving a tactual component. This suggests that age changes in visual to tactual cross-modal matching could be attributable to development in the retention of tactual information.

Few studies have examined the development of the auditory and visual integration systems. Birch and Belmont (1965) studied auditory-visual equivalence in 220 normal children between the ages of five and twelve years. The task was an auditory to visual pattern matching test in which the child was required to identify one of the three spatially arranged visual dot patterns which was the same as a pattern of auditory taps. The performance of the kindergarten children indicated that 70 percent of these children were functioning at a chance level. There was improvement in performance until the fifth grade level. By grade five, the ability being measured appeared to have reached its asymptote. The most rapid growth in auditory-visual integration occurred between kindergarten and second grade, the same age period cited as the period of greatest change in visual and haptic integration abilities (Blank & Bridger, 1964; Kinsbourne & Warrington, 1963). However, Muehl and Kremenak (1966) report that auditory intrasensory integration is more difficult for first graders than auditory to visual, visual to auditory or visual to visual integration suggesting that auditory ability develops later than visual ability. Since Birch and Belmont (1965) did not include the intrasensory controls, the development in cross-modal integration may reflect an improvement in

the auditory ability. Vande Voort, Senf and Benton (1972) for instance, report auditory and visual intrasensory and cross-modal integration data for eight-to twelve-year-old children which question the Birch and Belmont (1965) conclusions. Using a 3-second or a 6-second interval between the initial and comparison stimulus patterns, Vande Voort, Senf and Benton (1972) found a sharp difference between the older and younger children on the A-V task at the longer interval favoring the older children. However, they failed to obtain a significantly greater age effect on the A-V task compared to the A-A and V-V tasks at the shorter 3-second interval. It appears that memory demands may be responsible for the apparent age difference on the cross-modal task. However, examination of the appropriate data failed to reveal an overall effect of the length of the interval. As an alternate hypothesis Vande Voort, Senf and Benton (1972) suggest the processes involved in the accurate encoding of the initial stimulus may be more important than memory.

Another possible explanation of developmental changes in integration abilities concerns the necessity of translating temporal information to spatial information. The Birch - Belmont (1965) A-V technique requires the subject to match auditory-temporal to visual-spatial patterns. Thus a development in the auditory to visual ability could reflect an age change in the ability to translate information from a temporal to a spatial format. Klapper and Birch (1971) investigated within-modal matching of temporally arranged visual and auditory

stimuli. Compared to performance with spatially presented visual patterns, within-modal matching of temporally presented visual patterns was more difficult. Kuhlman and Wolking (1972) studied auditory and visual intrasensory and cross-modal integration in which all stimuli were presented temporally and found that the difficulty of the task depended on the modality of the initial stimulus rather than whether the task was intrasensory or cross-modal suggesting that cross-modal skills develop at the same time as within-modal skills. This result questions Birch and Belmont's (1964) hypothesis that cross-modal skills develop later than within-modal skills.

The bulk of the evidence suggests that improvements in cross-modal integration with age are attributable to improvements in discriminatory ability within a specific modality. Although Birch and Belmont (1965) report that performance reached an asymptote by grade 5, the task was relatively easy and the data may reflect a ceiling effect in task difficulty. Kuhlman and Wolking (1972) report an age change in within- and cross-modal matching between the ages of five and eight. The performance of the eight-year-old children had not reached an asymptotic level although the task was relatively easy. Thus it is possible that development continues beyond age eight.

One question to which the present study will address itself concerns the development of sensory integration abilities. Specifically, are there age changes in the cross-modal integration of auditory, visual and tactual temporal patterns which are independent of age changes

in intrasensory abilities?

Sensory Integration and Reading Ability

Several experimental techniques have been used in the examination of the sensory integration abilities in relation to reading skill. These techniques usually involve (a) reaction time measures, (b) serial learning, (c) paired associate learning, or (d) equivalence judgements. Although most studies have used the equivalence task, studies employing the other technique will be considered briefly.

(a) Reaction Time Measures

Raab, Deutsch and Freeman (1960) compared the performance of normal school children of different reading achievement levels on a reaction time task. The Stanford Reading Achievement Test was used to classify 24 children ranging in age from 9.6 to 12.5 years as good readers (reading at or above grade level) or as poor readers (reading at a level one year or more below grade level). Good readers were able to shift responses from one sensory modality to another (light to sound) more efficiently than the reading retarded children. The correlation between IQ scores and modality shifting scores was not significant. Although reaction times to sound were similar for both groups, the poor readers were slower to respond to the onset of a visual stimulus than the good readers. This finding lead Raab, Deutsch and Freeman (1960) to suggest that poor readers might benefit from an auditory approach rather than the traditional visual channel emphasis.

In a later study, Katz and Deutsch (1963) attempted to obtain developmental data on the relationship between auditory-visual shifting and reading achievement. Grades 1, 3, and 5 were selected for the study and 48 children were included in the experiment. The first-grade children were administered the Reading Prognosis Test and the third-and fifth-grade children were given the Gates Advanced Primary Reading Test. Good and Poor readers were defined as the upper and lower thirty percent of the children tested. Reaction times to the auditory and visual stimuli indicated that all children required more time to respond to stimuli preceded by stimuli in a different modality and that older children have faster over-all reaction times. The poor readers experienced more difficulty than normal readers in shifting from one modality to another. As in the Raab, Deutsch and Freeman (1960) investigation, the correlation between IQ scores and performance scores was not reliable.

(b) Serial Learning

Katz and Deutsch (1964) presented three lists of four pictures (visual) and four nouns (auditory) and required the subject to repeat the eight items after each trial. Lists were also presented in the auditory modality only and in the visual channel only. Generally, good readers remembered more items, and memory for auditory stimuli was poorest for all subjects. Retarded readers learned more slowly in general and had particular difficulty with auditory stimuli. The auditory-visual task was easier than the auditory task, but more

difficult than the visual task.

Although this finding suggests that visual modality learning will be easier, particularly for the retarded reader, other studies using words or digits rather than pictures as stimuli have found auditory learning to be superior for both good and poor readers, with the advantage of the auditory over visual learning greater for poor readers (Dornbush & Bassow, 1970; Senf, 1969). Generally fourth- and fifth-grade children have been shown to learn meaningful information better with auditory presentation while older children and adults show a superiority for visual presentation (Senf, 1969). However, Geschwind (1964) suggests that visual perceptual abilities are less important to reading progress by age nine while variations in auditory perceptual abilities and in the ability to transpose between the auditory and visual modalities become more important.

Generally, studies of the visual and auditory learning abilities of good and poor readers have provided contradictory data. The overall impression is that both good and poor readers perform better on auditory tasks involving words or digits than on visual tasks, but the discrepancy for poor readers is considerably greater. Dornbush and Bassow (1970) found that more auditory material than visual material was recalled by both good and poor readers when different digits were presented successively between channels to the auditory and visual modalities. Recall, however, was not of a function of reading level.

The subjects in this experiment were required to store auditory information then visual then auditory in rapid succession. When the rate of presentation of the visual material was decreased, recall for visual information increased. No changes occurred in auditory recall as a function of decreases in the rate of presentation of auditory information.

Senf (1969) suggested that retarded readers may store visual symbols in a different form than the stored auditory symbols whereas good readers store both kinds of information in a similar way. According to Senf (1969) these different storage systems may result in the necessity for the retarded reader to translate the visually encoded material into the same internal representation as the stored auditory material. This line of reasoning suggests that cross-modal integration should be more difficult for the retarded reader than intramodal integration, since an extra step is involved in the cross-modal situation. The cross-modal task would not necessarily be more difficult for normal readers, however, since visual and auditory information is assumed to be stored in the same way. Bjorkman (1967) argues that intramodal integration should be easier than cross-modal integration for at least two reasons. Firstly, there are more common aspects when stimulus information is presented only in one channel. Secondly, the two perceptual systems involved in cross-modal integration may work independently even though the important aspects to be compared may be the same. Bjorkman argues that the two discriminable dispersions

resulting from input in two modalities should be more independent than when they belong to the same modality. The accuracy of cross-modal matching should therefore be lower than, or, in the limiting case, equal to the accuracy of intramodal matching. Following Senf's (1969) suggestion regarding the possible use of different internal representations for information in different modalities, it seems reasonable to suggest that the retarded reader will have even more difficulty with cross-modal integration relative to intramodal integration than the good reader.

(c) Paired-Associate Learning Tasks

Zigmond (1966) studied the intrasensory and intersensory integration abilities of good and poor readers using auditory-auditory, visual-visual, auditory-visual, and visual-auditory verbal paired associates. Although the poor readers had greater difficulty with the A-A and A-V tasks than the good readers, there was no difference in performance on the V-V and V-A tasks. Zigmond (1966) suggested that the results of this study support the Birch and Belmont (1964) finding that poor readers are deficient in A-V integration. Zigmond (1966) also suggested that auditory deficiencies are more important to reading disabilities than are visual deficiencies.

In a similar study, MacKinnon and McCarthy (1973) required good and poor readers to learn nonsense sounds in association with various letterlike forms. The good readers were superior to the poor

readers on this task. According to MacKinnon and McCarthy (1973) the major source of difficulty seemed to be in the association of the visual with the auditory symbols. However, there were no intrasensory controls in this study and the method of defining good and poor readers was unusual. The subjects were classified as good or poor readers by subtracting the IQ standard score (Otis Quick-Scoring Test of Mental Ability) from the reading standard score (Gates-MacGinitie Reading Test). Children obtaining negative scores formed the poor reader group and children obtaining positive scores formed the good reader group.

Vellutino, Steger and Pruzek (1973) suggest that the verbal nature of the auditory tasks employed in the Zigmond (1966) study make it difficult to interpret the difficulty the poor readers experienced in that study. In order to minimize the possibility that previous learning affects performance on a paired associate task, Vellutino, Steger and Pruzek (1973) used a nonverbal intrasensory and intersensory paired associates. The poor readers performed the A-A, V-V, and V-A tasks as well as the good readers. Thus, Vellutino, Steger and Pruzek (1973) suggest that the retarded reader does not have a generalized intersensory functioning defect.

(d) Equivalence Judgements

Most of the studies on sensory integration in relation to reading ability have employed the method of equivalence. Nonverbal stimuli are used to avoid differences in letter and word knowledge

which associated with different reading levels. The procedure usually involves a visual presentation of spatially ordered dots and an auditory presentation of temporally ordered sounds. The children are required to identify a visual dot pattern that corresponds to or matches the pattern of auditory stimulation or visa versa. Birch and Belmont (1964) first used the technique in examining the sensory integrative abilities of retarded readers. Their procedure, which has come to be known as the Birch-Belmont technique, involves the tapping of an auditory temporal pattern followed by the presentation of three visual dot comparison patterns. The subject is required to select one of these patterns as being identical to the auditory pattern.

The subjects in Birch and Belmont's (1964) study were 150 boys who were at the lowest 10 percent level on at least three out of four of the reading tests administered, and 50 boys matched with the poor readers on the basis of birthdate and grade, who were not in the lowest 10 percent of readers. The tests were a British sentence reading test, Form N.S. 6, published by the National Foundation for Educational Research, and three parts of the American Metropolitan Achievement Test, Elementary Battery, Form B, Test 1, Word Knowledge, Test 2, Word Discrimination, and Test 3, Reading. All children had IQ scores greater than 80 on the Otis Quick Scoring Test. The results indicated that the poor readers did significantly less well on the auditory-visual equivalence task than the good readers. There are, however, a number of confounding factors which challenge the conclusion that retarded

readers have a deficit in the ability to integrate information across modalities. First of all, performance on the integration task was related to IQ. Although Birch and Belmont (1964) argue that the relationship between integration performance and reading cannot be attributed to IQ differences, this conclusion seems unwarranted since the data of all children with IQ scores below 100 were eliminated. A second source of difficulty lies in the fact that the visual patterns were presented spatially and the auditory patterns temporally. Poor auditory to visual matching could possibly be attributed to a difficulty transposing temporal information to a spatial format for comparison. A third source of difficulty in Birch and Belmont's (1964) interpretation of their data stems from the fact that within-modal controls were not included.

A developmental study of the relation of auditory-visual integration to reading ability (Birch & Belmont, 1965) reported a decreasing correlation with age between integration performance and reading, but an increase with age in the relation between IQ and reading ability. This could mean that initial reading problems are related to sensory integration difficulties whereas, at the older age levels, intellectual skills become more important. This makes sense in view of the fact that advanced reading involves comprehension more than the mechanical translating of visual symbols to auditory sound patterns which is probably more important initially. Unfortunately, Birch and Belmont's (1965) developmental study is subject to all of the criticisms pertaining

to their earlier study. Thus, meaningful conclusions are impossible.

Several studies have examined the relation between auditory-visual integration and reading abilities using minor variations on similar techniques. Kahn (1965) for instance added ten new items to Birch and Belmont's existing ten items in an attempt to raise the difficulty level of the task. The subjects were 350 boys, 70 per grade, randomly chosen from the second to the sixth grade. In addition to the test of auditory-visual integration, the Metropolitan Reading Achievement Battery, the Lorge-Thorndike Intelligence Battery, and Digit Span subtest of the Weschler Intelligence Scale for Children were administered. The results of Kahn's (1965) study indicated a positive correlation between chronological age and auditory-visual integration scores in addition to significant positive correlations at all grade levels between reading achievement and integration scores. Intelligence was also found to be positively related to integration scores. Procedures which measured visual discrimination, auditory rhythm discrimination, and auditory memory suggested that these factors could not account for the results. The data obtained by Kahn (1965) support the suggestion that a ceiling effect may have masked correlations between reading and auditory-visual integration in Birch and Belmont's (1965) older aged groups. However, these data are subject to the criticism concerning the different formats of the auditory and the visual patterns and the failure to include intrasensory controls since the

technique was basically the same as that used by Birch and Belmont (1964, 1965).

In contrast to Kahn's (1965) finding that a lengthened version of the Birch-Belmont technique resulted in a greater discriminatory ability between good and poor readers at all grade levels tested, Beery (1967) did not find that lengthening the Birch-Belmont technique by ten stimuli increased the discriminability of the test. Since no information is presented on the exact stimuli added or scores obtained at each age level the possibility exists that Kahn's items increased the difficulty of the test while Beery's items did not. Nevertheless, regardless of the length of the test and whether the standard was auditory or visual, the ability of dyslexic children to match auditory and visual stimuli was significantly inferior to that of average readers.

Although Beery (1967) attempted to select children of different reading levels, the method used to define the groups is questionable. The dyslexic children were all at least two years behind in reading and the average readers obtained reading scores within two years of the appropriate grade placement. Thus the possibility exists that some of the average readers were almost two years behind. This could have reduced differences between the two samples. In addition, a wide range, eight to thirteen years, was sampled, but the total number of children included in the study was small. Different factors may be important different ages (Birch & Belmont, 1964; Kahn, 1965; Rudnick, Sterritt &

Flax, 1967) and more children should have been tested at each age or the study should have confined itself to one age group in order to reduce the variability possibly attributable to this age related factor.

Muehl and Kremenak (1966) used only one visual comparison pattern and presented the auditory stimuli with an electric telegraph key to avoid the possibility that there are extraneous visual cues as a result of the tapping procedure used by Birch and Belmont (1964, 1965). The subjects in the Muehl and Kremenak (1966) study were 119 first-grade children. Reading readiness was assessed with the Harrison-Stroud Reading Readiness Profiles, Intelligence was assessed by the Lorge-Thorndike Intelligence Test and reading ability at the end of the first year was assessed with the Metropolitan Achievement Tests. Children were required to match auditory to auditory, visual to visual, auditory to visual, and visual to auditory stimuli. The group of poor readers were the children whose scores were below the 60th percentile on the Metropolitan reading test, and the good readers all had scores above the 60th percentile. The visual-visual task was easiest and the auditory-auditory task was the most difficult. The cross-modal matching tasks were intermediate in difficulty. Neither the ability to match visual pairs nor auditory pairs contributed to predicting reading achievement. However, beginning-of-the-year ability to match visual to auditory and auditory to visual pairs made significant contributions to predicting reading. In addition the ability to relate information across the visual and auditory modalities, with IQ controlled,

was markedly associated with later reading achievement. The fact that intramodal matching was not related to reading achievement does not eliminate the possibility that the auditory intrasensory integration difficulties can account for the cross-modal difficulties.

The finding that auditory intra-modal matching was the most difficult opposes the general finding of reaction time and serial learning tasks that auditory learning and recall is the easier of auditory or visual presentation tasks. There are several possible explanations. The cross-modal equivalence task may not involve the same central processes as the recall task. Alternatively, the use of non-meaningful information in the equivalence tasks may be the differentiating factor. However, procedural limitation associated with the use of temporal auditory stimuli and spatial visual stimuli has already been discussed.

In order to assess and control any effects that the Birch-Belmont tapping procedure may have had on auditory-visual integration scores, Sterritt and Rudnick (1966) employed the Birch-Belmont technique in addition to a test using purely auditory stimuli, and a third using purely visual stimuli. In each case, the child had to select one of three spatial dot patterns which was the same as the one which he had seen or heard. The subjects were 36 boys in fourth grade. The Lorge-Thorndike Intelligence Scale and the Iowa Tests of Basic Skills were used to assess mental age and reading ability respectively. Mental age (MA) was found to be a significant independent determinant, accounting for 50 percent of the variance of reading scores. Neither the Birch-Belmont

technique nor the visual-visual test made a significant contribution independently of MA. The auditory-visual matching test using purely auditory stimuli was, however, a significant independent predictor of reading scores. Sterritt and Rudnick (1966) found that the use of multiple regression equations to control for the effects of intelligence led to strong relationships even at the grade four level, between sensory integration and reading ability. As well as the failure to administer an auditory intrasensory task, it is plausible that the difficulty relates to temporal-spatial ordering rather than deficient intersensory integration.

The percentage of reading score variance accounted for by the purely auditory sensory integration test was high in spite of the fact that few errors were made on each of the three tests. The constricted range of scores may have resulted in reduced correlations between integration test scores and reading scores. Rudnick, Sterritt and Flax (1967) replicated the study using third grade boys. A greater range of scores did not occur in the third grade, and prediction of reading scores was not as good for the third graders as it had been for the fourth graders. Mental age and performance on the purely auditory integration test (auditory to visual matching) predicted reading at the third level, although the percentage of reading score variance accounted for dropped somewhat. An additional finding was that the visual to visual matching test predicted reading in third grade children but not in the fourth grade sample. These authors interpret this finding

as suggesting that visual perceptual abilities become less important to reading progress while the ability to integrate auditory and visual information becomes more important with age. Geshwind (1964) made a similar suggestion based on studies of the auditory and visual perceptual abilities of good and poor readers. However, the relationship between visual intrasensory abilities and reading ability has more important implications: the cross-modal deficit could be attributable to underlying intrasensory deficits. The failure to include an auditory intrasensory control in either the grade 3 or grade 4 study makes the conclusion of a cross-modal deficit even more suspect. With the inclusion of an auditory control, Vande Voort, Senf and Benton (1972) did not find retarded readers to have greater difficulty with the cross-modal task than with the intramodal task.

A few studies have assessed the relationship of tactual-visual integration to reading achievement. Buchner (1965) for instance assessed the relationship between school achievement, intelligence and tactual-visual integration in 110 fourth grade children. The children were required to choose one of four visual shapes which matched a shape they had examined tactually. The Metropolitan Achievement Tests were used to assess school achievement and the Lorge-Thorndike Intelligence tests were used to assess intelligence. Performance on the 32 item test of tactual-visual integration was highly correlated with intelligence and with performance on the reading and word comprehension subtests of the Metropolitan Achievement Tests. No attempt was made to control for

the effects of intelligence or intramodal abilities.

A second study which has also assessed tactual-visual integration in fourth grade boys reported a low correlation between tactual-visual integration scores and reading achievement (Ford, 1967). Reading achievement was assessed by the Iowa Tests of Basic Skills. These results are in contrast to those obtained by Buchner (1964). In addition, Ford (1967) found that the auditory-visual test showed low but significant relationships with intelligence and reading achievement, confirming Kahn's (1965) fourth grade results. When intelligence was controlled statistically, the relationship between auditory-visual integration and reading disappeared (Ford, 1967). The role of intelligence remains unclear since Kahn (1965) and Sterritt and Rudnick (1966) found that intelligence could not account for all of the reading score variance.

A study by Thom (1970) investigated the relationship of intersensory intergration to grade one reading achievement in two groups of children, one of which was taught by the multisensory-motor method and the other by the sight-word approach. Scores were obtained at the beginning of the year on the Dominion Group Test of Reading Readiness and the sensory integration tests. Later in the year achievement scores were obtained and the sensory integration tests were readministered. Differences were found between the two groups on the sensory integration tests as well as on the test of achievement in the absence of pretest

differences in reading readiness, sensory integration or IQ.

The intersensory integration tests included measures of tactual-visual integration, auditory-visual integration, and proprioceptive-visual abilities. Each test consisted of ten test items in addition to practice items. In addition to the finding that subjects taught by the multisensory-motor method achieved higher intersensory scores on all three tests, Thom (1970) reported positive correlations between each of the tactual-visual integration, auditory-visual integration, proprioceptive-visual integration scores and scores on the test of reading achievement. Intelligence was related only to total intersensory integration score in the group taught by the sight-word method; the correlations between intelligence test scores and particular intersensory test scores were all non-significant.

In summary, it seems evident that conclusive statements concerning the relationship between sensory integration abilities and reading retardation are impossible. Although a number of studies have found cross-modal difficulties among retarded readers, the failure to include appropriate controls either for intelligence or intrasensory skills makes these results difficult to interpret. Furthermore, it is important to consider whether the integration of spatial to temporal information is an important aspect of the integration of auditory and visual information. All studies to date have confounded temporal-spatial integration with auditory-visual integration. Thus, a number of questions

concerning the sensory integration abilities of good and poor readers will be examined in the present investigation. For instance:

- (i) Is cross-modal integration less accurate than intramodal integration for retarded readers when all stimuli are presented temporally?
- (ii) Are the cross-modal integration abilities of good and poor readers related to the modalities involved?

Remedial Reading Techniques

There are at least three basic approaches to the teaching of reading to children who have failed to learn by the usual classroom procedure. One approach is to place these children in smaller groups and to increase the amount of attention they receive. Usually the teaching techniques remain the same. The efficacy of such an approach is questionable with regards to the teaching of dyslexic children. A second approach is corrective intervention in which the corrective procedures individualize the regular programme. A different developmental approach is used than that initially used to teach the child to read. Often assets are used to overcome the deficit. For instance, if a child who has failed to learn to read by the visual whole-word approach, an auditory approach might be recommended. This tendency of corrective intervention to use an "opposite" method has received a great deal of

clinical support, but there is no research evidence to suggest that this approach is the most efficient. A third intervention procedure involves remedial methods devised to improve the deficits thought to underlie poor reading. Although this approach may utilize the child's assets, the deficit areas are of primary concern. If a child has poor visual discriminatory abilities, for instance, a remedial approach would include procedures to improve this specific skill.

Most remedial methods include some phonic work, although some emphasize the visual aspects by having the child focus on the whole word. Gray (1960) proposed the teaching of the whole word followed by phonic analysis of sound-letter correspondences. Similarly, Kirk (1940) recommended the acquisition of a sight vocabulary prior to phonic instruction. Phonic approaches are concerned mainly with teaching decoding of written language. Although comprehension is not overlooked the phonic method emphasizes the analysis of words apart from their meanings.

One problem confronting the beginning reader being taught by the phonic approach is that the phoneme-grapheme relationship in English is not direct. Consequently, the phonic approach often causes confusion. The initial teaching of the alphabet (i.t.a.) is a modified alphabet scheme devised to overcome this problem. Although studies by Downing (1962, 1964a, 1964b) suggest that i.t.a. trained children are better on oral recognition than children using traditional orthography and that

i.t.a. trained children have little difficulty transferring to traditional orthography, these studies provide little conclusive evidence for the superiority of i.t.a. because of procedural and methodological problems in the studies.

Another method of simplifying the inconsistent phoneme-grapheme correspondences of English is the use of colour coding. In a phonic system using colour coding, differences in sounds are indicated by differences in colours. Gillingham and Stillman (1940) used different colours to identify vowels and consonants. Bannantyne (1966) uses colour coding to differentiate the various graphemes used to represent phonemes. The theory behind Bannantyne's colour phonics system is that most dyslexic children are unable to remember constantly changing patterns of sound-symbol associations and that the simultaneous tactual auditory and visual sequencing of phonemes and letters is the essential element in learning to read. The system stresses the fundamental importance of sequencing.

Hegge, Kirk and Kirk (1940) developed a phonic method of remedial reading in which the child is required to write a letter or word from memory while he says the sound. Integration of the visual, auditory, and tactual-kinesthetic information resulting from this approach is assumed to be adequate. The integrated multisensory approaches have a number of strengths. Since the identification of the cause of reading failure is often difficult, a procedure using several input channels may be effective. In addition to stressing word-attack skills rather than

comprehension, multisensory approaches often supplement the usual visual and auditory cues with colour, motor, or kinesthetic cues. Monroe (1932), Orton (1937), and Fernald (1943) all stressed the use of haptic cues by letter tracing in their remedial approaches. Orton (1937) suggested that the following principles are important in the teaching of reading:

1. Training for simultaneous associations of visual, auditory, and kinesthetic language stimuli by tracing and sounding the visually presented word.
2. Finding such units as the child can use without difficulty and directing the training toward developing larger and more complex wholes through the fusion of these smaller units.

As well, Gillingham and Stillman (1940) developed remedial methods for reading based on the systematic development of increasingly complex phonetic units. The method attempts to establish visual, auditory and kinesthetic associations. Fernald (1943) combined the visual emphasis with vocalization and kinesthetic activity--the VAKT method (visual, auditory, kinesthetic tracing method).

A more recently devised integrative method, Linn's (1968) multisensory-motor approach, involves the auditory, visual, tactile and proprioceptive sensory systems in tracing, vocalizing and viewing the stimuli. One distinction between the remedial multisensory methods and Linn's program is that the multisensory-motor method was developed as

an initial approach to teaching children to read, whereas other multisensory approaches were devised as remedial techniques. Linn's (1968) technique is based on two concepts: "(a) The higher processes of learning operate more effectively when preceeded in the early years by sensori-motor training involving the major sensory modalities; (b) Sensory systems used simultaneously tend to form functional, integrated sensory units [p 57]." Unlike most remedial approaches which have developed from clinical experience and have little or no sound experimental evidence to support the efficiency of the technique, there is some evidence to support the multisensory-motor approach to the teaching of reading. Linn and Ryan (1968) compared the reading and spelling scores of two groups of grade-one children. One group was taught by traditional methods which involved learning sight words, with the later introduction of phonics. The other group was taught by the multisensory-motor method. The results indicated better reading and spelling scores for the pupils taught by the multisensory-motor method. In addition, the multisensory-motor approach was equally effective for the various IQ ranges. Similarly a study by Thom (1970) found that tactile-visual, auditory-visual, proprioceptive-visual, and the total intersensory integration score of grade one children can be increased by the multisensory-motor reading method and that intersensory integration is related to reading and spelling achievement. Pupils instructed by the multisensory-motor reading method achieved higher reading and spelling scores than children taught by the sight method. There is, however, no supportive evidence for the use of the multisensory-motor technique as

a remedial technique for dyslexic children.

The evidence for the appropriateness of multisensory approaches is primarily theoretical. Wepman (1962) has suggested that individuals may differ in modality maturation, and that they may be generally visile or audile. This theory implies three approaches to teaching reading: emphasis on the child's asset, emphasis on remediation of the child's deficit, or a multisensory approach which uses both intact and weak sensory channels in a complementary fashion.

Logically, the multisensory approach seems most appropriate since it takes in the requirement of all children regardless of their visile or audile strengths. However, Schwalb, Blau and Zanger (1968) point out that research suggests that the dyslexic child suffers from an integration handicap, thus modality blocking may be a more suitable remedial technique. One such technique is the nonvisual AKT method. Myklebust (1964) argues that the psychoneurosensory systems can function semi-independently. He suggests that simultaneous delivery to the brain of two or more types of information may cause a breakdown in the neurological processes involved because of neurosensory overloading. Accordingly, Myklebust (1964) states that:

At times a given system functions in a supplementary way with another, and at times, all of the systems function interrelatedly as a unit. This concept has many implications for the understanding of neurogenic learning disorders, especially in terms of differential diagnosis. It follows that it is necessary to appraise each psycho-neurosensory system as it functions semi-autonomously, in coordination with other systems, and as all of the systems function simultaneously. The auditory-neurological process must be appraised, as must the

visual, motor, and tactile. Each of these must be evaluated as they function semi-independently, then in coordination with others, and finally as they function simultaneously as a unit [p. 356].

The purpose of the nonvisual AKT method is to block off the conflicting modality. The visual modality was identified as the critical one because speech has usually developed in an acceptable fashion, suggesting that the auditory input system is working properly. In support of this approach, Shipley and Jones (1969) report that dyslexic children are less able than normal children to ignore irrelevant auditory stimulation during the intake of visual stimuli. Such an approach to remediation of reading disabilities is based then on the theory that multisensory simultaneous stimulation may cause confusion rather than clarification in the decoding process. Unfortunately there is no experimental evidence to justify the theoretical premise of either the multisensory or the modality blocking approaches to remediation. Although Linn and Ryan (1968) found better reading scores among normal children initially taught by the multisensory motor method compared to a group taught by traditional methods, there is no experimental support for Linn's (1968) suggestion that "sensory systems used simultaneously tend to form functional, integrated sensory units [p. 5]." There is even less reason to even believe that this is the case in the dyslexic child since a number of studies have found integrational difficulties among these children (Beery, 1967; Birch & Belmont, 1964; Senf, 1969; Zurif & Carson, 1970). However, none of these studies involved the

integration of sensory information from more than two sensory modalities. Since multisensory methods involve integration of auditory visual and tactual information, there is need for research on trimodal integration.

There are at least two ways of testing the validity of the multisensory approach in the remedial treatment of dyslexic children. The first is the usual method of comparing groups of children taught by different methods. The second is to test the assumptions underlying the approach. Most experimental research on reading methods is of the first sort. However, as Robinson (1966) points out, the inferences made possible by such an approach are limited by considerations such as teacher variables. Ultimately, such a test of any reading programme is a necessary prerequisite to its institution into a school programme. Nevertheless, preliminary research should be concerned with a test of the basic tenets underlying a teaching method.

Some of the basic assumptions underlying the purported efficacy of a multisensory approach are, first, that multisensory stimulation results in a superior percept to that resulting from stimulation of either a single modality or of a dual-modality in the case of VAKT methods. Further, the multisensory stimulation advantage is assumed to be more evident in dyslexic populations, since the normal child learns to read regardless of the method used. Finally, there is some suggestion of amelioration of sensory integrative abilities following multisensory integrative training. Thom's (1970) study provides evidence suggesting that training can enhance sensory integration at least in normal children

in their first year of grade one. There is no evidence to suggest that this finding can be generalized to dyslexic children, that is children of normal intelligence who are retarded two or more years in reading ability. Thus one purpose of the present study will be to examine the validity of the assumptions underlying the various remedial approaches. The multisensory method assumes that increases in the number of modalities simultaneously transmitting relevant information to the integration centers improves the child's percept of the task whereas the modality blocking techniques assumes that redundant information from two or more modalities results in confusion.

To summarize, the questions of particular interest in the present investigation in regard to intervention procedures are:

- (i) Does the child's ability to judge the equivalence of temporal patterns improve with the presentation of relevant redundant information in more than one sensory modality?
- (ii) Is there experimental evidence to suggest that a modality blocking technique is more appropriate for the poor reader than the multisensory technique?
- (iii) Are there changes with age in the ability to process redundant information in the cross-modal task?

The Hypotheses

Two studies were designed to answer the questions previously posed regarding age changes in sensory integration abilities, the relation between sensory integration abilities and the ability to obtain meaning from visual communication, that is, reading ability, and the assumptions underlying various intervention techniques. Specifically, the hypotheses can be summarized as follows:

1. Ontogenetic Trends

- (a) There is no significant change in the ability to perform the intramodal integration subtests between the ages of 10 and 12 years.
- (b) There are improvements with age in the ability to perform cross-modal integration tasks which are independent of developmental changes in intrasensory integration abilities. The difficulty of a cross-modal integration subtest depends on the specific modalities involved. Similarly, there are developmental changes in cross-modal integration which relate to the modalities involved in the task.

2. Reading Ability and Sensory Integration

- (a) There are no differences in the accuracy of good and poor readers on the intrasensory integration subtests.

- (b) Poor readers perform less well on the cross-modal integration subtests than good readers, and this difference between good and poor readers increases with age.

3. Redundancy in the Cross-Modal Task and the Question of Remedial Reading Techniques

- (a) The addition of relevant redundant information in a different modality to the modality of presentation of the standard stimulus results in an improvement in the accuracy of cross-modal integration for good readers and a decrement in the performance of poor readers.

Method

Two studies were conducted to investigate the sensory integration abilities of good and poor readers at three age levels, 10, 11 and 12 years. Study 1 was conducted in the Spring of 1972 and Study 2 in the Fall of that year. With the exception of one modification in procedure and the fact that different age groups were used, Study 1 and Study 2 were similar.

Study 1

Subjects

The Ss were 48 ten-and twelve-year old boys selected from the appropriate age groups in eight middle class elementary schools. Twenty-four of the Ss were good readers and twenty-four were poor readers. The good

readers were selected to meet all of the following criteria:

- (a) IQ 85 and above;
- (b) absence of any obvious sensory, motor, or emotional disturbances;
- (c) reading comprehension at or above the normal grade-placement.

Similarly, the poor readers were selected to meet all of the following criteria:

- (a) IQ 85 or above;
- (b) absence of any obvious sensory, motor, or emotional disturbances
- (c) reading comprehension two or more years below the normal grade-placement.

Reading comprehension was assessed with the Gates-MacGinitie Reading Test, Survey D, Forms 1 and 2 (Comprehension Test). The test was administered in a group setting. Intelligence scores were obtained using the Slossen Intelligence Test for Adults and Children. This test was administered individually in a 20- to 30-minute session. The child's sensory, motor and emotional health were discussed with the principal and the teacher. Cumulative records were reviewed when possible.

Twelve of the good readers and twelve of the poor readers were ten years old, the 1962 birthdates. The remaining twelve children in the two groups were twelve years old, the 1960 birthdates. The average ages of the groups are presented in Appendix 1. The appropriate grade placements were grade 4.9 and grade 6.9 respectively. The 12 Ss in each group were arranged in triplets according to reading score and each member of each of these relatively homogeneous sets was randomly

assigned to one of the three experimental conditions. The average reading score and the average IQ of each group thus formed are presented in Appendix 2.

Procedure

There were three main experimental conditions: the Intrasensory condition, the Bimodal condition, and the Trimodal condition. Each of these main conditions was comprised of three subtests of integration ability. Each subject was assigned to only one of the main conditions, but was given all three subtests of that condition.

1. Intrasensory Integration Subtests:

- (a) visual intrasensory integration (visual to visual);
- (b) auditory intrasensory integration (auditory to auditory);
- (c) tactual intrasensory integration (tactual to tactual).

In each of the intrasensory subtests the child was required to compare the standard pattern presented in one of the three modalities to the comparison pattern which followed in the same modality.

2. Bimodal Integration Subtests:

- (a) auditory to visual integration;
- (b) tactual to auditory integration
- (c) visual to tactual integration.

These subtests required that the child compare the standard pattern which was presented in one modality to the comparison pattern presented in a different modality.

3. Trimodal Integration Subtests:

- (a) auditory plus tactual to visual integration;
- (b) visual plus auditory to tactual integration;

(c) tactual plus visual to auditory integration.

In these subtests the standard pattern was presented simultaneously in two modalities and the child was required to compare this information to the comparison pattern which was presented in a different modality.

Thus, in all subtests the subjects were required to make same-different judgments regarding the perceived equivalence of two temporally ordered patterns which were generated by the apparatus. The patterns ranged from four to nine stimuli in length and were presented in sets of five trials such that all patterns of length four were presented first, those of length five next, and so on. A subtest was composed of 30 trials. The standard and comparison patterns were distinguishable on the basis of the positioning of the two 1.0 second interstimuli intervals which were randomly placed by the apparatus in each pattern. The usual interstimulus interval was 0.5 seconds. Each stimulus comprising the patterns had a duration of 0.2 seconds. A five-second interpattern interval separated the presentation of the standard and the comparison patterns and a ten-second interval occurred between trials.

The standard and comparison patterns were the same on a random half of the 30 trials, and different on the remaining 15 trials. The subject was required to respond "same" or "different" as soon as he made his decision. The score on each subtest was the number of correct responses.

The subjects were tested individually in a small quiet room either in the school or in the mobile laboratory. The measured incident light in front of the visual display screen was approximately 64 foot-candles. The subject was seated in front of the screen and the familiarization

instructions presented in Appendix 3 were read to him. Following this familiarization procedure, the subject's chair was adjusted to the appropriate height such that his head was supported in the chin rest at an eye level in line with the middle of the visual display panel. The subject's dominant hand index finger was then positioned in the finger tube. Cotton batting was used to compensate for differences in finger size, and to ensure that the subject did not move his finger out of position. The instructions for each specific subtest (see Appendix 3) were then read to the subject before the headphones were fitted. Three practice trials preceded the 30 test trials of each subtest. The subject was told whether or not he was correct only on the first two practice trials. On the third practice trial, all Ss were assured that they were doing well regardless of their performance. Following the completion of each subtest, the subject was allowed to remove the headphones and have a short rest while the equipment was being reset. Each subtest required approximately 15 minutes. A 10-minute break was given after 30 minutes.

Order of Administration of the Subtests

Three orders of administering the three subtests in each condition were used in order to control for sequence effects. Equal numbers of subjects in each condition were randomly assigned to each of the three orders in each condition.

Intrasensory Subtests

Order 1	Order 2	Order 3
A-A	V-V	T-T
V-V	T-T	A-A
T-T	A-A	V-V

Bimodal Subtests

Order 1	Order 2	Order 3
A-V	V-T	T-A
V-T	T-A	A-V
T-A	A-V	V-T

Trimodal Subtests

Order 1	Order 2	Order 3
A+V-T	V+T-A	T+A-V
V+T-A	T+A-V	A+V-T
T+A-V	A+V-T	V+T-A

The Apparatus

The apparatus consisted of a 20.75 in. x 23 in. Hammond steel desk rack panel faced with a standard 1/8 in. Hammond rack plate and a 11x10.25x19 in. control panel, both painted flat gray. A photograph of the apparatus is presented as Appendix 4. A 6 in. x 6 in. white opaque plexiglass screen was centered in the rack plate. A 4 in. x 3 in. opening

centered at the bottom of the rack plate allowed the subject to insert his hand inside the desk rack. A rubber flap covered this opening.

A Wein Bridge oscillator utilizing a Motorola MCH 2870 M/C power operational amplifier integrated circuit produced the auditory stimuli which were 1.0 kHz beeps presented over a set of Sharpe HA 10A head phones. The visual stimuli were produced by a GE 44 lamp mounted behind the plexiglass screen in the rack plate. A steel aperture plate concentrated the light to a 3/8 in. spot in the center of this screen. The tactile stimuli were produced by a Guardian TP6X12, 24 volt DC push-type solenoid which was mounted inside a 3/4 in. diameter plexiglass tube. The force of the solenoid was 20 oz. The tube was affixed to a plexiglass plate mounted on the base of the desk rack. The S rested his hand on the plate with the index finger of the dominant hand in the tube.

The circuitry was constructed using modern digital techniques and utilizing TTL integrated circuit logic. A master counter kept track of the length of the pattern being run and limited the circulation of the memory. Patterns ranging in length from four to nine pulses could be selected on the four dials mounted on the front of the control panel. The equipment automatically presented five trials of each of the four pattern lengths selected. The first two dials were reset to obtain the trials of lengths eight and nine.

A custom programme Read-Only memory was used to store all possible

permutations of two pauses in patterns of four to nine pulses. Information was stored for instance as two B.C.D. digits indicating interpulse positions. These digits were compared to the position number of the pulse currently being generated. Whenever like numbers occurred the next interstimulus interval was doubled from the usual 0.5 sec. interval to 1.0 seconds. For example, with the pattern length set at five and the number of pulses requested set at two, the memory may read out as 2.4. The output sequence would then be 0.2 second pulse, 0.5 second pause, 0.2 second pulse, 1.0 second pause, 0.2 second pulse, 0.5 second pause, 0.2 second pulse, 1.0 second pause, 0.2 second pulse. At this point the 5-second interpattern timer is automatically activated and the output from the random pulse generator is blocked stopping the memory circulation. The address where the memory stopped is compared to the previous address which is stored in a five bit memory buffer. When the interpattern timer is activated, a pulse is sent to advance the memory address counter if the comparator indicates that the same address has been chosen when a different comparison pattern had been selected for this particular trial. The timer alternately produces 5-second and 10-second intervals. The 5-second interval is the interpattern interval and the 10-second interval is the intertrial interval.

The output modes, visual, auditory and tactual, can be selected individually or in any combination for the standard pattern and for the

comparison pattern. A block diagram of the digital circuitry in the control box is presented in Appendix 5.

Results

The correlation coefficient computed on the reading scores and IQ scores for all children in Study 1 was $+ .41$ ($p < .01$) indicating a significant relationship between reading ability and IQ. A $2 \times 2 \times 3$ analysis of variance was calculated on the IQ data. The two levels of age (1962 vs 1960 birthdates), the two levels of reading ability (good vs poor) and the three levels of subtest (Intrasensory, Bimodal, and Trimodal) were between-subjects factors. The results of this analysis, summarized in Appendix 6, indicated no reliable IQ differences between the groups assigned to the different conditions or between the age groups. There was a significant difference between the good and poor readers, however, favoring the good readers.

In order to control for the IQ differences associated with reading comprehension levels, analyses of covariance were computed on the data. The score on the dependent variable was the number of correct equivalence judgements made by the subject. The sensory integration scores for all conditions are presented in Appendix 7.

The data in the three main experimental conditions, Intrasensory, Bimodal and Trimodal, were subjected to separate $2 \times 2 \times 3$ analyses of covariance. The two levels of Age (1962 vs 1960) and the two levels of Reading Ability (good vs poor) were the between-subject factors. The three levels of the within-subject factor, Subtest, were A-A, V-V and

T-T in the Intrасensory condition, A-V, V-T and T-A in the Bimodal Condition, and A+V-T, V+T-A and T+A-V in the Trimodal Condition.

A summary of the results of the analysis of covariance computed on the Intrасensory data is presented in Appendix 8. None of the main effects were significant and only one interaction, Age x Reading Ability x Subtest, was reliable, $F(2,24) = 3.99$, $p < .05$. This interaction is shown in Figure 1. The interaction appears to be a function of the reliable difference between younger and older poor readers on the A-A subtest. Although the poor readers performed somewhat better than the good readers on the V-V and T-T subtests, these differences were not reliable. The procedure outlined by Winer (1962, p. 610) was used for comparisons of means at the same level of the between-subject factors. Comparisons of means not at the same level of the between-subject factors were made using a modification of the procedure outlined by Winer (1962, p. 610) which is presented in Appendix 9.

Performance on the Bimodal subtests, A-V, T-A and V-T, at the two ages and two reading levels was examined with an analysis of covariance. A summary of the results of this analysis is presented in Appendix 10. The main effect of Age was significant, $F(1,11) = 7.95$, $p < .05$. Examination of the adjusted means for Age revealed that the older children performed better than the younger children ($\bar{M}_1 = 19.70$; $\bar{M}_2 = 17.68$). None of the other main effects or interactions were reliable.

Finally the analysis of covariance computed on the Trimodal data is reported in Appendix 11. The levels of the within-subject factor, Subtest,

Figure 1. Age x Reading Level x Subtest Interaction
for Study I Intrase nsory Data

were A+V-T, T+A-V, and V+T-A. None of the main effects of Age, Reading Ability or Subtest were significant. Similarly, none of the interactions were significant.

The effect of redundancy on the ability to perform cross-modal integration tasks was examined by comparing the appropriate Bimodal and Trimodal subtests. Thus, three separate $2 \times 2 \times 2$ analyses of covariance were computed on these data. The two levels of Age (1962 vs 1960), the two levels of Reading Ability (good vs poor) and the two levels of subtest were administered between-subjects.

The analysis of covariance computed on the T-A and T+V-A tasks indicated no significant difference in performance attributable to the addition of visual information to the standard pattern: the main effect of Subtest was not reliable. However, the interaction between Age and Reading level was significant, $F(1, 23) = 4.703$, $p < .05$ and is shown in Figure 2. Analyses of the simple effects of Age for the two levels of Reading Ability indicated a reliable age difference only for the good readers, $F(1, 23) = 8.904$, $p < .05$. The older good readers performed better ($\bar{M} = 22.00$) than the younger good readers ($\bar{M} = 15.85$). Similarly, analyses of the simple effects of Reading Ability for the two levels of Age indicated a reliable difference between the Reading Ability levels only at the older Age level, $F(1, 23) = 5.048$, $p < .05$. The older good readers performed better than the older poor readers ($\bar{M}_1 = 22.00$; $\bar{M}_2 = 17.37$). The main effect of Age was also significant $F(1,23) = 4.31$, $p < .05$, but this is attributable

Figure 2 : Age x Reading Level Interaction in Study I T-A and T+V-A Subtest Data

to the difference in the performance of the younger and older good readers. The results of this analysis are presented in Appendix 12.

Similarly, an analysis of covariance was computed on the A-V and A+T-V subtest data. There is a reliable difference between the Age groups $F(1, 23) = 7.652$, $p < .05$, with the older group making more correct judgments than the younger group ($\bar{M}_1 = 20.03$; $\bar{M}_2 = 16.09$). The main effects of Subtest and Reading level were not significant and none of the interactions were significant. These results are summarized in Appendix 13.

The analysis of covariance on the V-T and V+A-T data revealed a significant main effect of Age, $F(1, 23) = 7.401$, $p < .05$. Again the older group performed better than the younger group, ($\bar{M}_1 = 19.44$; $\bar{M}_2 = 16.44$). Neither of the other main effects and none of the interactions were reliable. The results of this analysis are summarized in Appendix 14.

In order to examine the possibility that the developmental trends in cross-modal integration abilities are attributable to similar developments in intrasensory integration abilities, the appropriate Intrasensory and Bimodal subtest data were subjected to a $2 \times 2 \times 2$ analysis of covariance. The three factors, Age, Reading Ability and Subtest, were between-subjects.

Thus, the V-V data were compared to the A-V data and to the V-T data in two separate analyses. For the V-V and A-V analysis, none of the main effects of Age, Subtest or Reading level were significant and

none of the interactions were reliable. A summary of this analysis is presented in Appendix 15.

There was a significant main effect of Age [$F(1, 23) = 4.965$, $p < .05$] and of Subtest [$F(1, 23) = 5.422$, $p < .05$] in the analysis of the V-V and V-T data. The older group performed better than the younger group ($\bar{M}_1 = 19.37$; $\bar{M}_2 = 17.20$) and the cross-modal subtest was easier than the intrasensory subtest ($\bar{M}_1 = 19.42$; $\bar{M}_2 = 16.71$). A summary of this analysis is presented in Appendix 16.

The results of the analysis of covariance computed on the T-T and V-T subtests revealed a reliable main effect of Age, $F(1, 23) = 5.101$, $p < .05$. Again, the older children performed better than the younger children ($\bar{M}_1 = 19.40$; $\bar{M}_2 = 16.17$). The main effect of Subtest was also significant, $F(1, 23) = 5.626$, $p < .05$. Performance was better on the cross-modal subtest than on the intrasensory subtest ($\bar{M}_1 = 19.44$; $\bar{M}_2 = 16.77$). None of the interactions were significant. A summary of this analysis is presented in Appendix 17.

The analysis of covariance computed on the T-T and T-A data indicated a significant main effect of Age, $F(1, 23) = 6.005$, $p < .05$. The performance of the older children was significantly better than that of the younger children ($\bar{M}_1 = 19.36$; $\bar{M}_2 = 15.79$). The main effects of Reading Ability and Subtest were not reliable and none of the interactions were reliable. A summary of this analysis is presented in Appendix 18.

Finally, analyses of covariance were computed on the auditory

intrasensory and cross-modal subtests. There were no reliable differences indicated by the analysis of the A-A and A-V data. This analysis is summarized in Appendix 19.

The analysis of data for the A-A and T-A subtests indicated a significant interaction between Age, Reading level and Subtest, $F(1, 23) = 6.579, p < .05$. This interaction is shown in Figure 3. An analysis of the simple effects indicated a significant difference between the performance of the older and younger good readers on the T-A cross-modal task with better performance by the older children ($\bar{M} = 22.22$) than the younger children ($\bar{M} = 14.04$). The results of this analysis are summarized in Appendix 20.

In addition to the main analyses performed on the data, a binomial test was used to determine whether the number of children reporting a number coding technique exceeded the number not reporting this method. The results of the binomial test computed on the number code data indicated that the number of children using this technique was reliable at the $p < .06$ level, ($z = 1.58, p = .057$). Further to this analysis, the number of children performing at or above the 50% correct level was compared to the number of performing below this level using the binomial test. The results of these binomial tests are summarized in Appendix 21. In all three main conditions, significantly more children performed at or above a 50% level than below the 50% level.

The regression coefficients used to adjust the dependent variable,

Figure 3. Age x Reading Level x Subtest Interaction for Study I T-A and A-A Subtest Data

for differences in IQ scores are presented in Appendix 22. Since analyses of variance were also computed on the data from the three main conditions, it was possible to compare the results of the analyses of covariance to the results of the analyses of variance. Only one interaction in the analysis of variance of the Bimodal data, Age X Reading Ability, was removed in the analysis of covariance. The Pearson product-moment correlation coefficients computed on the overall Intrasyntactic, Bimodal and Trimodal scores and IQ scores were not significant ($r = +.02$, $r = +.37$, $r = +.13$, respectively). Thus, the use of analysis of covariance did not alter the results of the study drastically.

Furthermore, the results of the various analyses of covariance were examined for any main effects or interactions which were reliable at the $p = .10$ level. Since the number of subjects in this first study was small, the power of the statistical test is low. In relation to the effects which were reliable at the $p = .05$ level, no effects of interest were revealed at the $p = .10$ level. The average adjusted scores on the nine subtests are presented in Table 1.

TABLE 1

Study 1, Adjusted Average Scores for Intramodal
Bimodal and Trimodal Conditions

	Good Readers		Poor Readers	
	1962	1960	1962	1960
1. Intramodal Subtests				
A - A	17.76	16.59	14.18	19.99
V - V	14.01	15.59	17.43	19.74
T - T	14.76	17.59	16.92	17.74
2. Bimodal Subtests				
A - V	15.54	19.50	19.51	20.82
V - T	16.95	21.25	19.51	20.07
T - A	13.70	19.50	18.51	19.57
3. Trimodal Subtests				
A + T - V	16.45	13.61	23.10	16.06
T + V - A	18.69	22.60	17.11	15.56
V + A - T	16.19	21.25	14.61	15.06

Discussion

A summary of the reliable effects revealed by the twelve analyses of covariance computed on the integration performance data is presented in Table 2. Although study 1 was primarily of an exploratory nature and is considered of secondary importance, a brief discussion of the results is warranted. Thus the discussion will consider the results of study 1 in relation to the hypotheses advanced concerning (1) Ontogenetic Trends, (2) Reading Ability and Sensory Integration and (3) Redundancy in the Cross-modal Task. In a final section, (4) Conclusions, the results of the study will be related to methodological considerations.

1. Ontogenetic Trends

Hypothesis (a): There is no significant change between the ages of ten and twelve years in the ability to perform the intramodal integration subtests.

The data confirmed the hypothesis for the good readers only. There was a development between the ages of ten and twelve years in the poor readers ability to perform the auditory intrasensory subtest.

One previous study of the development of intrasensory integration abilities reported developments between the ages of five and seven years in the ability to match forms (Milner & Bryant, 1968). Improvements in visual intrasensory and auditory intrasensory matching of patterns between five and eight years of age has also been reported (Kuhlman &

TABLE 2

A Summary of the Reliable Effects in the Analyses
of Covariance Computed on the Study 1 Data

Analysis	Reliable Effects
1. Intrasensory	Age X Reading Ability X Subtest
2. Bimodal	Age
3. Trimodal	<hr/>
4. T - A and T + V - A	Age; Age X Reading Ability
5. A - V and A + T - V	Age
6. V - T and V + A - T	Age
7. A - A and T - A	Age; Age X Reading Ability X Subtest
8. A - A and A - V	<hr/>
9. T - T and T - A	Age
10. T - T and V - T	Age; Subtest
11. V - V and V - T	Age; Subtest
12. V - V and A - V	<hr/>

Wolking, 1972). One previous study of the visual and auditory intrasensory matching of temporal patterns found the most marked improvements between the ages of five and eight years and a decrement in the rate of improvement thereafter (Klapper & Birch, 1971).

The results of the present study suggest, however, that the absence of a development in intrasensory integration between the ages of ten and twelve years for good readers does not reflect a full development at a younger age in auditory, visual or tactual intrasensory abilities. The tasks used in the present study were quite difficult even for the older group of children.

Hypothesis (b): There are improvements with age in the ability to perform cross-modal integration tasks which are independent of developmental change in intrasensory integration abilities.

This hypothesis was not confirmed in the present study. In spite of the fact that the overall analysis of the study 1 Bimodal data revealed a significant effect of age, separate analyses of the intrasensory data in relation to the cross-modal data suggest that the age change in cross-modal integration ability is not independent of performance on the corresponding intrasensory tasks.

Bryant (1968) suggested that valid evidence for a development in intrasensory integration abilities requires that younger children make more errors on cross-modal tasks than on within-modal tasks while older children perform equally well on the two kinds of tasks. In the present

study, the younger and older children performed the cross-modal subtests as well as the within-modal subtests. Thus, the data do not support a developmental hypothesis within the age range studied. The analyses of the trimodal data support this conclusion as well.

The second part of the hypothesis can be answered negatively as well. Since the results of the two studies did not reveal developmental changes in cross-modal skills, there are no developmental changes which are related to the modalities involved in the cross-modal task.

2. Reading Ability and Sensory Integration

Hypothesis (a): There are no differences in the accuracy of good and poor readers on the intrasensory integration subtests.

The study 1 data did not reveal differences between the good and poor readers on the intrasensory subtests. This is interesting in view of the fact that previous studies of the auditory abilities (Bond, 1935; Dykstra, 1966; Durrell & Murphy, 1953; Goetzinger, Dirks & Baer, 1960; Harrington & Durrell, 1965; Silver & Hagin, 1966; Thompson, 1963) and previous studies of visual abilities (Goins, 1958; Lyle & Goyen, 1968) have found deficits within one or both of these specific modalities. However, these studies did not consider the integrational aspects of some of the tasks used, such as the Wepman Auditory Discrimination Test. Thus, it is possible that some of these modality-specific deficits were

actually deficits in integration.

However, the present study did not require the discrimination of different sounds or different visual stimuli. Thus it is difficult to compare the results to these previous studies of single-modality functioning. Doebling and Rabinovitch (1969) found that children with learning problems were normal in their response to verbal stimuli and the simplest of nonverbal stimuli. However, the learning problem children had difficulty with more complex nonverbal auditory stimuli. Results of the present study do not rule out auditory deficits or visual deficits relating to other complex nonverbal stimuli. However, the retarded readers in the present study did not experience greater difficulty than the good readers in the discrimination of complex auditory, visual or tactual temporal patterns.

Hypothesis (b): Poor readers perform less well on the cross-modal integration subtests than good readers, and this difference increases with age.

The results of the present study do not support the hypothesis that retarded readers have a sensory integration deficit. Previous studies which have found an integrational deficit in poor readers have been interpreted as supporting the position that reading retardation is an integration difficulty. The retarded reader is said to have difficulty integrating auditory information with visual information (Beery, 1967; Birch & Belmont, 1964, 1965; Buchner, 1965; Kahn, 1965). There are a

number of issues relating to this interpretation, however. Firstly, previous studies have confounded auditory-visual integration with temporal-spatial integration. Secondly, these studies have not included a control of differences in intrasensory integration abilities. Thirdly, studies reporting the integrational deficit have involved heavy memory demands. The child was required to examine three alternatives. These issues will be considered in detail in the discussion of the results of study 2.

3. Redundancy in the Cross-Modal Task

Hypothesis (a): The addition of relevant redundant information in a different modality to the modality of presentation of the standard stimulus results in an improvement in the accuracy of cross-modal integration for good readers and a decrement in the performance of poor readers.

Comparison of the bimodal to the trimodal subtests failed to support this hypothesis. There were no reliable differences between performance on the cross-modal subtests and performance on the cross-modal subtests with redundant information in the standard pattern.

4. Conclusions

The results of study 1 revealed no differences in integrational ability between the good and poor readers. The poor readers performed the Intrasensory, Bimodal and Trimodal subtests as well as the good readers.

The main effect of Age was reliable in six of the twelve analyses of covariance computed on the integration data. In addition, age interacted with subtest and/or reading ability in three of the six analyses of covariance in which age was not a main effect. It could be speculated that the differences in integration abilities revealed in the analyses of the study 1 data are attributable to age differences in ease of understanding the instructions. Although the main effect of Age was not significant in all three main conditions as would be predicted on the basis of such an hypothesis, study 2 was designed to ensure that all children understood the task thoroughly by demonstrating competence in a very simple matching task.

A second purpose of the Preliminary session included in study 2 was to make the task easier. Although performance was better than would be expected on the basis of chance, the task was quite difficult. Thus, it could be argued that the failure to find differences between the good and poor readers is attributable to a floor effect.

Study 2

Subjects

The Ss were 72 ten-and eleven-year old boys selected from the appropriate age groups in nine middle-class elementary schools. Thirty-six of the Ss were good readers and thirty-six were poor readers selected to meet the criteria for inclusion in the good and poor reader groups as outlined in Study 1. Eighteen of the children in each of these groups were ten years old (1962 birthdates) and eighteen were eleven years old (1961 birthdates). The average ages of the groups are presented in Appendix 2. The appropriate grade placements were grade 5.1 and grade 6.1 respectively. The 18 Ss in each age group were arranged in triplets according to reading score and one member of each of these relatively homogeneous sets was randomly assigned to one of the three experimental conditions. The average reading score and the average IQ of each group thus formed are presented in Appendix 1.

The majority of subjects were administered Form 1 of the Gates-MacGinitie Reading Test in the Spring. Since participation in the experiment was delayed until the Fall, the children were retested using Form 2 of the same test. Spring-Fall reading test scores were thus obtained for 82 subjects. The correlation computed on these first and second reading test scores $+ .72$, $p < .01$.

Procedure

The procedure followed in Study 2 was the same as that followed

in Study 1 with the exception that a Preliminary Session was introduced in Study 2. The instructions and procedure followed in the Preliminary Session are presented in Appendix 23. The entire session was conducted first visually, with the visual stimuli being flashes of light from a miniature 1.5 volt hand-held flashlight containing a Norelco 222 bulb. Following success on the visual patterns, the subject was required to judge the test items as same or different when presented as pencil-tapped patterns. Similarly, the subject was required to make three consecutive judgements on the test items when the patterns were tapped with the eraser-end of a pencil on the palm of his dominant hand. If the subject made two consecutive incorrect judgements, E returned to one of the Demonstration items before proceeding with the test items. Although 18 children made one or more mistakes, it was necessary to return to Demonstration items with only four children. Appendix 24 summarizes the age, reading level, and experimental condition to which these 18 children had been assigned. All children reached the criterion within 10 test trials. Following the completion of the Preliminary Session, the Experimental Session began. The procedure, apparatus, and instructions were the same as those used in Study 1.

Results

As was the case in Study 1, there was a relation between IQ and reading scores. The correlation between the Form 2 reading scores and the IQ scores for the subjects in Study 2 is $+0.51$, $p < .01$. An analysis of variance computed on the IQ data indicated no significant differences

in IQ for the two age levels or for the groups assigned to the three main conditions. The main effect of Reading Ability was significant as in study 1, however, indicating a significant difference in the IQ scores of the good and poor readers favoring the good readers. The results of this analysis are presented in Appendix 25. In order to control for the IQ differences associated with the two levels of reading ability, the data were subjected to analyses of covariance.

The data of the three main experimental conditions were subjected to separate $2 \times 2 \times 3$ analyses of covariance in which the two levels of age (1962 vs 1961 birthdates) and the two levels of reading ability (good vs poor) were the between-subjects factors while the three levels of the Subtest factor were administered within-subjects. The levels of the Subtest factor are specified in the discussion of the results of the specific analyses below.

The results of the analysis of covariance computed on the Intrasyntactic Integration data are summarized in Appendix 26. The levels of the within-subject factor, Subtest, were A-A, V-V and T-T integration. The significant Reading Ability $\times$ Subtest interaction $\sqrt{F}(2,40) = 3.82$, $p < .057$ is depicted in Figure 4. For the good readers, performance was significantly better on the auditory integration subtest than on the tactual subtest or the visual subtest. There were no differences in performance on the three intrasyntactic tasks for the poor readers nor were any of the differences between good and poor readers reliable. Thus, the reliable main effect of Subtest, $F(2,40) = 4.37$, $p < .05$, is

Figure 4. Reading Ability x Subtest Interaction
for Study 2 Intrasensory Data

attributable to the differences between the subtests for the good readers only. The differences between the adjusted interaction means were investigated using the procedure outlined in Appendix 9.

The cross-modal integration abilities of good and poor readers at two ages were examined in two of the main experimental conditions. The Bimodal condition required the children to compare a standard pattern presented in one modality to a comparison pattern presented in a different modality. The Trimodal subtests required same-different judgements of a standard pattern, presented simultaneously in two modalities, and a comparison pattern presented in a different modality. Thus the Trimodal subtests were cross-modal tasks with redundancy in the standard pattern.

The analysis of covariance computed on the Bimodal subtest data is summarized in Appendix 27. None of the main effects of Age, Reading Ability or Subtest were significant and none of the interactions were significant.

The analysis of covariance computed on the data for the Trimodal condition and reported in Appendix 28 revealed a significant Age x Reading Ability x Subtest interaction, $F(2, 40) = 3.96, p < .05$. This interaction is shown in Figure 5. At the younger age level, the performance of the good readers was significantly better than the performance of the poor readers on all three subtests. For the older group, the good readers performed better on the A+V-T and T+A-V tasks but not on the V+T-A subtest. There were no differences between the young poor readers and the older

Figure 5. Age x Reading Ability x Subtest Interaction for Study 2 Trimodal Data

poor readers on the three subtests. Similarly the only age change for the good readers was a drop in performance with the age increase for the V+T-A task. Multiple comparisons of the interaction means were computed using the procedure outlined in Appendix 9.

The effect of redundancy on the ability to perform cross-modal equivalence tasks was examined in three separate $2 \times 2 \times 2$ analyses of covariance. The two levels of Age, Reading Ability and Subtest (bimodal vs trimodal) were the between-subject factors.

The analysis of the A-V and A+T-V subtest data revealed a significant Reading Ability x Subtest interaction $\sqrt{F}(1, 39) = 4.92$, $p < .05$ which is shown in Figure 6. Analyses of the simple effects of Reading Ability at the two levels of Subtest indicated a reliable difference between the good and poor readers on the trimodal subtest, A+T-V, with the good readers performing better than the poor readers. A summary of the results of this analysis is presented in Appendix 29.

Analyses of covariance were used to investigate the effects of redundancy in the other cross-modal subtests (T-A vs T+V-A and V-T vs V+A-T) but no reliable main effects or interaction effects were apparent. The results of these analyses are presented in Appendix 30 and 31 respectively.

Finally, in order to rule out the possibility that there are intrasensory integration ability differences which could account for the differences obtained in the cross-modal conditions, the individual intrasensory subtests were compared to the appropriate cross-modal subtests

Figure 6. Reading Ability x Subtest Interaction
for Study 2 A-V and T+A-V Subtest Data

in separate $2 \times 2 \times 2$ analyses of covariance in which the levels of Age, Reading Ability and Subtest were between subjects.

The T-T subtest data were compared with the T-A data and with the V-T data. There were no reliable differences in either of these analyses which are presented as Appendices 32 and 33 respectively.

The V-V subtest data were compared to the V-T data and to the A-V data in two separate $2 \times 2 \times 2$ analyses of covariance presented in Appendices 34 and 35 respectively. Again, there were no reliable differences.

The A-A data were compared to the A-V and the T-A data. No reliable differences were revealed. These two analyses are summarized in Appendices 36 and 37 respectively.

In addition to the main analyses performed on the data, a binomial test was used to determine whether the number of children reporting a number coding technique exceeded the number not reporting this method. The results indicated that the number of children using this technique was greater than would be expected on the basis of chance, $z = 4.24$, $p = .000$.

Binomial tests were used to compare the number of children in the three main conditions performing at or above the 50% correct level with the number performing below this level. The results of these three binomial tests are summarized in Appendix 21. In all three main conditions, significantly more children performed at or above a 50% level than below the 50% level. The adjusted average scores on the nine subtests are presented in Table 3.

The regression coefficients used to adjust the dependent variable in the three main conditions for IQ differences are presented in Appendix

TABLE 3

Study 2 Adjusted Average Scores for Intramodal,
Bimodal and Trimodal Conditions

	Good Readers		Poor Readers	
	1961	1960	1961	1960
1. Intramodal Subtests				
A - A	20.25	20.11	17.86	20.93
V - V	17.08	17.28	19.20	18.76
T - T	16.08	15.11	16.86	21.76
2. Bimodal Subtests				
A - V	17.73	17.51	20.97	19.59
V - T	18.75	19.18	20.14	18.42
T - A	14.58	18.35	20.14	19.09
3. Trimodal Subtests				
A - T - V	21.89	20.58	14.54	16.33
T + V - A	21.88	17.75	16.20	16.83
V + A - T	21.72	17.54	22.75	16.00

22. Since analyses of variance were also computed on the data, it is possible to compare the results of the analyses of covariance to analyses in which no adjustment for IQ differences was made. This comparison revealed that only one significant main effect in the analysis of variance of the Trimodal data, Reading Ability, did not reach a significant level in the corresponding analysis of covariance. The Age x Reading Ability x Subtest interaction was reliable in the analysis of covariance however.

The results of the analyses of covariance were also examined for main effects or interactions which were reliable at the $p = .10$ level since the number of subjects in the study was relatively small, and hence the power of the statistical tests relatively low. However, no effects which were reliable at the $p = .10$ level were of interest in relation the effects which were reliable at the $p = .05$ level.

Discussion

A summary of the reliable effects revealed by the twelve analyses of covariance computed on integration performance scores is presented in Table 4. The discussion considers the results of study 2 in relation to the hypotheses advanced and the critical issues raised by the findings of the present investigation. The discussion is divided into four sections: (1) Ontogenetic Trends, (2) Reading Ability and Sensory Integration, (3) Redundancy in the Cross-Modal Task, and (4) Conclusions. Within each of these sections, the hypotheses originally proposed are restated and the findings of the present studies are brought to bear on the important

TABLE 4

A Summary of the Reliable Effects in the Analyses
of Covariance Computed on the Study 2 Data

Analysis	Reliable Effects
1. Intrasensory	Subtest; Reading Ability X Subtest
2. Bimodal	_____
3. Trimodal	Age X Reading Ability X Subtest
4. T - A and T + V - A	_____
5. A - V and A + T - V	Reading Ability X Subtest
6. V - T and V + A - T	_____
7. A - A and T - A	_____
8. A - A and A - V	_____
9. T - T and T - A	_____
10. T - T and V - T	_____
11. V - V and V - T	_____
12. V - V and A - V	_____

issues surrounding each hypothesis.

1. Ontogenetic Trends

Hypothesis (a): There is no significant change between the ages of ten and eleven years in the ability to perform the intramodal integration subtests.

The results of Study 2 support the hypothesis that there are no significant developments between the ages of ten and eleven in the ability to match temporal patterns within the modalities of audition, vision, and touch.

Although these abilities do not seem to have reached a level suggestive of peak performance, there were no significant developments within the two-year age range studied. The results of two follow-up studies (Drader & Kennedy, 1973; Drader & Sharp, 1973) suggest that intrasensory development is very gradual and continues into adulthood. For instance, the auditory and visual intrasensory abilities of fourteen-year-old children were slightly better than the auditory and the visual intrasensory abilities of eleven year old children (Drader & Kennedy, 1973). Similarly, the visual and tactual intrasensory abilities of adults are somewhat better (Drader & Sharp, 1973) than those of the children in the present studies.

Previous studies of developmental trends in the ability to judge the equivalence of temporally ordered patterns have found most rapid development between the fifth and eighth years (Klapper & Birch,

1971; Kuhlman & Wolking, 1972). According to Klapper and Birch (1971), there is a decrement in the rate of improvement thereafter. The tasks used in these studies were relatively easy. The results of the present study, taken together with the results of the two follow-up studies, suggest that intramodal matching in a more difficult task is inaccurate at age ten and improves very gradually into adulthood.

Hypothesis (b): There are improvements between the ages of ten and eleven years in the ability to perform cross-modal integration tasks which are independent of developmental change in intrasensory integration abilities.

This hypothesis was not confirmed. Bryant (1968) suggested that valid evidence for a development in intersensory integration abilities requires that younger children make more errors on cross-modal tasks than on within-modal tasks while older children perform equally well on the two kinds of tasks. In the present studies, the younger children performed the cross-modal tasks as well as the within-modal tasks. Similarly there was no reliable difference in the intramodal and cross-modal performance of the older children. Thus, the data do not support a developmental hypothesis with the age range studied. The analyses of the trimodal data support this conclusion.

A number of investigations of sensory integration skills have reported improvements with age in the visual-tactual integration of form (Blank & Bridger, 1965; Connors, Shuette & Goldman, 1967; Kinsbourne & Warrington, 1963). In addition to the fact that the task used in these

studies involved forms rather than patterns, the age ranges studied were greater than in the present study. Blank and Bridger (1965) for instance, studied children in the three-to six-year old age range. Birch and Lefford (1963) studied the five-to eleven-year old range. Connors, Shuette and Goldman (1967) studied children from five- to eleven- years of age. Kinsbourne and Warrington (1963) studied 4 1/2- to 7 1/2-year old children.

The wider age range studied in the investigations reporting a development in V-T integration or the fact that the task used involved forms rather than patterns could account for the discrepancy in results between these previous studies and the present study 2. However, none of the previous studies included the necessary intrasensory control (Bryant, 1968). Thus, the age changes in visual-tactual integration could perhaps be accounted for by intrasensory developments (Bryant, 1968). Milner and Bryant (1970) found improvements between the ages of five- and seven- years in the V-T cross-modal integration of form were attributable to improvements in intrasensory abilities.

The development of A-V integration between the ages of five- and twelve-years was investigated by Birch and Belmont (1965) who reported most rapid growth between the ages of five- and seven-years. By age ten, performance had reached an asymptotic level. The task used in the present study was more difficult and involved temporal visual patterns rather than spatial visual patterns. In addition to the difference in tasks, Birch and Belmont (1965) did not include an intrasensory control.

However, Muehl and Kremenak (1966) report that auditory integration

in a similar task to that used by Birch and Belmont (1965) was more difficult for first graders than auditory to visual, visual to auditory or visual to visual integration suggesting that the auditory abilities develop later than visual abilities. Thus a development in cross-modal integration may reflect an improvement in auditory abilities. More recently, Kuhlman and Wolking (1972) found that age changes in A-V integration were attributable to improvements in intrasensory integration skills.

Although previous studies reporting age changes in the V-T and A-V integration abilities of children have used a wider age range than that used in the present study, the failure to include the intrasensory controls makes the results difficult to interpret. Studies which have included these controls (Kulman & Wolking, 1972; Milner & Bryant, 1970; Muehl & Kremenak, 1966) report developments in intrasensory abilities which could account for the apparent intersensory developments.

Hypothesis (c): The difficulty of a cross-modal integration subtest depends on the specific modalities involved. Similarly, there are developmental changes in cross-modal integration which relate to the modalities involved in the task.

There were no reliable differences in the relative difficulty of the three bimodal subtests. Thus, the difficulty of the cross-modal task does not seem to be related to the specific modalities involved in the present task. Although Kuhlman and Wolking (1972) and Sterritt, Martin and Rudnick (1969) suggest that the difficulty of the cross-modal task depends primarily on the initial modality, the results of the present study do not support this suggestion. The cross-modal subtests were of

equal difficulty regardless of the initial modality. Although the intrasensory auditory subtest was easier than the visual or tactual intrasensory subtests for the good readers in study 2, this superiority does not seem dependent on the modality in which the first pattern was presented. The superiority of the auditory modality was evident only when both the standard and the comparison patterns were presented in the auditory channel. The auditory intrasensory advantage did not affect the relative ease of either of the cross-modal tasks involving the auditory modality. This makes sense in view of the fact that integration involves a comparison of an incoming pattern to the internal representation of another pattern. If the incoming pattern is incorrectly represented at a central level or if the stored pattern was incorrectly represented, there will be a breakdown in integration. Thus even if the auditory pattern in the cross-modal task is accurately stored, the accuracy of equivalence judgements will not be ensured unless the pattern being received in the other modality is also represented accurately.

The second part of the hypothesis can be answered negatively as well. Since the results did not reveal developmental changes in cross-modal skills, there are no developmental changes which are related to the modalities involved in the cross-modal task used in the present investigation.

To summarize, the difficulty of the cross-modal subtests used in present study was not related to the specific modalities involved, nor were there developmental changes in cross-modal integration abilities which relate to the specific modalities involved.

2. Reading Ability and Sensory Integration

Hypothesis (a): There are no significant differences in the accuracy of good and poor readers on the intrasensory integration subtests.

Although there were no reliable differences between the good and poor readers on the intrasensory tasks, the good readers performed better on the auditory intrasensory subtest than on the subtests of tactual integration or visual integration. Two previous studies have found that an auditory temporal task is easier than a visual temporal task (Klapper & Birch, 1971; Kuhlman & Wolking, 1972), but not after nine years of age. On the other hand, Sterritt, Martin and Rudnick (1969) found that a visual temporal task and an auditory temporal task were of equal difficulty for nine-year-old children. The results of the present study, however, are in agreement with studies of digit recall, which generally report that auditory presentation is easier than visual presentation regardless of age.

Examination of the Klapper and Birch (1971) task suggests that the failure to find an auditory superiority after age nine may be attributable to a ceiling effect. With a difficult intrasensory integration task, such as that used in the present study, the auditory superiority is apparent after nine years of age among good readers.

The auditory store must be more efficient over time than the visual store in order to comprehend the information being received. Generally, recall of auditory material requires time before comprehension is complete since auditory information is temporal in nature. Visual information on the other hand is usually spatial in format. Although visual information requires spatial resolution when it is presented, it does not generally

require attention over time before comprehension is complete as does auditory information. Auditory processing of temporal information would be expected to be more accurate than the visual or tactual processing of temporal information as a result of prior experience and practice.

Previous studies which have compared the efficiency of the auditory and visual systems report auditory superiority if the visual task is temporal in nature (Dornbush & Bassow, 1970; Klapper & Birch, 1971; Kuhlman & Wolking, 1972; Senf & Freundl, 1972) and visual superiority if the visual task is spatial in nature (Sterritt, Martin & Rudnick, 1969; Vande Voort, Senf & Benton, 1972). These studies taken together with the results of the present study suggest that a particular sensory modality is most adept in the processing of information received in a specific format. The usual format of visual information is spatial and of auditory information is temporal. Generally, tactual information seems to require the use of both temporal and spatial formats. Active examination of an object is generally spatial in nature, although a temporal component may be involved if the object being examined tactually has to be explored in a successive fashion.

Although there are no previous studies involving temporal presentation of tactual patterns of stimuli, studies of shape discrimination have reported poorer performance with tactual presentation than with visual presentation of forms. Goodnow (1971) found that adult memory for objects inspected by hand is less stable than memory for objects inspected by eye. Similarly, Rose, Blank and Bridger (1972) found differences in the

performance of three-year-old children on a tactual and a visual intrasensory task with delayed presentation. Although these studies involved shape perception, the findings suggest that the tactual memory store is less resistant to the detrimental effects of time delays than is the visual store. The results of the present studies, however, did not reveal a difference in the efficiency of the visual and tactual systems. This is probably a function of the fact that the visual stimuli were presented temporally, whereas Goodnow (1971) presented the visual stimuli spatially. Temporal presentation of the visual stimuli results in a more difficult task than spatial presentation. Since the tactual system is more accustomed to the temporal method of examining objects than is the visual system, the method of presenting the stimuli in the present study does not seem to have adversely affected tactual processing. Thus the effect of presenting the stimuli temporally is most apparent in the visual task.

The ability to integrate auditory information more accurately than visual or tactual information is a distinguishing feature of the good readers. Examination of the performance of each subject on the three subtests indicates that nine of the twelve good readers scored highest on the auditory subtest, while the best performance of the poor readers was divided almost equally among the three subtests. The individual performances agree with the finding that the good readers performed better on the auditory subject while the poor readers did not perform any one subtest better than the other subtests.

As suggested earlier, the auditory superiority shown by the good readers could be attributed to the fact that the method of presentation is in accord with the customary format of auditory information. The implication is that the auditory system is more able than the visual or the tactual modalities to process temporal stimulation. This does not appear to hold true for poor readers. Previous studies have suggested that poor readers have a deficiency in the verbal labelling of temporally arranged stimuli in the visual modality (Blank & Bridger, 1966). Blank, Weider and Bridger (1968) argue that temporal stimuli cannot be used unless coded in a number system. Certainly a significant proportion of the children in study 2 of the present investigation reported the use of a number code. Although there was not a significant difference in the number of poor and good readers using a number code, the possibility remains that the poor readers used the number code less accurately.

The fact that the poor readers did not demonstrate the auditory superiority shown by the good readers could be interpreted as suggesting that previous experience and thus practice with the auditory processing of temporal information has not resulted in an accrued superiority of this modality in processing temporal information.

To summarize, the good readers performed the auditory intrasensory subtest more accurately than the visual or tactual subtests. The poor readers did not demonstrate a favored modality. It was argued that the customary format for a specific modality is an important determinant of task difficulty. The fact that the poor readers did not

show a modality-specific format was attributed to a failure of the poor readers to benefit from previous experience.

Hypothesis (b): Poor readers perform less well on the cross-modal integration subtests than good readers, and this difference increases with age.

The results of the present study do not support the hypothesis that retarded readers have a sensory integration deficit. Previous studies which have found a sensory integration deficit in poor readers have been interpreted as supporting the position that reading retardation is an auditory-visual integration difficulty (Beery, 1967; Birch & Belmont, 1964, 1965; Kahn, 1965). However, a comparison of the procedure and the results of the present study with the procedure and the results of previous studies suggests that this interpretation is incorrect.

Most of the sensory integration studies have concentrated on A-V integration. The A-V task used in the present study differed from the traditional Birch-Belmont and similar techniques in two important aspects. One important procedural difference between the present studies and previous studies is that the subjects in the present study judged one visual pattern as same or different from the auditory standard whereas subjects in the studies reporting A-V deficits usually required the children to retain the auditory standard in memory while examining three visual alternatives. The memory requirements of this sort of task are obviously more demanding than those of a task involving only one comparison pattern. In previous research, the memory factor is confounded with the temporal-

spatial factor and therefore it is difficult to judge the relative contributions of these two factors in terms of the discrepancy between the results of the present and previous studies.

Two studies of the effects of memory demands on the A-V integration abilities of poor readers are suggestive in regard to the relative importance of memory demands on integration tasks. Vande Voort, Senf and Benton (1972) presented the auditory standard pattern and the visual spatial comparison patterns simultaneously. The retarded readers performed this A-V task more poorly than the good readers. Similarly varying the interpattern interval from 3 seconds to 6 seconds did not alter the performance of poor readers on an A-V task. Furthermore, Meuhl and Kremenak (1966) found A-V integration to be related to reading ability when only one comparison pattern was presented. Taken together these studies suggest that the absence of an A-V deficit among the poor readers in the present study cannot be explained on the basis of a differential memory demand hypothesis.

A more likely explanation of the failure of the present study to confirm previously reported A-V deficits among poor readers relates to a second procedural difference. In the present investigation the visual patterns were temporally ordered. The A-V task was therefore a temporal to temporal equivalence judgement. The procedure used in other studies involved spatially-ordered visual stimuli. The A-V task in this case is a temporal to spatial judgement. The present investigation abolished the necessity of the spatial-temporal translation, and failed to find an

A-V deficit among poor readers. This suggests that the crucial factor discriminating good from poor readers on the A-V task is related to the temporal-spatial nature of previous tasks. Previous studies have interpreted the poorer performance of retarded readers as reflecting a deficiency in their ability to judge visual information as equivalent to auditory information in the absence of memory deficits. Since the temporal-spatial nature of the task was not considered as relevant to the deficit, the implication of these data is that poor readers cannot transpose visual to auditory information for comparison. The task employed in the present study could have required only one of two postulated kinds of encoding: the translation of visual to auditory information. In the absence of confounding factors, there is no support for the suggestion that poor readers have difficulty judging the equivalence of auditory and visual information.

The fact that the poor readers experienced difficulty performing A-V temporal-spatial tasks in previous studies, but perform as well as good readers on an A-V temporal-temporal task could be attributed to a difficulty with the spatial patterns or to a deficit in transposing the spatial into temporal internal representations.

Vande Voort, Senf and Benton (1972) report that poor readers perform as well as good readers on a V-V task in which the patterns were spatially arranged. Thus poor readers do not appear to be deficient in processing spatially arranged stimuli. The alternate explanation of the previously reported A-V deficit for poor readers is that the temporal-

spatial cross-modal task requires a spatial-temporal translation. Thus in order to compare the auditory standard to the visual comparison pattern, it may be necessary to convert the spatial pattern into a temporal format or visa versa. Since the retarded reader has been found to have difficulty performing the A-V temporal-spatial task and a V-V temporal-spatial task (Blank & Bridger, 1966; Rudnick, Sterritt & Flax, 1967) but not an A-V temporal-temporal task, such an explanation is plausible. Bergin (1973) found no differences between good and poor readers on an auditory-visual temporal-temporal task which was similar to that used in the present study. However, there were no differences between the good and poor readers on an A-V temporal-spatial task or a V-V temporal-spatial task either. The failure to find deficits on these latter two tasks could be attributed to a floor effect in Bergin's task. Only twelve trials were administered and performance ranged from 56% correct to 68% correct. In most instances, the average score was approximately 58% correct.

Examination of the traditional A-V task reveals that the cross-modal nature of the task is comprised of the comparison of temporally-ordered auditory stimuli to spatially-ordered visual stimuli. Presumably the equivalence task requires the subject to encode and store the standard pattern. Then the comparison pattern must be compared to this stored pattern. In order to effect this comparison of the two patterns, it may be necessary to encode the comparison pattern in the same way as the standard pattern. The encoding could involve two kinds of translation. Firstly,

the visual comparison pattern may be translated to an auditory format. Secondly, the spatial pattern (visual) may be translated to a temporal format for comparison with the stored temporal pattern. The A-V task could involve one or both of these kinds of translation at the encoding level.

The encoding of the patterns in the present study seems to have taken the form of a verbal response. An analysis of the strategies used by the subjects suggests that the verbal response was most often a number code. Blank, Weider and Bridger(1966) suggest that temporal stimuli must be coded numerically in order to be utilized. If this is indeed the case, a cross-modal task in which all patterns are temporarily ordered may result in the storage of all patterns in the auditory memory store, regardless of modality of presentation. According to Sperling (1963) for instance, there are different stores for different kinds of sensory information, one for auditory and one for visual information. According to Sperling, the contents of the auditory information store decay more slowly than the contents of the visual store. When the contents of the visual store are rehearsed such rehearsal takes the form of a verbal response, and therefore there is input to the auditory information store. Thus the amount of interference with stored material produced by the introduction of new material would be expected to be independent of the modality of input. Thus in the cross-modal task, the amount of inference produced by the comparison pattern would not relate to the sensory modality in which the pattern is presented. Given then that amount of

interference is independent of modality, a difference in the accuracy of two cross-modal tasks such as the V-T and the A-V subtests would have to depend on differential accuracy of encoding information in the specific sensory modalities involved. Although the auditory intrasensory subtest was performed better than the tactual or visual subtests by the good readers in the present study 2, the advantage was not apparent in the cross-modal subtests. That is, one might expect the A-V subtest to be easier for the good readers than the V-T subtest. Presumably, accurate equivalence judgements require that the two patterns be accurately encoded and stored.

A different explanation of the apparent A-V deficit argues that poor readers store visual symbols in a different form than auditory symbols. Senf (1969) suggests that the deficit on the A-V spatial-temporal task is attributable to the necessity of transposing the visually encoded material into the same internal representation as the stored auditory material. The results of the present study, however, suggest that this hypothesis is questionable since the retarded readers performed as well as the good readers on an A-V temporal-temporal task. In the absence of the necessity of translating spatial representation to a temporal representation, there are no differences between the good and poor readers. Thus the critical translation, if in fact the necessity of transforming information is critical, is not modality dependent. Rather, it is an operation relating to the nature of the organization of the stimulus material.

The performance of the poor readers on V-T task was as accurate as the performance of the good readers. Although previous studies (Buchner,

1965; Thom, 1970) reported that scores on T-V tests are related to reading test scores, methodological differences make it difficult to compare the results of the present study to the results of these studies. One such difference relates to the method of presenting the tactual stimuli. In the present investigation, the patterns were tapped on the subjects' finger. In previous studies, the subject has actively explored the forms. The results of the present study suggest that differences between good and poor readers on tasks involving the integration of tactual and visual information are probably attributable to methodological variables. In a situation in which the tactile patterns are presented in the same temporal manner as the auditory and visual patterns, poor readers perform as well as good readers on intrasensory and cross-modal subtests involving the tactual modality.

To summarize, the results of the present investigation of the cross-modal integration abilities of good and poor readers were interpreted as suggesting that the reading retardation is not necessarily an auditory-visual integrational deficit as previously suggested (Beery, 1967; Birch & Belmont, 1964, 1965; Buchner, 1965; Kahn, 1965). Two procedural differences, the greater memory demands and the temporal-spatial nature of previous tasks, were examined in relation to the present data. It was argued that the discrepancy between the present study and previous studies of the A-V abilities of poor readers is attributable to the temporal-spatial nature of previous tasks. Since the difficulty with temporal-spatial tasks cannot be attributed to spatial processing deficits, the discriminatory

feature of the temporal-spatial task was held to be the necessity of translating the spatial patterns to a temporal format for comparison. Finally, the adequate performance of the poor readers on the V-T and T-A subtests was attributed to the fact that no internal format transformations were required since all patterns were temporally ordered.

3. Redundancy in the Cross-Modal Task

Hypothesis (a): The addition of relevant redundant information in a different modality to the modality of presentation of the standard stimulus results in an improvement in the accuracy of cross-modal integration for good readers and a decrement in the performance of poor readers.

Comparison of the bimodal to the trimodal subtests failed to support this hypothesis. There were no reliable differences between performance on the cross-modal subtests (bimodal condition) and performance on the cross-modal subtests with redundant information in the standard pattern (trimodal condition). However, the performance of the good readers in study 2 was more accurate than that of the poor readers on most of the cross-modal redundant subtests. The ten-year-old good readers performed better on all three trimodal subtests, whereas the eleven-year-old good readers performed better on the A + V - T and the T + A - V subtests, but not on the V + T - A subtest.

The poorer performance of the retarded readers on the trimodal subtests is not attributable to deficits within any modality or to a basic deficiency in cross-modal integration since the poor readers performed as

well as the good readers on the intrasensory and bimodal subtests.

A more plausible explanation of the trimodal performance difference between good and poor readers is that the poor readers are less able to ignore the redundant information. Shipley and Jones (1969) for instance, found that poor readers are less able to ignore irrelevant stimulation. Although the redundant information was relevant in the present task, it was not necessary to process this information in order to make equivalence judgements.

Interference of the sort suggested by Shipley and Jones (1969) could occur at the encoding or at the storage level. That is, the simultaneous presentation of a temporal pattern in two modalities may make encoding of the pattern more difficult for the poor readers, but not for the good readers. On the other hand, simultaneous input could result in a weaker memory trace. However, it has already been suggested that temporal patterns are stored as a numerical code regardless of the modality involved. Presumably, once this number code reaches the memory store the number of modalities involved in its creation would be unimportant. Furthermore, the effect of varying memory demands in a cross-modal task has not previously been found to account for differences in the integration abilities of good and poor readers (Muehl & Kremenak, 1966; Vande Voort, Senf & Benton, 1972). Myklebust (1964) has suggested that simultaneous sensory stimulation in two or more modalities may result in neurosensory overloading. Although Myklebust does not specify the nature of the proposed overloading, the implication is that information is lost because it cannot be held long enough to be processed. The results of present study suggest,

however, that the breakdown for poor readers is at the conceptual level of encoding or labelling the stimuli since it was not necessary to retain both of the standard patterns in order to make equivalence judgements.

Thus, the deficit of the retarded readers seems most likely to be in the encoding of the initial pattern. If the good readers ignore the redundant information, encoding of the standard pattern in the bimodal subtests should be as accurate as encoding of the standard pattern in the trimodal subtest. The data support this position. For the poor readers, however, encoding of the standard pattern may be interfered with in the redundant situation possibly because the poor readers are distracted or confused by the additional information. Although the data are in the appropriate direction to support such a position, the differences between the bimodal and trimodal subtests were not reliable.

Nevertheless, it is interesting to examine the possibility that poor readers were less able to ignore the redundant information. Consider, for instance, the fact that the eleven-year-old good readers in study 2 were superior only on two of the three subtests. The two subtests on which the good readers were superior involved an auditory component. Although the good readers do not perform an auditory intrasensory task more accurately than poor readers, the auditory component in the trimodal subtest discriminated the good and poor readers in study 2. If the ability to ignore redundant or irrelevant information discriminates good and poor readers, a task which involves a favored modality for only one group should also discriminate the groups. The performance of the two groups on the intrasensory subtests suggest that good readers perform best using the

auditory modality, whereas poor readers did not have a modality preference. Thus in a situation in which one modality should be attended to and the other ignored, good readers should be able to ignore the redundant channel most readily when the other modality is their strong channel. In a situation involving equally strong channels such as the V + T - A task, the good readers would not be expected to perform better than the poor readers since the standard pattern does not involve the preferred channel.

Wepman (1962) hypothesized that individuals differ in the maturation rate of the various modalities, and as a result some individuals may be visile and others audile. The results of the present investigation suggest that good readers are audile whereas poor readers have no special strength.

The fact the retarded readers did not perform as well as the good readers on the multimodal task is interesting in view of the educators' strong support of the multisensory remedial reading methods. In the absence of the necessity to process multiple information simultaneously, poor readers perform as well as good readers. The suggestion that a multisensory approach to remediation is appropriate, since the identification of the precise cause of the reading retardation may be difficult, is obviously questionable. For at least some children, simultaneous input is detrimental.

Thom (1970) suggests that training can enhance sensory integration at least in normal children in grade one. There is some evidence to suggest that auditory skills can be enhanced by training, but is there

strong evidence to suggest that the distracting effects of redundant information can be overcome by training. An approach to teaching reading which avoids simultaneous input of different kinds of information is suggested by the results of the present investigation. The results of the present study, although not conclusive, suggest that a modality blocking technique may in fact be more appropriate in the treatment of reading problems.

The appropriateness of the multisensory technique with retarded readers is further challenged by the argument presented here concerning the difficulty the retarded reader encounters in translating spatial to temporal information. With the simultaneous presentation of visual-spatial and auditory information processing of the information would necessarily involve both of the proposed deficits. Since the multisensory techniques usually involve seeing and hearing words simultaneously, or seeing, hearing and tracing letters simultaneously, it may be difficult for some children to verbally encode the information because of the interfering effect of the redundant information. Furthermore, the auditory and visual information would be encoded differently, the auditory information temporally and the visual information spatially. Assuming this were perceptually possible in the simultaneous input situation which seems unlikely, comparison of the two kinds of input (auditory information and visual information) would require translation to a different format. Thus, both of the abilities which appear to discriminate good from poor readers are possibly required in the multisensory reading technique.

4. Conclusions

A series of questions concerning the developmental course of sensory integration abilities, the relationship of these abilities to reading abilities, and the implications of sensory integration deficits for remedial reading programs were posed in the Introductory sections of the thesis. The nature of the hypotheses were determined by these critical questions. At this concluding point, the original questions will be restated and the research results related directly to the question.

Are there age changes in the cross-modal integration of auditory, visual and tactual temporal patterns which are independent of age changes in intrasensory abilities? The results of the present study suggest that there are no significant changes between the ages of ten and eleven years of age which are independent of similar improvements in the underlying intrasensory skills.

Are there changes with age in the ability to process redundant information in a cross-modal task? No differences between the cross-modal subtests with redundancy (trimodal) and the cross-modal subtests without redundancy (bimodal) were revealed in the analyses of the present data. Thus no changes with age were revealed for the trimodal subtests.

Is cross-modal integration less accurate than intramodal integration for retarded readers when all stimuli are presented temporally? The performance of the ten-and eleven-year-old retarded readers was as accurate on the cross-modal tasks as on the intrasensory tasks. This was interpreted as suggesting that the feature of the task which is instrumental in determining the difficulty which retarded readers usually experience with the A-V and V-T tasks is the necessity of transposing the spatially ordered visual stimuli into a temporal format for comparison. It was suggested that this translation may be in the form of a verbal response. Thus it was argued that retarded readers may have difficulty verbally labelling spatially-ordered stimuli.

Are the cross-modal integration abilities of good and poor readers related to the specific modalities involved? Performance on the cross-modal task was not related to the specific modalities involved, possibly because the patterns in all modalities were temporally ordered. In the absence of the necessity of transforming visual or tactual information from one format to another, the ability to judge the equivalence of the stimuli patterns was independent of specific modalities. The failure of the good readers to perform better on cross-modal subtests involving an auditory component than on subtests without an auditory component was interpreted as indicating the importance of accurately encoding both the standard and comparison patterns.

Does the child's ability to judge the equivalence of temporal patterns improve with the presentation of relevant redundant information in more than one sensory modality? Comparisons of the accuracy with which equivalence judgments are made when the standard pattern is presented in just one modality and when the standard pattern is presented in two modalities simultaneously revealed no reliable differences. The addition of relevant redundant information did not significantly alter performance. Thus there is no reason to believe that the percept of the patterns was improved in the redundant situation.

Is there experimental evidence to suggest that a modality blocking technique is more appropriate for the poor reader than the multisensory techniques?

The results of the present investigation have led to conclusions concerning the nature of the retarded readers' perceptual processing abilities. Firstly, the retarded reader does not appear to demonstrate channel-specific strengths or weaknesses. Secondly, the retarded reader seems to have difficulty translating spatial information into a temporal format, but does not experience difficulty matching patterns which are temporally ordered. Thirdly, simultaneous input of two kinds of sensory information results in poorer performance by retarded readers relative to the performance of the good readers. This was interpreted as suggesting that the poor reader has difficulty ignoring redundant information.

Thus the results of the present investigation suggest that the multisensory remedial approach may not be the most appropriate. The modality blocking technique does not involve simultaneous input of sensory information and would thus appear to be the more appropriate of the two remedial techniques.

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APPENDIX 1

Average Ages of Subjects in Study 1 and Study 2
(Calculated on the Day of Participation)

Study 1				
Birthdate	Good Readers		Poor Readers	
	1962	1960	1962	1960
Intrasensory Condition	10.42	11.96	10.06	11.92
Bimodal Condition	9.81	11.83	9.98	12.10
Trimodal Condition	10.29	12.06	10.25	11.81

Study 2				
Birthdate	Good Readers		Poor Readers	
	1962	1961	1962	1961
Intrasensory Condition	10.33	11.14	10.14	11.37
Bimodal Condition	10.40	11.46	10.60	11.81
Trimodal Condition	10.38	11.50	10.36	11.06

APPENDIX 2

Average Grade Level in Reading and IQ Scores
of Subjects in Study 1 and Study 2

Study 1								
Birthdate	Good Readers				Poor Readers			
	1962		1960		1962		1960	
	Reading Level	IQ	Reading Level	IQ	Reading Level	IQ	Reading Level	IQ
Intrasensory	7.0	117.8	8.7	116.5	2.9	100.8	4.4	92.5
Bimodal	6.3	112.0	8.7	129.3	3.2	98.0	3.5	99.5
Trimodal	6.7	120.8	9.4	112.3	2.7	104.8	3.8	104.3

Study 2								
Birthdate	Good Readers				Poor Readers			
	1962		1960		1962		1960	
	Reading Level	IQ	Reading Level	IQ	Reading Level	IQ	Reading Level	IQ
Intrasensory	7.7	122.0	8.9	125.0	2.9	102.0	3.5	96.0
Bimodal	8.5	120.0	8.8	121.0	3.2	105.0	3.4	104.0
Trimodal	8.1	124.0	9.0	112.0	2.9	105.0	3.3	99.0

APPENDIX 3
INSTRUCTIONS

All Subjects ... Familiarization

"You are going to take part in a scientific experiment. See this screen. You are going to see dots of light on it."
(E demonstrates) "If you put your hand in here you will feel some taps on your finger." (E demonstrates) "Now if you put on these earphones you will be able to hear beeps." (E demonstrates)

Intrasensory and Bimodal Groups

"Sometimes you will just see lights, sometimes you will just hear sounds and sometimes you will just feel taps on your finger."

Trimodal Group

"Sometimes you will hear beeps and see dots of light at the same time. Sometimes you will see dots of light and feel taps on your finger at the same time. Other times you will hear beeps and feel taps on your finger at the same time."

(E then proceeds to specific instructions for the first subtest being administered)

Intrasensory Subtests

Visual - Visual

"You are going to see a pattern of lights on the screen. Watch the screen carefully. After you see the first pattern of lights there will be a short pause, then you will see another pattern of lights. After you see the second pattern I want you to tell me if it was the same as the first pattern or if it was different. Sometimes the two patterns will be the same and sometimes they will be different. Just say same or different as soon as you decide."

Auditory - Auditory

"You are going to hear a pattern of beeps through the earphones. Listen carefully. After you hear the first pattern there will be a short pause, then you will hear another pattern of beeps. After you hear the second pattern I want you to tell me if it was the same as the first pattern or if it was different. Sometimes the two patterns will be the same and sometimes they will be different. Just say same or different as soon as you decide."

Tactual - Tactual

"You are going to feel a pattern of taps on your finger. After you feel the first pattern of taps, there will be a short pause then you will feel another pattern of taps. After you feel the second

pattern, I want you to tell me if it was the same as the first pattern or different. Sometimes the two patterns will be the same and sometimes they will be different. Just say same or different as soon as you decide."

Bimodal Subtests

Visual - Tactual

"You are going to see a pattern of lights on the screen. After you see the pattern of lights there will be a pause then you will feel a pattern of taps on your finger. After you feel the taps on your finger, I want you to tell me if the pattern of taps was the same as the pattern of lights or if it was different. Sometimes they will be the same and sometimes they will be different. Just say same or different as soon as you decide.

Auditory - Visual

"You are going to hear a pattern of beeps through the earphones. After you hear the pattern of beeps there will be a short pause then you will see a pattern of lights on the screen. After you see the pattern of lights, I want you to tell me if the pattern you saw was the same as the pattern you heard or if it was different. Sometimes they will be the same and sometimes they will be different. Just say same or different as soon as you decide.

Tactual - Auditory

"You are going to feel a pattern tapped on your finger. After

you feel the pattern tapped on your finger there will be a short pause, then you will hear a pattern of beeps. After you hear the pattern of beeps I want you to tell me if the pattern you heard was the same as the pattern tapped on your finger or if it was different. Sometimes they will be the same and sometimes they will be different. Just say same or different as soon as you decide.

Trimodal Subtests

Auditory Plus Visual - Tactual

"You are going to hear a pattern of beeps and see a pattern of lights at the same time. That will be the first pattern. Then there will be a short pause followed by the second pattern which will be tapped on your finger. After you feel the second pattern tapped on your finger I want you to tell me if it was the same as the first pattern or if it was different. Sometimes they will be the same and sometimes they will be different. Just say same or different as soon as you decide."

Visual Plus Tactual - Auditory

"You are going to see a pattern of lights and feel a pattern tapped on your finger at the same time. That will be the first pattern. Then there will be a short pause followed by the second pattern which you hear through the earphones. After you hear the second

pattern I want you to tell me if it was the same as the first pattern or if it was different sometimes they will be the same and sometimes they will be different. Just say same or different as soon as you decide."

Tactual Plus Auditory - Visual

"You are going to feel a series of taps on your finger and hear a series of beeps at the same time. That will be the first pattern. Then there will be a short pause followed by the second pattern which you will see on the screen. After you see the second pattern I want you to tell me if it was the same as the first pattern or if it was different. Sometimes they will be the same and sometimes they will be different. Just say same or different as soon as you decide."

APPENDIX 4

Photograph of the Apparatus

APPENDIX 5

Block Diagram of Digital Circuitry

APPENDIX 6

Analysis of Variance of Study 1 IQ Data

Source	df	MS	F
Age	1	0.02	0.00
Reading Ability	1	3942.20	41.09 **
Subtest	2	37.90	0.60
Age X Reading Ability	1	72.52	0.76
Age X Subtest	2	261.40	2.72
Reading Ability X Subtest	2	114.44	1.19
Age X Reading Ability X Subtest	2	144.27	1.50
Error	60	195.95	

**p < .01

APPENDIX 7

Study 1 and Study 2 Raw Data

Unadjusted Scores for Study 1

a. Intrasyntactic Subtests

Birthdate:		1962		1960	
	Good Readers	Poor Readers	Good Readers	Poor Readers	
A-A					
Subject					
1	18	18	18	25	
2	22	14	21	20	
3	15	16	15	17	
4	19	7	15	14	
V-V					
Subject					
1	12	20	18	26	
2	16	20	15	19	
3	17	14	19	14	
4	14	14	14	16	
T-T					
Subject					
1	14	21	19	23	
2	20	16	17	15	

3	18	15	19	14
4	10	14	18	15

b. Bimodal Subtests

Birthdate: 1962

1960

	Good Readers	Poor Readers	Good Readers	Poor Readers
A-A				

Subject

1	14	17	26	10
2	16	19	24	21
3	16	23	13	25
4	17	13	25	22

V-T

Subject

1	16	21	22	17
2	14	18	28	23
3	22	17	20	17
4	17	16	25	18

T-A

Subject

1	16	20	21	18
2	10	17	19	17
3	11	18	23	23
4	19	13	25	15

c. Trimodal Subtests

Birthdate:		1962		1960	
		Good Readers	Poor Readers	Good Readers	Poor Readers
V+T-A					
Subject					
1	18	15	25	12	
2	17	15	16	20	
3	20	12	25	18	
4	17	28	24	14	
A+V-T					
Subject					
1	19	13	25	17	
2	11	10	18	14	
3	16	12	24	17	
4	16	25	20	14	
T+A-V					
Subject					
1	20	17	22	11	
2	11	10	23	20	
3	17	11	25	18	
4	15	18	22	17	

Unadjusted Scores for Study 2

a. Intrasyntactic Subtests

	Birthdate: 1962		1961	
	Good Readers	Poor Readers	Good Readers	Poor Readers
A-A				
Subject				
1	19	24	25	16
2	26	12	15	23
3	12	14	22	22
4	22	16	25	12
5	29	16	25	23
6	24	16	22	15
V-V				
Subject				
1	14	24	17	14
2	22	13	20	22
3	16	18	18	15
4	16	15	21	13
5	30	19	20	19
6	15	19	21	15
T-T				
Subject				
1	14	18	17	18
2	19	16	17	18
3	17	10	14	22

4	14	15	21	22
5	27	16	15	22
6	16	17	20	14

b. Bimodal Subtests

Birthdate: 1962

1961

	Good Readers	Poor Readers	Good Readers	Poor Readers
--	--------------	--------------	--------------	--------------

A-V

Subject

1	18	12	17	17
2	19	19	15	17
3	22	21	19	17
4	15	19	18	26
5	19	24	21	19
6	24	24	17	15

V-T

Subject

1	17	17	19	19
2	18	19	20	18
3	27	22	16	16
4	18	22	21	22
5	19	14	23	18
6	24	20	18	11

T-A

Subject

1	18	20	20	18
2	19	14	11	17
3	14	18	22	11
4	12	17	21	27
5	18	23	22	20
6	17	22	16	15

c. Trimodal Subtests

Birthdate: 1962

1961

Good Readers

Poor Readers

Good Readers

Poor Readers

V+T-A

Subject

1	21	20	18	21
2	22	15	11	14
3	20	15	22	17
4	21	16	18	17
5	18	20	13	22
6	23	15	20	17

A+V-T

Subject

1	13	15	25	21
2	28	21	17	17
3	16	19	30	11

4	22	14	20	15
5	20	20	18	22
6	25	20	22	17

T+A-V

Subject

1	21	15	21	18
2	21	14	15	20
3	20	17	27	15
4	23	11	21	14
5	18	17	14	24
6	22	17	21	14

APPENDIX 8

Analysis of Covariance of Study 1 Intrasensory Data

Source	df	MS	F
<u>Between Subjects</u>			
Age	1	38.120	1.222
Reading Ability	1	3.554	0.114
Age X Reading Ability	1	7.964	0.255
Error	11	31.22	
<u>Within Subjects</u>			
Subtest	2	0.896	0.17
Age X Subtest	2	0.271	0.05
Reading Ability X Subtest	2	15.646	2.94
Age X Reading Ability X Subtest	2	21.271	3.99*
Error	24	5.326	

* $p < .05$

APPENDIX 9

Winer (1962, p. 610) outlines a procedure for comparing the AB interaction means when one of the factors is administered within subjects. In the case of a significant ABC interaction in which one of the factors is within subjects, an adjustment has to be made to Winer's procedure to accommodate the third factor. In the present study, this adjusted error variance has the form:

$$\frac{2\left[Sp^2 + \frac{(p-1)(r-1)}{2} + (q-1) Sw^2\right]}{nq \frac{(p+q)}{2}} + \frac{[(\bar{A}_{xy} - \bar{A}_{xm}) + (B_{xy} - B_{xm})/2] Sp^2}{P_{xx}}$$

Where Sp^2 is the adjusted between-subject mean square for error, sw^2 is the adjusted within-subject mean square for error. The number of levels of factors A, B and C are represented by p, q, and r respectively. Factors A and B are the between-subject factors and factor C is the within-subject factor. P_{xx} represents the covariate SS error for the between-subject factor. No adjustment was necessary in the method of calculating the difference between two adjusted cell means. The adjusted error variance was used as the MS error in the Newman-Keuls procedure of comparing means.

APPENDIX 10

Analysis of Covariance of Study 1 Bimodal Data

Source	df	MS	F
<u>Between Subjects</u>			
Age	1	165.667	7.957*
Reading Ability	1	5.559	0.265
Age X Reading Ability	1	88.880	4.24
Error	11	20.946	
<u>Within Subjects</u>			
Subtest	2	10.750	0.83
Age X Subtest	2	1.083	0.08
Reading Ability X Subtest	2	4.750	0.37
Age X Reading Ability X Subtest	2	1.000	0.08
Error	24	12.924	

* $p < .05$

APPENDIX 11

Analysis of Covariance of Study 1 Trimodal Data

Source	df	MS	F
<u>Between Subjects</u>			
Age	1	370.191	3.008
Reading	1	94.672	2.308
Age X Reading Ability	1	89.848	2.190
Error	11	41.03	
<u>Within Subjects</u>			
Tasks	2	10.646	1.59
Age X Tasks	2	11.437	1.71
Reading Ability X Subtest	2	0.646	0.10
Age X Reading Ability X Subtest	2	0.438	0.07
Error	24	6.681	

APPENDIX 12

Analysis of Covariance of Study 1
T-A and T+V-A Subtests

Source	df	MS	F
Age (A)	1	73.120	4.305*
Reading Ability (B)	1	14.814	0.872
Simple effect of A for b_1	1	151.290	8.907**
for b_2	1	0.030	0.002
Simple effect of B for a_1	1	10.240	0.603
for a_2	1	85.748	5.048*
Subtest	1	3.727	0.219
Age X Reading Ability	1	79.875	4.703*
Age X Subtest	1	16.312	0.960
Reading Ability X Subtest	1	18.844	1.109
Age X Reading Ability X Subtest	1	0.176	0.176
Error	23	16.986	

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

APPENDIX 13

Analysis of Covariance of Study 1
A-V and A+T-V Subtests

Source	df	MS	F
Age	1	145.353	7.652*
Reading Ability	1	11.125	0.586
Subtest	1	18.572	0.978
Age X Reading Ability	1	42.408	2.233
Age X Subtest	1	3.580	0.188
Reading Ability X Subtest	1	34.597	1.821
Age X Reading Ability X Subtest	1	0.245	0.013
Error	23	18.995	

* $p < .05$

APPENDIX 14

Analysis of Covariance of Study 1
V-T and V+A-T Subtests

Source	df	MS	F
Age	1	99.999	7.165*
Reading Ability	1	44.739	3.206
Subtest	1	49.025	3.513
Age X Reading Ability	1	67.821	4.859*
Age X Subtest	1	0.689	0.049
Reading Ability X Subtest	1	1.798	0.129
Age X Reading Ability X Subtest	1	0.189	0.014
Error	23	13.956	

* $p < .05$

APPENDIX 15

Analysis of Covariance of Study 1
V-V and A-V Subtests

Source	df	MS	F
Age	1	49.980	2.743
Reading Ability	1	32.770	1.799
Subtest	1	26.601	1.460
Age X Reading Ability	1	2.296	0.126
Age X Subtest	1	1.259	0.069
Reading Ability X Subtest	1	11.164	0.613
Age X Reading Ability X Subtest	1	8.423	0.462
Error	23	18.220	

APPENDIX 16

Analysis of Covariance of Study 1
V-V and V-T Subtests

Source	df	MS	F
Age	1	55.302	4.965*
Reading Ability	1	0.054	0.005
Subtest	1	60.385	5.422*
Age X Reading Ability	1	15.026	1.349
Age X Subtest	1	8.060	0.724
Reading Ability X Subtest	1	40.734	3.657
Age X Reading Ability X Subtest	1	18.342	1.647
Error	23	11.137	

* $p < .05$

APPENDIX 17

Analysis of Covariance of Study 1
T-T and V-T Subtests

Source	df	MS	F
Age	1	55.421	5.101*
Reading Ability	1	13.235	1.218
Subtest	1	61.125	5.626*
Age X Reading Ability	1	37.872	3.486
Age X Subtest	1	12.424	1.143
Reading Ability X Subtest	1	7.441	0.685
Age X Reading Ability X Subtest	1	6.387	0.588
Error	23	10.866	

*p < .05

APPENDIX 18

Analysis of Covariance of Study 1
T-T and T-A Subtests

Source	df	MS	F
Age	1	72.593	6.005*
Reading Ability	1	0.033	0.003
Subtest	1	8.338	0.690
Age X Reading Ability	1	36.691	3.035
Age X Subtest	1	15.238	1.261
Reading Ability X Subtest	1	0.025	0.002
Age X Reading Ability X Subtest	1	8.527	0.705
Error	23	12.088	

* $p < .05$

APPENDIX 19

Analysis of Covariance of Study 1
A-A and A-V Subtests

Source	df	MS	F
Age	1	65.123	3.129
Reading Ability	1	0.242	0.012
Subtest	1	20.355	0.978
Age X Reading Ability	1	2.437	0.117
Age X Subtest	1	3.940	0.189
Reading Ability X Subtest	1	3.969	0.117
Age X Reading Ability X Subtest	1	59.844	2.875
Error	23	478.738	

APPENDIX 20

Analysis of Covariance of Study 1
A-A and T-A Subtests

Source	df	MS	F
Age	1	90.490	6.579*
Reading Ability	1	8.957	0.651
Subtest	1	4.814	0.350
Age X Reading Ability	1	0.494	0.036
Age X Subtest	1	16.654	1.211
Reading Ability X Subtest	1	2.315	0.168
Age X Reading Ability X Subtest	1	90.425	6.579*
Error	23	13.754	

* $p < .05$

APPENDIX 21

Results of Binomial Tests Computed on Number of
Subtest Scores Exceeding 50% Correct

Condition						
Intrasensory			Bimodal		Trimodal	
	Number	Z	Number	Z	Number	Z
Study 1 (N=48)	25	3.18**	40	4.61**	36	3.56**
Study 2 (N=72)	59	5.75**	65	7.25**	61	6.25**

** $p < .01$

APPENDIX 22

Regression Coefficients for Study 1
and Study 2 Main Analyses

Study 1 Analysis			
Factor	Intrasensory	Bimodal	Trimodal
Reading Ability	+0.01337	+0.05670	0.34841
Age	-0.01688	+0.21498	-0.10392
Reading Ability X Age	+0.12937	+0.12937	-0.06785

Study 2 Analysis			
Factor	Intrasensory	Bimodal	Trimodal
Reading Ability	+0.25653	+0.15646	+0.19065
Age	+0.18545	+0.21741	-0.07084
Reading Ability X Age	+0.15890	+0.17848	-0.09039

APPENDIX 23

Preliminary Session Instructions

"Before we begin the experiment, I want to make sure that you understand what a pattern is. First I'll show you patterns of lights. Watch the screen."

.. .. (E makes a pattern exaggerating pause.)

You saw 2 lights then there was a pause then you saw two more lights. That's one pattern. I could also make a pattern like this.

... .

That's a different pattern than the first one you saw because this time you saw three lights, then there was a pause then you saw just one light. Now I'm going to show you more patterns. This time the first pattern will be the same as the second pattern. Here's the 1st pattern.

. ... and here's the second (exaggerating pause) \

You see these two patterns were the same because both patterns had one light, a pause, and then three lights.

Now I'll show you two patterns that are different from each other.

Here's the first pattern.

.. ..

and here's the second

. ...

The first pattern had two lights, a pause, then two more lights. The

second pattern had one light, a pause, and then two more lights. So they were different patterns. Now I'll let you try a few of your own. You tell me if the first pattern is the same as the second pattern, or if the patterns are different.

1.

Different - "Good, those two patterns were different".

Same - "No, those two patterns were different".

WRONG ANSWER:

I'll show it to you again.

... .

The 1st pattern was three lights, a pause, then one light.

. .. .

The second pattern was one light, a pause and then three lights. So the patterns are different.

2.

Same - Good, those two patterns are the same.

Different - No, those two patterns were the same. I'll show them to you again.

. ... The first pattern has one light, a pause and then 3 lights.

. ... The second pattern has one light, a pause and then three lights. So the patterns were the same.

3.

Same - Good, those two patterns were the same.

Different - No, those two patterns were the same. I'll show them to you again.

... . The first pattern has 3 lights, a pause, and then one light.

... . The second pattern has 3 lights, a pause and then one light. So these two patterns are the same.

4.

Different - Good.

Same - No, those patterns were different.

5.

Same - Good.

Different - No, those patterns were the same.

6.

Different - Good.

Same, No, those patterns were different.

7.

Different - Good.

Same - No, those patterns were different.

8.

Same - Good.

Different - No, those two patterns were the same.

APPENDIX 24

Subjects who made one or more errors
on the Preliminary Session

Birthdate	1962		1961	
	Good Readers	Poor Readers	Good Readers	Poor Readers
Intrasensory Condition	1	2	1	4
Bimodal Condition	0	2	1	2
Trimodal Condition	2	0	1	2
Totals	3	4	3	8

APPENDIX 25

Analysis of Variance of Study 2 IQ Data

Source	df	MS	F
Age	1	210.120	1.87
Reading Ability	1	6403.300	56.90**
Subtest	2	19.292	0.17
Age X Reading Ability	1	7.347	0.07
Age X Subtest	2	19.792	0.18
Reading Ability X Subtest	2	275.850	2.45
Age X Reading Ability X Subtest	2	100.180	0.89
Error	60	112.53	

** $p < .01$

APPENDIX 26

Analysis of Covariance on Study 2
Intrasensory Integration Data

Source	df	MS	F
<u>Between Subjects</u>			
Age	1	51.229	0.462
Reading Ability	1	10.066	0.091
Age X Reading Ability	1	51.787	0.467
Error	19	110.918	
<u>Within Subjects</u>			
Subtest	2	35.014	4.37 *
Reading Ability X Subtest	2	30.597	3.82 *
Age X Subtest	2	7.097	0.89
Reading Ability X Age X Subtest	2	16.014	2.00
Error	40	8.014	

* $p < .05$

APPENDIX 27

Analysis of Covariance of Study 2
Bimodal Integration Data

Source	df	MS	F
<u>Between Subjects</u>			
Age	1	12.441	0.177
Reading Ability	1	21.553	0.306
Age X Reading Ability	1	44.214	0.628
Error	19	70.397	
<u>Within Subjects</u>			
Subtest	2	8.167	0.99
Reading Ability X Subtest	2	13.722	1.67
Age X Subtest	2	8.722	1.06
Reading Ability X Age X Subtest	2	5.389	0.65
Error	40	8.233	

APPENDIX 28

Analysis of Covariance of Study 2
Trimodal Data

Source	df	MS	F
<u>Between Subjects</u>			
Age	1	4.367	0.048
Reading Ability	1	346.275	3.771
Age X Reading Ability	1	49.975	0.544
Error	19	91.838	
<u>Within Subjects</u>			
Subtest	2	12.667	2.26
Reading Ability X Subtest	2	11.056	1.98
Age X Subtest	2	6.500	1.16
Age X Reading Ability X Subtest	2	22.167	3.96*
Error	40	5.597	

* $p < .05$

APPENDIX 29

Analysis of Covariance of Study 2
A-V and A+T-V Subtests

Source	df	MS	F
Age (A)	1	2.477	0.201
Reading Ability (B)	1	27.396	2.226
Subtest (C)	1	3.784	0.307
Simple Effect of B for c_1	1	2.457	0.200
for c_2	1	84.826	6.900*
Simple effect of C for b_1	1	16.534	1.343
for b_2	1	47.377	3.849
Age X Reading Ability	1	10.338	0.840
Age X Subtest	1	14.023	1.139
Reading Ability X Subtest	1	60.595	4.923*
Age X Reading Ability X Subtest	1	6.162	0.501
Error	39	12.310	

* $p < .05$

APPENDIX 30

Analysis of Covariance of Study 2
T-A and T+V-A Subtests

Source	df	MS	F
Age	1	0.675	0.052
Reading Ability	1	0.036	0.003
Subtest	1	0.202	0.016
Age X Reading Ability	1	1.839	0.141
Age X Subtest	1	11.897	0.913
Reading Ability X Subtest	1	15.592	1.196
Age X Reading Ability X Subtest	1	53.827	4.030
Error	39	13.034	

APPENDIX 31

Analysis of Covariance of Study 2
V-T and V+A-T Subtests

Source	df	MS	F
Age	1	1.323	0.085
Reading Ability	1	26.437	1.693
Subtest	1	1.211	0.078
Age X Reading Ability	1	7.959	0.510
Age X Subtest	1	6.955	0.445
Reading Ability X Subtest	1	5.427	0.348
Age X Reading Ability X Subtest	1	0.911	0.058
Error	39	608.949	

APPENDIX 32

Analysis of Covariance of Study 2
T-T and T-A Subtests

Source	df	MS	F
Age	1	21.898	1.505
Reading Ability	1	12.326	0.847
Subtest	1	4.245	0.292
Age X Reading Ability	1	1.139	0.078
Age X Subtest	1	2.521	0.173
Reading Ability X Subtest	1	0.657	0.045
Age X Reading Ability X Subtest	1	54.859	3.770
Error	39	14.555	

APPENDIX 33

Analysis of Covariance of Study 2
T-T and V-T Subtests

Source	df	MS	F
Age	1	0.973	0.080
Reading Ability	1	1.703	0.141
Subtest	1	32.677	2.702
Age X Reading Ability	1	11.210	0.927
Age X Subtest	1	26.851	2.081
Reading Ability X Subtest	1	10.312	0.853
Age X Reading Ability X Subtest	1	22.723	1.879
Error	39	12.093	

APPENDIX 34

Analysis of Covariance of Study 2
V-V and V-T Subtests

Source	df	MS	F
Age	1	6.199	0.425
Reading Ability	1	10.569	0.725
Subtest	1	12.865	0.882
Age X Reading Ability	1	5.155	0.353
Age X Subtest	1	2.353	0.161
Reading Ability X Subtest	1	0.087	0.000
Age X Reading Ability X Subtest	1	0.365	0.025
Error	39	14.587	

APPENDIX 35

Analysis of Covariance of Study 2
V-V and A-V Subtests

Source	df	MS	F
Age	1	7.002	0.469
Reading Ability	1	6.082	0.005
Subtest	1	9.333	0.626
Age X Reading Ability	1	1.934	0.130
Age X Subtest	1	3.076	0.206
Reading Ability X Subtest	1	10.381	0.696
Age X Reading Ability X Subtest	1	1.608	0.108
Error	39	14.920	

APPENDIX 36

Analysis of Covariance of Study 2
A-A and A-V Subtests

Source	df	MS	F
Age	1	0.343	0.021
Reading Ability	1	0.219	0.013
Subtest	1	7.161	0.433
Age X Reading Ability	1	3.933	0.238
Age X Subtest	1	17.771	1.074
Reading Ability X Subtest	1	39.147	2.365
Age X Reading Ability X Subtest	1	7.406	0.447
Error	39	16.554	

APPENDIX 37

Analysis of Covariance of Study 2
A-A and T-A Subtests

Source	df	MS	F
Age	1	19.671	1.066
Reading Ability	1	0.657	0.036
Subtest	1	33.641	1.824
Age X Reading Ability	1	1.386	0.075
Age X Subtest	1	0.161	0.009
Reading Ability X Subtest	1	45.716	2.478
Age X Reading Ability X Subtest	1	36.289	1.967
Error	39	18.448	