READING ABILITY AND HEMISPHERIC SPECIALIZATION IN BOYS AND GIRLS

Wayne Arnold

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Abstract

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The present study assessed the relation between reading ability and the degree of lateralization of verbal and nonverbal functions to the left and right hemispheres respectively. Four groups, each consisting of 16 right-handed subjects, were matched in terms of chronological age and I.Q., and were differentiated by sex and reading ability (superior or subaverage). Each subject was presented with both a verbal (consonants) and a nonverbal (tones) dichotic listening task and was tested for recognition using a <u>same-different</u> response paradigm. As predicted, verbal information was generally better recognized when presented to the right ear, nonverbal information when presented to the left ear. Contrary to hypothesis, these asymmetries did not differ with sex and, with verbal materials, the right-ear superiority was found only with subaverage readers. However, the superior readers did tend to be more efficient and sensitive than the subaverage readers in processing auditory information. The results were interpreted as suggesting that variation in reading ability within the non-clinical population may not be a function of degree of lateralization but rather may reflect general differences in the ability to process auditory information.

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Although the cerebral hemispheres in man are structurally similar, they serve different functions. Usually, the left hemisphere predominates in the processing of verbal information whereas the right hemisphere appears to process nonverbal material. It has been suggested that the functional specialization of the hemispheres occurs at an early age and develops differentially in boys and girls. More specifically, it appears that the lateralization of language develops at an earlier age in girls (Bryden, 1970) with boys possibly showing earlier lateralization of mechanisms serving the processing of nonverbal stimuli (Knox and Kimura, 1970). The apparently differential development of hemispheric functioning in boys and girls is of particular interest since several studies (Money, 1966; deHirsh, 1968; Critchley, 1970) have suggested a link between delay in lateralization of function and reading disability. The present study examines this whole question of a relation between lateralization to the left and right hemispheres, sex, and reading ability.

The concept of specialization of function of the cerebral hemispheres is based on the observation that damage to the left and right hemispheres is accompanied by different perceptual impairments. Until recently, however, knowledge about the perceptual asymmetries of the cerebral hemispheres has depended mainly on studies of neurological patients with structurally altered brains and it has been difficult to generalize these clinical findings to normal individuals with intact nervous systems. The investigation of hemispheric functions in the normal person had to await the development of techniques applicable to the normally functioning brain. Such a technique was developed by Kimura (1961a) who adapted Broadbent's (1954) dichotic listening technique for use in the study of hemispheric asymmetry of function in normal adults (Kimura, 1961b). The technique involves the simultaneous presentation of two different auditory messages, one to each ear, by means of a dual channel tape recorder with stereophonic earphones.

Kimura (1961b) observed that with dichotic auditory presentation of verbal information (digits), normal right-handed adults were able to recall more information presented to the right ear than that delivered to the left ear. She attributed this perceptual asymmetry to the functional superiority of the contralateral auditory pathways over the ipsilateral pathways in transmitting verbal information to the speech processing regions of the brain (Kimura, 1961b). This interpretation is consistent with electrophysiological evidence demonstrating that the crossed connections from ear to cerebral cortex in the cat (Rosenzweig, 1951), the dog (Tunturi, 1949) and man (Bocca, Calearo, Cassinari, and Migliavacca, 1955) are more efficient than the uncrossed pathways. Confirmation of the superiority of the crossed over uncrossed pathways in man was obtained in a study (Kimura, 1961b) of unilateral brain-damaged patients for whom the localization of speech representation had been established by the sodium amytal technique (Milner, Branch, and Rasmussen, 1964). Patients with speech representation in the left hemisphere showed a right-ear superiority on the dichotic digits test, while patients with speech representation in the right hemisphere showed a left-ear superiority. Thus, the perceptual asymmetries observed on normal right-handed subjects and unilateral brain-damaged patients indicate a clear relation between the ear laterality effect on the dichotic verbal listening test and cerebral hemispheric dominance for language.

Right-ear superiority in dichotic listening has since been replicated on groups of normal right-handed adult subjects for verbal stimuli such as digits, words, function words, nonsense words, and consonant configurations (Kimura, 1967; Curry, 1967; Curry and Rutherford, 1967; Shankweiler and Studdert-Kennedy, 1967). However, when verbal stimuli are presented dichotically to left-handed groups more variability is observed with respect to ear asymmetry (Curry, 1967; Curry and Rutherford, 1967). These findings appear to reflect the fact that handedness is a much better predictor of cerebral dominance for language in right-handers than in left-handers (Milner, Branch, and Rasmussen, 1964). To be more specific, using the sodium amytal technique to assess the locus of speech representation, Milner (personal communication, 1973) has recently found that 92 percent of right-handed patients ($\underline{n} = 95$) are left-hemispheric dominant for speech while 49 percent of left-handers ($\underline{n} = 87$) have left-hemispheric speech representation.

In addition to its application to the problems of cerebral dominance for language and the dominance-handedness relation, the dichotic listening technique has been used to investigate the functions of the right hemisphere. When nonspeech sounds such as melodic patterns and environmental noises (e.g. car starting, tooth brushing, etc.) are dichotically delivered to normal right-handed individuals, a significant left ear laterality effect emerges (Kimura, 1964; Curry, 1967). Since the contralateral connections between the ear and cortex are more efficient than the ipsilateral pathways, this perceptual laterality effect supports the contention that the right hemisphere predominates in the processing of nonverbal auditory stimuli. Furthermore, Shankweiler (1966) reported that when melodies were dichotically presented to patients with temporal lobe damage, those with right-hemispheric lesions showed more impairment than subjects with left-brain damage. Thus, the auditory asymmetries of the dichotic listening procedure reflect the differential contribution of the cerebral hemispheres in the processing of verbal and nonverbal auditory information.

One of the most interesting uses of the dichotic listening technique has been its application to the study of the development of hemispheric lateralization. Kimura (1963) studied the performance of right-handed boys and girls between the ages of 4 and 9 on a dichotic digits test. She found a right-ear superiority effect for all age-sex groups, suggesting that cerebral dominance for language is established as early as age 4. The right-ear laterality effect for dichotically presented digits has since been replicated on normal right-handed children between the ages of 5 and 8 (Kimura, 1967; Knox and Kimura, 1970). The data suggest that the lateralization of speech functions does not develop with increasing age. In fact, the findings indicate that the degree of laterality decreases with age. These observations seem to contradict the clinical data on aphasia following early brain damage which indicate that language is more equipotentially represented in the left and right hemispheres at younger ages (Basser, 1962) and that hemispheric specialization increases with cerebral growth until about the age of puberty (Lenneberg, 1967).

However, the failure to obtain any developmental trends with the dichotic listening procedure could be attributed to a phenomenon which has been termed the ear order of report (Bryden, 1962). Bryden (1962) has shown that when digits are presented dichotically at a rate of 2 pairs per second, most subjects prefer to recall all the material delivered to the right ear before giving any from the left ear. Inglis and Sykes (1967) and Bryden (1970) have shown that the overall performance on a dichotic digits test, especially on the second ear reported, improves with age. In the Kimura studies (Kimura, 1963; 1967; Knox and Kimura, 1970) order of report was not controlled, and if her subjects did tend to report the right ear material first, the more limited memory span of the younger subjects may have limited their left ear recall, producing the apparent lateralization as an artifact. In support of this interpretation, when Bryden (1970) presented digits dichotically to right-handed boys and girls from grades 2, 4, and 6 and controlled statistically for the effects of ear order of report by calculating the relative incidence of right-ear superiority, he found that cerebral dominance for language emerged earlier in girls than in boys and that lateralization of speech functions developed with age and was clearly established only by age 12 or 13 (grade six), a finding consistent with the clinical data on aphasia in children (Bryden, 1970).

The dichotic listening technique has also been used to test the hypothesis that developmental dyslexia is attributed to cerebral immaturity; that is, faulty or incomplete lateralization of language functions (Money, 1966; deHirsh, 1968; Critchley, 1970). A child with developmental dyslexia is unable to learn to read with proper facility despite conventional instruction, adequate intelligence, and sociocultural opportunity. A large number of deficits usually accompany the reading difficulty such as left-right confusion (Belmont and Birch, 1965), calculation difficulties (Belmont and Birch, 1966), finger differentiation problems (Kinsbourne and Warrington, 1966), spontaneous writing and spelling impairments (Zangwill, 1962), impairment in form perception (Benton, 1962) and depressed verbal intelligence (Belmont and Birch, 1966). The pattern of deficits observed in children with developmental dyslexia varies greatly from individual to individual and as yet no sign or group of signs has been identified as characteristic of developmental dyslexia. It has been, therefore, difficult to isolate cases of developmental dyslexia from amongst the total population of poor readers and the consideration of developmental dyslexia as a unique form of reading retardation becomes highly suspect.

The differences of opinion regarding the existence of developmental dyslexia apart from the total population of poor readers stem from the difficulty in integrating the empirical findings in the literature. Several studies have included subjects from heterogeneous populations of poor readers (Belmont and Birch, 1966). Furthermore, many investigations have been based on clinic samples which have included children from socially and educationally deprived areas, many of whom have neurological complications, sensory deficits, emotional problems or even impaired intelligence (Satz and Sparrow, 1970). The empirical findings reported in the literature have been contaminated by poor experimental methodology making it difficult to integrate the results and thereby to identify the existence of developmental dyslexia apart from reading retardation.

However, the consideration of developmental dyslexia as a diagnostic entity still persists and several researchers (Money, 1966; deHirsh, 1968; Critchley, 1970) postulate that the primary cause in developmental dyslexia is faulty or incomplete cerebral dominance for language. This conclusion is primarily based on the observation that the pattern of deficits seen in developmental dyslexic children are similar to impairments in adults who have sustained damage to the left cerebral hemisphere. Furthermore, many children with developmental dyslexia are left-handed (Zangwill, 1960) or show weak, mixed, or inconsistent manual preferences (Ingram, 1959; 1960). These findings suggest that delayed or incomplete lateralization of cerebral function is closely linked with developmental dyslexia.

Because of the difficulties in diagnosing developmental dyslexia apart from reading retardation, it may be more profitable to consider reading ability as existing along a continuum with severe reading retardation at one end of the distribution and superior reading ability at the other end of the distribution. It then becomes appropriate to investigate the relation between cerebral dominance and reading ability in normal children at operationally defined levels of reading ability. In support of this proposition, Goody and Reinhold (1961) postulate that the functional lateralization of the two cerebral hemispheres as a child develops is closely related to the performance of reading in general.

To date, research has centered on the relation between reading ability and the lateralization of language to the left hemisphere. This approach seems most obvious since reading is a language-derived skill. However, reading involves the transformation of visual-spatial information to some auditorily stored equivalent. The perception of visual-spatial configurations is a nonverbal task, and it has been convincingly demonstrated that the mechanisms of the right hemisphere predominate in the processing of nonverbal stimuli. Therefore, reading probably involves the processing mechanisms of the left and right cerebral hemispheres. Hence, it is postulated that the lateralization process may be slower in both hemispheres of children who are less proficient in reading than those who show superior reading ability.

The only study that has assessed left and right hemispheric differences in the same groups of normal right-handed boys and girls was reported by Knox and Kimura (1970). Subjects between the ages of 5 and 8 were presented with dichotic pairs of digits and environmental sounds (dog barking - dishwashing; phone dialing - clock ticking; children playing - car starting). They found a right-ear superiority for each age-sex group on the dichotic digits test and a left-ear superiority for each age-sex group on the environmental sounds task. The contrasting auditory asymmetries in the same groups of children suggest that the functional differentiation of the two hemispheres along the verbal-nonverbal dimension occurs by age 5 (Knox and Kimura, 1970), although as already noted, this apparent functional differentiation might be an artifact of the failure to control the ear order of report. A second problem with interpreting the Knox and Kimura (1970) findings is that the verbal and nonverbal dichotic tasks were not comparable. On the dichotic digits task, the subjects were instructed to recall the digits they had heard whereas on the environmental sounds task, the subjects were presented pairs of sounds and were asked to recognize the stimuli. Both recognition and recall presumably involve attention and memory, but recall is generally assumed to require specialized retrieval mechanisms as well (Murdock, 1968). Since the verbal and nonverbal tasks in this study were not strictly comparable in terms of the mechanisms involved in responding to them, caution must be taken in attributing the differences between them to the difference between the processing of verbal and nonverbal information.

In addition to finding a left- and right-ear superiority for each age-sex group with nonverbal and verbal stimuli respectively, Knox and Kimura (1970) also reported that the overall performance of the boys on the environmental sounds test was significantly better than that of the girls. The superiority of the boys over the girls in identifying nonverbal stimuli was interpreted as probably representing a differential maturation of functions (Knox and Kimura, 1970). Thus, the data suggest that the functional organization of the brain may be different in boys and girls and there may be a differential maturational development in the lateralization of mechanisms that serve verbal (Bryden, 1970) and nonverbal (Knox and Kimura, 1970) information processing.

The finding that left-hemispheric mechanisms lateralize at different rates in boys and girls (Bryden, 1970) and the suggestion in the Knox and Kimura (1970) data that right-hemispheric mechanisms may lateralize at different rates in boys and girls raises interesting questions regarding the relation between reading ability and cerebral hemispheric specialization. Reading ability has been shown to be more closely associated with the lateralization of verbal functions in boys than it is in girls (Bryden, 1970). Since girls are less efficient than boys in processing nonverbal material, a function of the right hemisphere, possibly reading ability in girls is more associated with the lateralization of nonverbal functions to the right hemisphere. However, reading disability is preeminently a male disorder (Bentzen, 1963) which suggests that reading ability may be related only to the lateralization of verbal functions to the left hemisphere despite the apparent requirements for visual-spatial skills.

Nevertheless, since reading may involve left- and right-hemispheric mechanisms and boys and girls may lateralize differentially, it is important to assess reading ability in relation to the lateralization of verbal and nonverbal functions in comparable groups of boys and girls. To date, no study has been undertaken which investigates the functions of both the left and right hemispheres of children of different levels of reading ability. The purpose of the present study, therefore, is to assess the relation between reading ability and the cerebral lateralization of verbal and nonverbal functions in normal right-handed boys and girls.

Method

Materials and Apparatus

The comprehension subtest of the Gates-MacGinitie Reading Test, the Goodenough-Harris Drawing Test and the ten hand preference items of the Harris Tests of Lateral Dominance (Harris, 1957) were used to classify subjects as to reading ability, intelligence and handedness respectively. Two sets of dichotic stimuli were prepared as experimental materials. These stimuli were presented to subjects by means of a dual channel tape recorder (Revox, Type 77A) and stereophonic earphones (Sharpe, Pro HA 660).

Subjects

A total of 260 Grade 3 students in four elementary schools in upper-middle class suburban areas under the Baldwin-Cartier Catholic School Commission were screened for intelligence and reading ability using the Goodenough-Harris and Gates-MacGinitie tests. The actual grade level of students at the time of screening was 3.8. During the screening, all students who wrote with their left hand were noted and were eliminated from further testing ($n = 45$). Following screening, four experimental groups of 16 subjects each were constructed. These groups were matched according to median and range of age and I.Q. and were differentiated by sex and reading ability. Table 1 presents the median and range scores of the superior and subaverage reading boys and girls on the various measures and includes the grade level performance equivalent to the median and range standard scores on reading ability. The superior and subaverage reading boys and girls did not differ significantly with respect to age or I.Q. and the boys and girls within the two reading groups showed no significant difference on reading ability. The superior readers, of course, differed from the subaverage readers on reading ability at a highly significant level.

The subjects in this study reported having no auditory deficits or uncorrected visual deficiencies and no subject showed any motor impairments. Furthermore, since all four schools were located in predominantly upper-middle class

TABLE 1

MEDIAN AND RANGE SCORES ON I.Q., AGE, AND READING ABILITY, WITH THE EQUIVALENT GRADE LEVEL PERFORMANCE, FOR THE SUPERIOR AND SUBAVERAGE READING BOYS AND GIRLS

	Superior Readers		Subaverage Readers	
	Boys	Girls	Boys	Girls
Reading Ability[a]				
Median	60.50 (6.0)	60.50 (6.0)	43.50 (3.0)	44.50 (3.1)
Range	57 - 71 (5.4)-(7.0)	57 - 71 (5.4)-(7.0)	32 - 47 (1.7)-(3.4)	30 - 47 (1.6)-(3.4)
Age in Months				
Median	109.50	105.50	107.00	105.00
Range	102 - 112	100 - 112	101 - 113	102 - 113
I.Q.				
Median	99.50	105.83	101.00	105.50
Range	90 - 119	91 - 119	90 - 118	92 - 116

[a] actual grade level at time of screening was 3.8

( ) equivalent grade level performance

areas, it was assumed that the groups were reasonably well matched on academic opportunity.

Dichotic Stimuli

In this investigation the subjects were presented with two sets of dichotic stimuli. One set consisted of nonverbal tonal patterns; the other was patterns of paired letters of the alphabet.

The verbal and nonverbal tests each consisted of 3 dichotic practice tests followed by two Series of 20 dichotic test presentations. Each dichotic presentation consisted of a warning signal, the dichotic stimuli and a recognition pattern. The blank interval between offset of the warning signal and onset of the dichotic stimuli was 2 seconds, that between the offset of the dichotic stimuli and the onset of the recognition pattern was 1 second. To give the subjects enough time to respond, a blank period of approximately 8 seconds separated the offset of the recognition pattern and the onset of the subsequent warning signal. Within each Series of the dichotic tests, 50 percent of the recognition stimuli were dissimilar from either pattern presented dichotically while 25 percent were identical to the pattern delivered to the left ear of the dichotic presentation and 25 percent were identical to that delivered to the right ear.

Prior to constructing the tapes, the verbal and nonverbal stimuli were randomly grouped in patterns of three with the restriction that within each triad no stimulus was identical to one previously chosen. The patterns of three stimuli were then paired randomly with the restriction that two identical stimuli were never paired together. Furthermore, in the dichotic verbal test, any meaningful combinations of letters were avoided. Within each Series of 20 patterns, it was randomly determined which 10 items had recognition patterns dissimilar from either dichotic pattern and which 5 items had recognition patterns similar to the left ear and right ear dichotic patterns respectively.

The stimuli for the nonverbal dichotic test consisted of sinewave tones comprising the octave from A4 to A5 on the chromatic scale (440, 494, 522, 586, 660, 700, 784, and 880 Hz.). The warning tone was arbitrarily set at a frequency of 500 Hz. The tones were derived from an audio generator and recorded on a tape recorder. In order to increase the accuracy of each tonal frequency and intensity, the tones were monitored over an oscilloscope at the time of recording.

With these stimuli, two tapes were constructed, one for channel 1 and the other for channel 2 of a dual channel tape recorder. On each of these tapes the 500 Hz. warning signals lasted approximately 1.75 seconds and each tone lasted 500 milliseconds. In constructing a tonal pattern, the tones were arranged to be played contiguously so that the duration of a tonal pattern was 1.5 seconds.

The nonverbal dichotic test was constructed with the tones generated on the two tapes. The tonal patterns were recorded on different tracks of a dual channel tape recorder so that one tonal pattern could be delivered to the left ear at the same time that the other tonal pattern was being delivered to the right ear.

The format of the dichotic verbal test was comparable to that of the dichotic nonverbal test. In constructing the verbal patterns, 8 letters of the alphabet were selected: r, s, l, k, c, h, v, q. Only consonants were chosen for the test and the selection was based on the apparent auditory discriminability of the 8 consonants from each other.

In the verbal dichotic test, the warning signal was the digit identifying the test item. In an attempt to ensure comparability of the stimulus presentation under the two dichotic tests, the experimenter recorded the letters of the alphabet to the beat of a metronome set at two beats per second. In constructing the dichotic verbal test, the warning signal, the recognition pattern and the dichotic pattern to be presented to the left ear were recorded on both channels 1 and 2 of a dual channel tape recorder. The left-ear dichotic pattern on channel 2 was then erased and replaced by the dichotic pattern to be presented to the right ear. With this procedure, the warning signal and the recognition pattern of the test presentation could be played stereophonically and one pattern of letters could be delivered to the left ear at the same time that a different pattern was being presented to the right ear. The onset and offset of each letter within the dichotically paired patterns were matched by sensitive recording meters, one connected to each channel of the dual channel tape recorder.

Procedure

Prior to testing, each subject was tested for hand preference using the Harris Tests of Lateral Dominance (Harris, 1957). The questions were read aloud by the experimenter and the students were encouraged to pantomime each of the 10 manual activities mentioned on the questionnaire. If a student performed an activity with the right hand a score of 10 was assigned; a score of 0 was assigned whenever a task was performed with the left hand. On tasks where students showed no manual preference, a score of 5 was credited. With this procedure, a score of 100 indicates strong right-handedness whereas a score of 0 indicates strong left-handedness. Harris (1957) elaborates further by considering scores between 75 - 95 as moderate right-handedness; 30 - 70 as mixed handedness and scores of 5 - 25 as moderate left-handedness.

Following the manual preference questionnaire, subjects were individually tested with the two dichotic tests. The sequential order of presenting the tests and the ear order of presentation were systematically counterbalanced across subjects within groups. By this means, half the subjects within each group received the verbal dichotic test followed by the nonverbal dichotic test and half the subjects received the reversed order of presentation. Within each order of dichotic test presentation half the subjects performed Series I of the dichotic tests with the right phone on the right ear and the left phone on the left ear and half the subjects received the reversed order. On the presentation of Series II for the two dichotic tests, the earphones were reversed for all subjects. Use of these procedures to balance for practice and fatigue effects, ears and channels controlled for possible biasing effects of these variables on the results. Throughout each test, the subjects were encouraged to attend to the stimulus material presented to both ears.

In each dichotic test, the subject's task was to identify whether the recognition pattern was the same as one of the patterns presented dichotically or different from both these patterns; that is, a same-different response was required of the subjects. Each dichotic test was preceded by three practice trials. The stimulus material on the two channels of the practice items was delivered monaurally and followed by the dichotic presentation of the practice trials. This procedure permitted the subjects to become familiar with the material and the task required of them. No dichotic test was presented until the subjects were able to identify correctly the monaural and dichotic presentations of the practice trials. In both dichotic tests, listeners were encouraged to guess carefully, when necessary. For each of the dichotic tests, the score for each ear was the number of correct _same_ identifications for that ear on items with recognition patterns identical to one of the dichotically delivered patterns. In addition, the experimenter recorded the latency from the offset of a recognition pattern to the subject's response. These response latencies were timed with a stopwatch and recorded in one-fifth units of a second. With these data, left- and right-ear median response latencies were tabulated on the items with recognition patterns identical to one of the dichotically presented patterns that were identified correctly.

The same-different response paradigm used in the present study gives rise to a 2 by 2 truth table in which there are four possible response outcomes. According to the truth table which is presented in Table 2, a correct <u>same</u> and <u>different</u> response would be regarded as a hit and a correct rejection respectively whereas an incorrect <u>same</u> and <u>different</u> response would be considered a false alarm and a miss respectively.

Results

Hand Preference

The results of the hand preference section of the Harris Tests of Lateral Dominance showed that 54 subjects obtained scores of 100, 6 obtained scores of 95 and the remaining 4 were credited with scores of 90. Thus, the sample of subjects in this study were predominantly right-handed.

Recognition

<u>Hits</u>. An analysis of variance was applied to the hits as a function of Reading Ability, Sex, Stimulus Type (verbal or nonverbal) and Ear to which the pattern was presented during the dichotic presentation. A highly significant main effect was obtained for Stimulus Type, F (1, 60) = 72.17, $p < .001$, with the subjects in the two reading groups correctly identifying significantly more verbal information ($\bar{X}$ = 16.00) than nonverbal information ($\bar{X}$ = 13.33).

In addition to the main effect of Stimulus Type, there was a significant Stimulus Type by Reading Ability by Sex interaction, F (1, 60) = 5.92, $p < .025$. Figure 1 gives the mean scores underlying this triple interaction. In order to

TABLE 2

TRUTH TABLE

		True state of affairs	
		Same	Different
Actual response	Same	hit	false alarm
	Different	miss	correct rejection

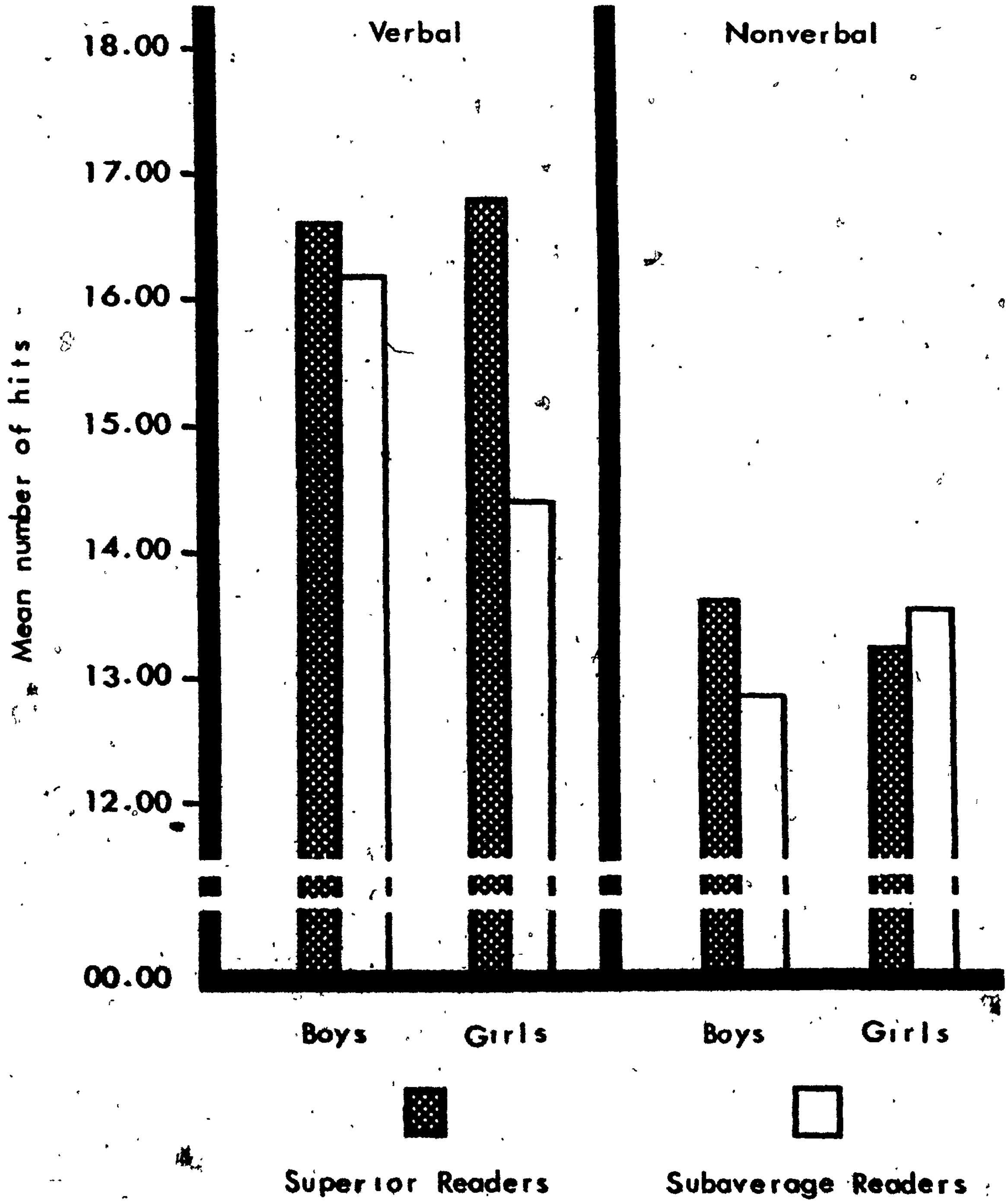

Figure 1. Mean number of hits for the boys and girls as a function of Stimulus Type and Reading Ability

assess this interaction and any subsequent interaction in this study, Cicchetti's modification (Cicchetti, 1972) of the Tukey (a) test (Winer, 1962) was applied to the data. This post hoc test showed that the significant Stimulus Type by Reading Ability by Sex interaction was due to the relatively poor performance of the subaverage reading girls with verbal material, with none of the Reading Ability by Sex groups differing in performance on the nonverbal material.

The double interactions, Ear by Reading Ability, F (1, 60) = 7.29, $p < .01$, and Stimulus Type by Ear, F (1, 60) = 8.59, $p < .005$, and the triple interaction Stimulus Type by Ear by Reading Ability, F (1, 60) = 4.79, $p < .05$, were all significant. As Figure 2 shows, the Ear by Reading Ability interaction reflected an overall significant left-ear superiority for superior readers and an overall right-ear superiority for subaverage readers. The Stimulus Type by Ear interaction replicated the typical finding of a right-ear superiority for verbal stimuli and a left-ear superiority for nonverbal material. However, as Figure 3 shows, the Stimulus Type by Ear by Reading Ability interaction modified this effect in that the superior readers, instead of showing the expected significant right-ear superiority with verbal materials, showed a slight left-ear superiority. The post hoc test on this interaction indicated that the performance of the superior readers differed significantly from that of the subaverage readers only in a significant superiority in recognizing verbal stimuli presented to the left ear ($p < .01$).

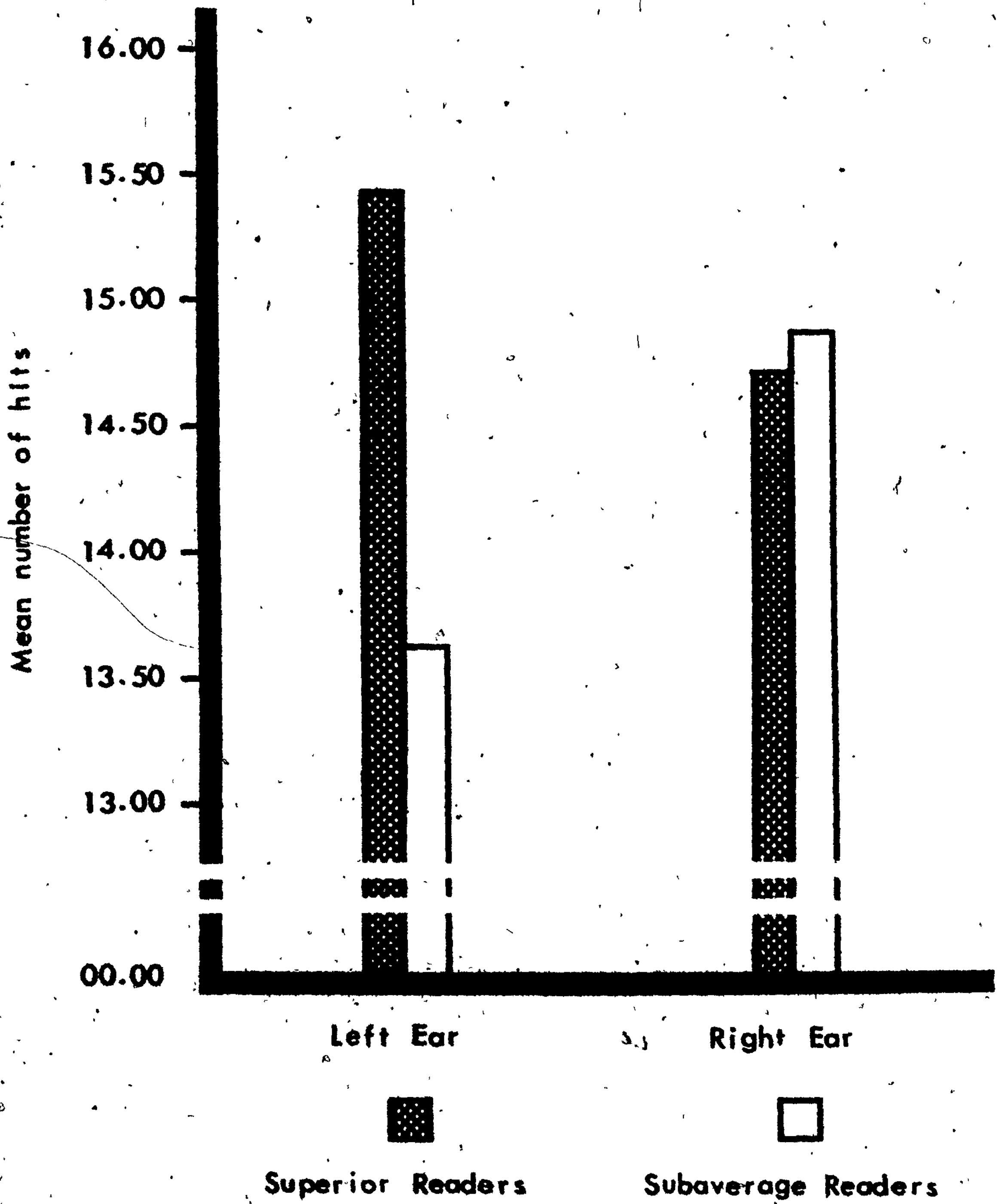

Figure 2. Mean number of left- and right-ear hits as a function of Reading Ability

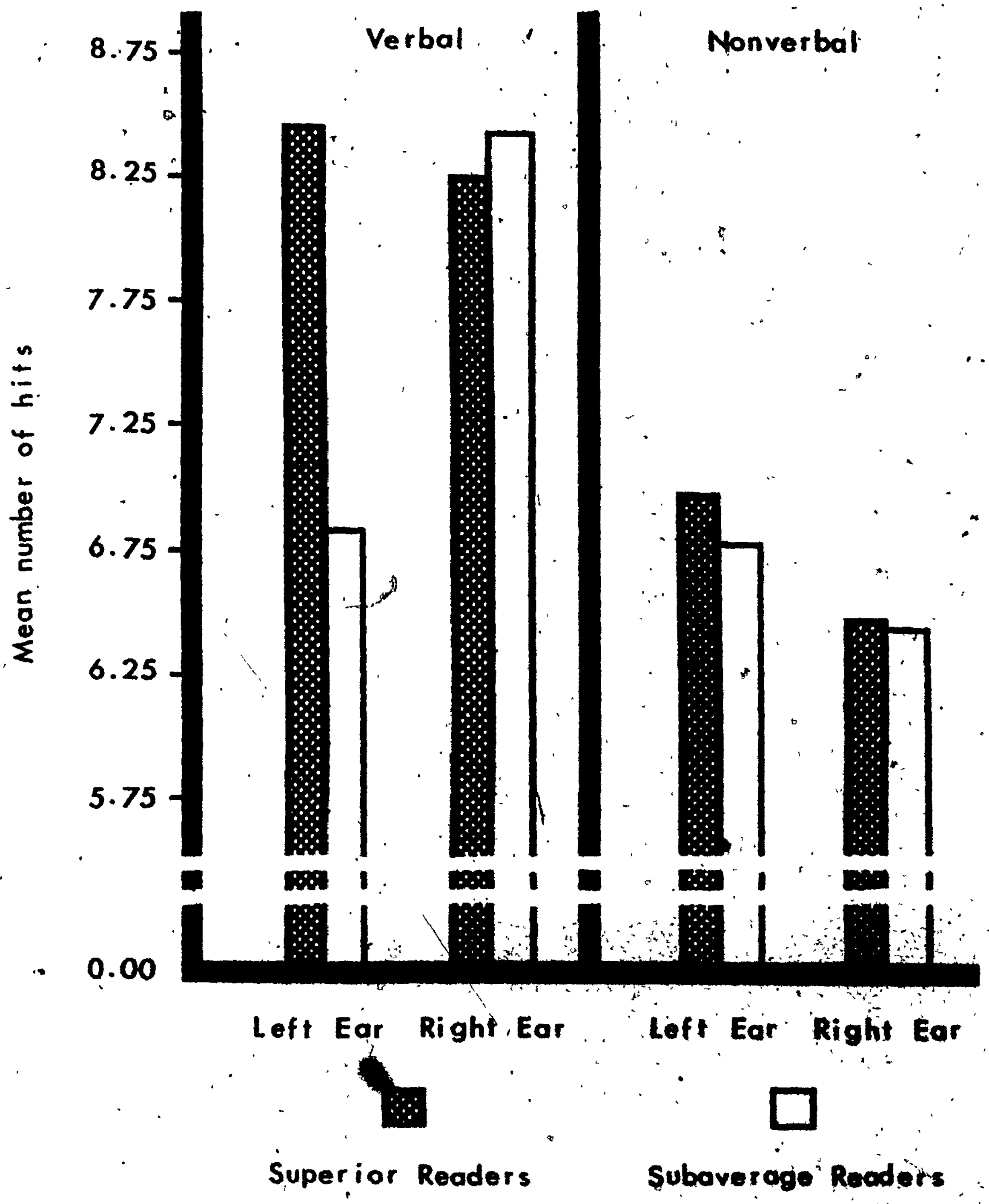

Figure 3. Mean number of left- and right-ear hits as a function of Stimulus Type and Reading Ability

To assess the possibility of a practice effect across Series I and Series II, an analysis of variance was applied to the hits as a function of Reading Ability, Sex, Stimulus Type, and Series. The findings of this analysis showed a highly significant main effect for Series, $\underline{F}$ (1, 60) = 15.43, $\underline{p} < .001$, with the subjects in the two reading groups correctly identifying significantly more information on Series II ($\bar{X}$ = 15.13) than Series I ($\bar{X}$ = 14.20) of the dichotic tests. In addition to the main effect of Series, there was a significant Stimulus Type by Series by Reading Ability interaction, $\underline{F}$ (1, 60) = 4.00, $\underline{p} < .05$. The mean scores underlying this triple interaction are presented in Figure 4. Inspection of the data in Figure 4 shows that the superior readers scored more hits than the subaverage readers except for a reversal on Series I of the nonverbal test. The post hoc test on the Stimulus Type by Series by Reading Ability interaction indicated that improvement from Series I to Series II was significant for subaverage readers with verbal materials only ($\underline{p} < .05$) and for superior readers with nonverbal materials only ($\underline{p} < .05$).

Sensitivity measures (d'). The superior readers in the present investigation obtained generally more hits suggesting that they were somewhat more efficient information processors. However, the subjects were required to recognize the stimuli, a procedure that is particularly sensitive to the effects of guessing. In order to assess whether the superior and subaverage reading boys and girls were differentially sensitive to auditory information, the measure of sensitivity used in

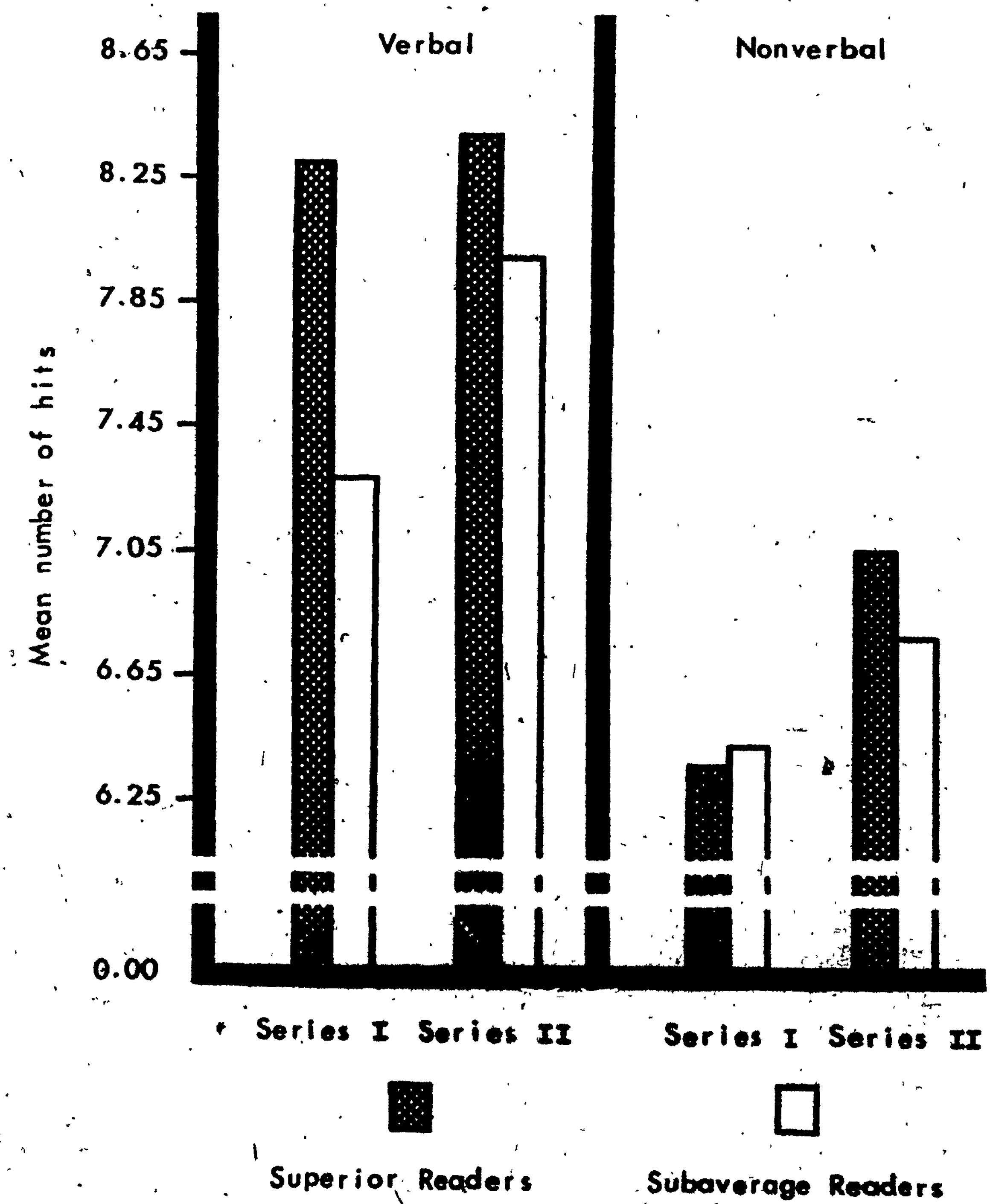

Figure 4. Mean number of hits for Series I and II as a function of Stimulus Type and Reading Ability

signal detection studies, d', (Tanner and Birdshall, 1964; Swets, 1964) was tabulated for each subject. Each d' score is derived from the proportion of hits and false alarms. A subject who adopts the strategy of making a lot of same responses will have a high rate of both hits and false alarms and hence a low d' score whereas a subject who is truly sensitive to the auditory input will have a high rate of hits, a low rate of false alarms and therefore a high d' score.

An analysis of variance was applied to the d' measures as a function of Reading Ability, Sex, Stimulus Type, and Series. The main effect of Stimulus Type, F (1, 60) = 67.40, $p < .001$, was highly significant with the subjects in the two reading groups being more sensitive in processing verbal information ($\bar{X}$ = 3.92) than nonverbal information ($\bar{X}$ = 2.05). The analysis also showed that the main effect of Series, F (1, 60) = 4.79, $p < .05$, was significant indicating that the subjects were more sensitive to auditory information processing in Series II ($\bar{X}$ = 3.18) than in Series I ($\bar{X}$ = 2.79). In addition to the main effects of Stimulus Type and Series, there was a significant Stimulus Type by Series by Reading Ability interaction, F (1, 60) = 5.25, $p < .05$. Figure 5 presents the mean scores in sensitivity for Series I and II as a function of Stimulus Type and Reading Ability. Inspection of the data in Figure 5 shows that the superior readers were more sensitive than the subaverage readers to both verbal and nonverbal auditory information except for a reversal on Series I of the nonverbal test. The post hoc test showed that significant improvement in sensitivity from

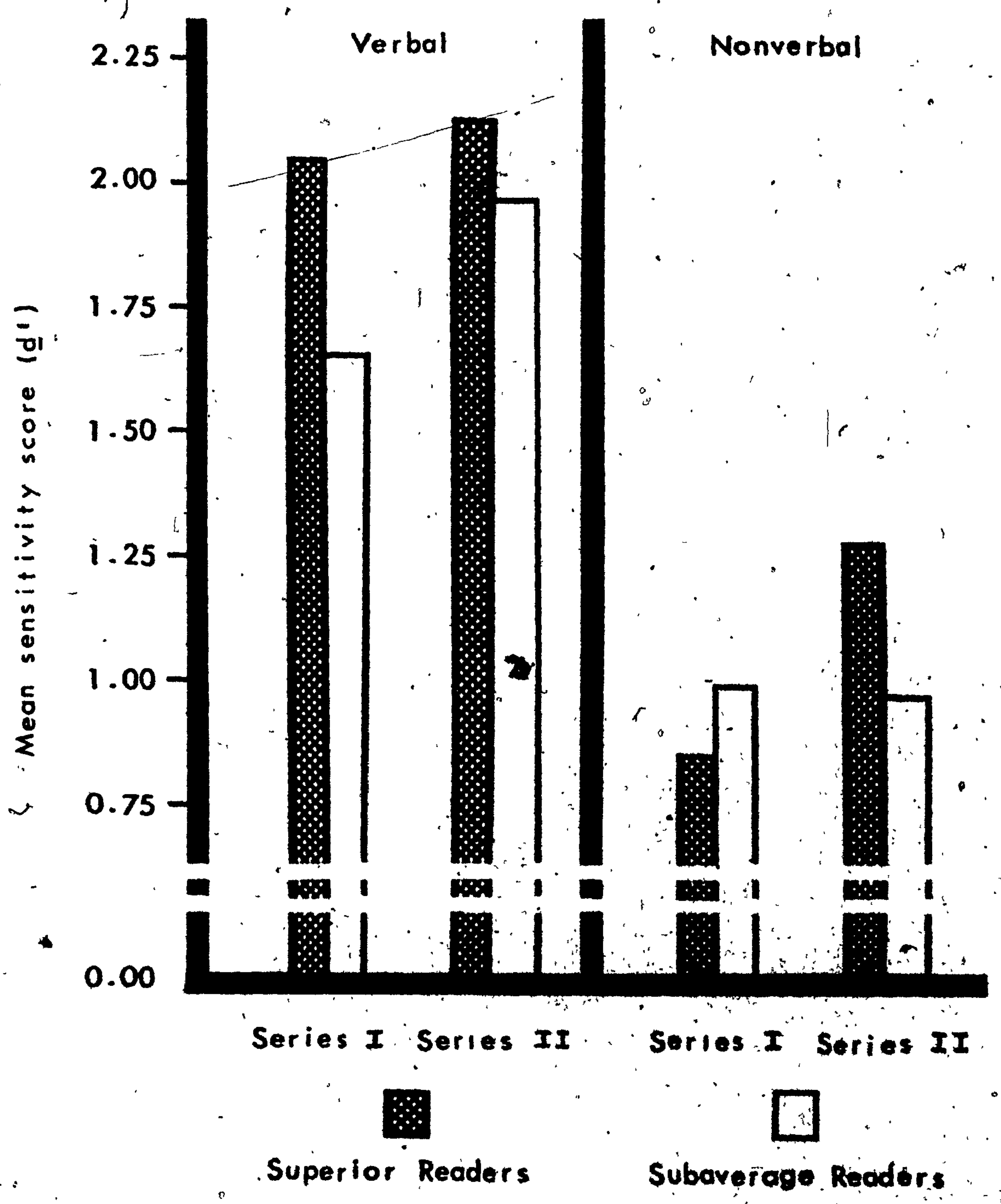

Figure 5. Mean scores in sensitivity for Series I and II as a function of Stimulus Type and Reading Ability

Series I to Series II occurred only with superior readers on the nonverbal task ($p < .05$).

Response Latencies

An analysis of variance was applied to the median response latencies for the hits as a function of Reading Ability, Sex, Stimulus Type and Ear to which the pattern was presented during the dichotic presentation. The main effect of Stimulus Type, $F(1, 60) = 46.40$, $p < .001$, was highly significant with the mean median response latencies for the verbal and nonverbal dichotic tests being 4.44 and 3.50 respectively. The longer response latency for the verbal material may reflect the fact that there was more information to process in the verbal than in the nonverbal dichotic test.

According to the statistical analysis of the median response latencies, no other main effects and no interactions were significant. The nonsignificant Stimulus Type by Ear interaction indicates that the response latencies for the left and right ears under the two dichotic tests did not differ; that is, no ear superiority in speed of recognition was obtained for either the verbal or nonverbal dichotic tests. In addition, no interaction with Stimulus Type by Ear proved to be significant.

Discussion

The present study assessed the relation between the lateralization of verbal and nonverbal functions in boys and girls at different levels of reading ability. The combined data for the two reading groups showed a left- and right-ear superiority for nonverbal and verbal materials respectively. With nonverbal material, the expected left-ear superiority was shown by both reading groups while with verbal material, although the subaverage readers showed a strong right-ear superiority, the superior readers, contrary to the expected hypothesis, showed a slight left-ear superiority. Boys and girls within the superior and subaverage reading groups showed no differential development in the lateralization of verbal and nonverbal functions. Finally, there was a suggestion in the data that the superior readers were more efficient and sensitive than the subaverage readers to auditory information processing.

The results of the present investigation indicate that when consonants are presented dichotically, normal right-handed children are able to recognize significantly more information presented to the right ear than that delivered to the left ear. The opposite pattern of ear superiority emerges with the dichotic presentation of tonal patterns. Previous studies on groups of normal right-handed children have demonstrated a right-ear superiority in dichotic listening for verbal stimuli such as digits (Kimura, 1963; 1967; Knox and Kimura, 1970; Bryden, 1970) and words (Sommers and Taylor, 1972), and a left-ear superiority in dichotic listening for nonverbal stimuli such as environmental sounds (Knox and Kimura, 1970). Thus, the present study replicated the typical left- and right-ear superiority for the dichotic auditory presentation of nonverbal and verbal information respectively.

The laterality effects of the dichotic listening technique have been interpreted to represent the differential contribution of the cerebral hemispheres in the processing of verbal and nonverbal auditory information (Kimura, 1961b; Kimura, 1964; Curry, 1967). This interpretation is consistent with evidence demonstrating that the contralateral connections between the ear and cortex are more efficient than the ipsilateral pathways (Bocca, Calearo, Cassinari, and Migliavacca, 1955). Assuming a close relation between the perceptual asymmetries on the dichotic listening technique and hemispheric specialization, the results of the present study support the contention that by age 9 the left hemisphere predominates in the processing of verbal information (Kimura, 1963; 1967; Knox and Kimura, 1970) while the right hemisphere appears to be more responsible in processing nonverbal information (Knox and Kimura, 1970). The fact that this study did replicate the usual laterality effects found with verbal and nonverbal materials can be interpreted as validating the representativeness of the particular samples of stimulus materials and subjects used in this study.

The results of the present study fail to indicate any association between reading ability and hemispheric specialization for language. On the verbal dichotic test, the subaverage readers obtained a highly significant right-ear laterality effect while the superior readers unexpectedly showed a slight left-ear superiority. This could be interpreted, contrary to previous research and theory, as meaning that cerebral dominance for language is more clearly established in children at lower levels of reading ability than in children who are more proficient in reading. However, the possibility exists that the superior readers failed to show cerebral dominance for language because their efficiency in assimilating the amount of verbal information presented resulted in a ceiling effect in the data. Such a ceiling effect would, of course, attenuate any significant laterality effects.

The concept that reading ability is related to hemispheric specialization for language stems from the notion that the primary cause in developmental dyslexia is faulty or incomplete cerebral dominance for language (Money, 1966; deHirsh, 1968; Critchley, 1970). The postulate that incomplete cerebral dominance for language is the causal factor of developmental dyslexia is largely based on the clinical observation that many reading disabled children are left-handed (Zangwill, 1960) or show weak, mixed, or inconsistent manual preferences (Ingram, 1959; 1960). Thus, the incidence of ambiguous- and left-handedness in reading disabled children is considered a measure of incomplete lateralization of verbal functions. As Kimura (1961b; 1967) has pointed out, however, the dichotic listening technique is a more adequate way of assessing cerebral dominance for language than is the use of manual preferences. According to a recent article (Shankweiler and Liberman, 1972), studies in which dichotic listening has been used to assess the relation between reading ability and degree of lateralization to the left hemisphere, as indexed by right-ear superiority, have had largely negative findings. Hence, the present results are not inconsistent with the previous literature, despite the widespread citation of delayed lateralization as being a factor involved in reading disability. A further problem with the present study is that the subaverage readers were not all that deficient in reading ability. It is still possible therefore that the association between reading ability and cerebral dominance for language does exist, but that it is limited to readers who are markedly retarded in reading ability.

The present study appears to be the only investigation that has used the dichotic listening technique to assess the relation between reading ability and the lateralization of nonverbal functions. The ear performance of the superior and subaverage reading groups did not differ on the nonverbal dichotic test. One possible interpretation of this finding would be that reading ability is not related to the lateralization of nonverbal functions to the right hemisphere because it is basically a language-derived skill. However, as already noted, the widespread belief in an association between reading ability and the lateralization of verbal functions to the left hemisphere has been questioned in more recent research. If lateralization of verbal functions is indeed unrelated to reading ability, it is not surprising that the results of the present study failed to demonstrate a relation between reading ability and the lateralization of nonverbal functions to the right hemisphere.

Shankweiler and Liberman (1972) suggest that possibly there is a relation between reading ability and hemispheric specialization but that it is far more complex than has been assumed and that it involves visual and motor functions as well.

The present study failed to find any sex differences in the lateralization of verbal and nonverbal processing capacities. In contrast, the Knox and Kimura (1970) study, which included children between the ages of 5 and 8, did show some suggestion of an earlier lateralization of right hemispheric functions in boys than in girls and Bryden (1970) reported earlier lateralization of left hemispheric functions in girls than in boys but only at grades 4 and 6. The subjects in the present investigation were older than most of the children in the Knox and Kimura (1970) study but were younger than the grade 4 and 6 children of the Bryden (1970) study. Thus, one possible explanation of the present findings may be that the children in this study were either too old or too young to show any sex differences in the rate at which lateralization of functions to the two hemispheres takes place. In further research on this problem one would obviously want to examine more than one age group, although the difficulty with using children younger than those of the present study is that they need some schooling before they can be classified as disabled readers.

The difference between superior and subaverage readers that was found in the present study was a tendency for the former to recognize more items correctly. This effect held generally over all conditions except Series I on the nonverbal task. That this higher hit rate is not simply an artifact of superior guessing strategies on the part of superior readers is shown by the analysis of the d' scores (Figure 5) where the superior readers were found to be more sensitive to auditory information under all conditions except Series I of the nonverbal task.

It could be argued that the differential abilities of the superior and subaverage readers in processing auditory information are associated with differences in attention. However, on the two dichotic tests both the superior and subaverage readers generally obtained more hits and higher d' scores on Series II compared to Series I whereas one would expect that if lack of attention were a factor, performance would deteriorate over what was a relatively long testing session.

The differences obtained between the superior and subaverage readers in processing auditory information are particularly interesting since the subaverage readers in this study were reading only slightly below expected grade level performance. It is possible that children who are still less proficient in reading would show even more pronounced difficulties in processing auditory information. It is intriguing to speculate that it might be more difficult to teach the skills of reading to average readers than to superior readers with the phonic method which involves the segmentation of words into sound units. Furthermore, it may be cautiously suggested that reading disabled children would benefit more from the whole-word method than from the phonic method of teaching reading.

The present findings suggest that future research in this area consider the presentation of verbal and nonverbal information dichotically to children at three different levels of reading ability: children at actual grade level and children reading two or three grade levels above and below expected grade level performance. However, it appears that finding such samples for investigation would be difficult if the socioeconomic variable were held constant. The present study was conducted in an upper-middle class area of Montreal and of the 260 children tested only a small proportion were reading below expected grade level performance. In contrast, Zurif and Carson (1970) conducted their study in a low socioeconomic area of Montreal and had difficulty finding children of average reading ability (Maag, 1973, personal communication).

The present findings also suggest the investigation of auditory information processing in reading disabled children. Any deficiency in auditory information processing may be a cause or an effect of reading disability. In order to tease out a cause-effect relationship, it would be necessary to conduct a longitudinal study assessing auditory information processing and subsequent ability to acquire the skills of reading.

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Appendix A

SCORES ON READING ABILITY, AGE, AND I.Q. AND THE ANALYSES OF VARIANCE SOURCE TABLES ON THESE MEASURES

Reading Ability

Standard scores on the comprehension subtest of the Gates-MacGinitie Reading Test (Primary C, Form 1)

	Superior Readers		Subaverage Readers	
Subject	Boys	Girls	Boys	Girls
1	61	60	40	44
2	58	63	47	47
3	70	60	43	45
4	61	60	45	41
5	61	60	36	45
6	63	58	44	35
7	60	71	47	47
8	58	71	44	47
9	57	63	43	46
10	58	61	43	38
11	71	61	45	45
12	57	70	43	46
13	61	61	45	35
14	58	60	47	30
15	60	58	32	44
16	70	57	37	43

Age in Months

	Superior Readers		Subaverage Readers	
Subject	Boys	Girls	Boys	Girls
1	108	108	101	105
2	111	104	113	102
3	109	102	103	103
4	112	111	107	113
5	110	103	107	105
6	111	104	110	104
7	110	101	107	111
8	109	110	103	102
9	105	104	112	107
10	108	100	103	103
11	106	107	105	102
12	110	110	113	106
13	111	112	112	104
14	106	105	111	109
15	111	106	104	109
16	102	108	107	110

Intelligence Quotient

Standard I.Q. scores on the Goodenough-Harris Drawing Test

	Superior Readers		Subaverage Readers	
Subject	Boys	Girls	Boys	Girls
1	100	95	94	106
2	97	97	104	114
3	90	112	104	93
4	109	111	100	92
5	95	101	102	108
6	116	106	100	101
7	95	108	102	98
8	99	114	106	116
9	94	91	97	97
10	92	97	102	105
11	118	110	94	110
12	99	119	97	105
13	102	92	94	116
14	106	106	90	97
15	116	106	114	112
16	119	105	118	107

TABLE 1

READING ABILITY
ANALYSIS OF VARIANCE

Source	SS	df	MS	F
Between groups	5990.30	3	1996.77	91.22+
Within groups	1313.44	60	21.89	

+$p < .001$

TABLE 2

AGE IN MONTHS
ANALYSIS OF VARIANCE

Source	SS	df	MS	F
Between groups	83.92	3	27.97	2.27 n.s.
Within groups	739.06	60	12.32	

TABLE 3

INTELLIGENCE QUOTIENT
ANALYSIS OF VARIANCE

Source	SS	df	MS	F
Between groups	132.88	3	44.29	0.64 n.s.
Within groups	4164.88	60	69.41	

Appendix B

INSTRUCTIONS

Instructions

Verbal dichotic test

Monaural presentation. You are going to hear letters of the alphabet (r, s, l, k, c, h, v, and q). When the man on the tape says the number 1 that means you should listen carefully because you are soon going to hear a set of three letters (e.g. h, c, q). And after a short pause you will hear another set of three letters played to your (right or left) ear and tell me whether the second set of letters is the same or different from the first set. O.K.? (If incorrect repeat. When correct continue.)

Now try the next two tests. Just before the second test begins the man will say the number 2 and before the third test he will say the number 3. When you hear the numbers, begin listening very carefully. (Repeat any incorrect trials. Continue if and when all responses are correct.)

We are going to do the same thing, this time with the other ear. O.K.? (Repeat any incorrect trials. Continue if and when all responses are correct)

Dichotic presentation. This time you will hear the man on the tape say the number 1 in both ears. This lets you know that you must start listening very carefully because you are going to hear letters of the alphabet. This time you will hear a set of three letters to one ear and at exactly the same time you will hear another set of three letters in the other ear. You must listen carefully to the two sets of letters played to your ears at the same time. After a short pause you will hear another set of three letters that will be the same in both ears. This set of letters may be the same as one of the two you just heard before or it may be different. I want you to tell me whether it's the <u>same</u> or <u>different</u>. To get each test right you must listen carefully to both ears at the same time. During the tests I'll keep reminding you to listen to both ears. At times you may have to guess. If you guess, try to make a very good guess. O.K.? (Play the 3 practice trials - if all are responded to correctly, continue. Repeat any incorrect trials.)

<u>Nonverbal dichotic test</u>

<u>Monaural presentation</u>. You are going to hear sounds like music (illustration). The first sound means that you should listen carefully because you are soon going to hear a set of three short musical notes (illustration). And after a short pause you will hear another set of three short musical sounds. I want you to listen carefully to these sounds played to your (right or left) ear and tell me whether the second set of three musical sounds is the same or different from the first set of three musical sounds. O.K.? (If incorrect repeat. When correct continue.)

Now try the next two tests. (Repeat any incorrect trials. Continue if and when all responses are correct.)

We are going to do the same thing, this time with the other ear. O.K.? (Repeat any incorrect trials. Continue if and when all responses are correct.)

<u>Dichotic presentation</u>. This time you will hear the first musical sound in both ears. Remember that this first

sound lets you know that you must start listening very carefully because you are going to hear more musical sounds very soon. This time you will hear a set of three short musical sounds to one ear and at exactly the same time you will hear a different set of three sounds in the other ear. You must listen carefully to the different musical sounds you hear in both ears at the same time. After a short pause you will hear another set of three short tones that will be the same in both ears. This set of three short musical sounds may be the same as one of the two you just heard before or it may be different. I want you to tell me whether it's the same or different. To get each test right you must listen carefully to both ears at the same time. During the tests I'll keep reminding you to listen to both ears. At times you may have to guess. If you guess, try to make a very good guess. O.K.? (Play the 3 practice trials - if all are responded to correctly, continue. Repeat any incorrect trials).

Appendix C

RAW DATA AND ANALYSES OF VARIANCE SOURCE TABLES: HITS, SENSITIVITY MEASURES, AND MEDIAN RESPONSE LATENCIES

Hits

Superior Readers

		Verbal		Nonverbal	
		Left Ear	Right Ear	Left Ear	Right Ear
Boys	**Subject**				
	1	10	7	8	5
	2	6	7	8	7
	3	7	8	9	5
	4	10	8	6	7
	5	8	9	9	6
	6	10	10	6	8
	7	9	8	6	7
	8	10	9	5	8
	9	10	8	8	6
	10	10	8	9	6
	11	6	9	8	7
	12	8	7	8	5
	13	5	6	6	2
	14	10	6	7	8
	15	8	10	7	8
	16	9	10	5	8
Girls					
	1	6	7	7	4
	2	8	7	7	5
	3	8	9	8	6
	4	10	7	7	5
	5	9	9	6	8
	6	5	4	4	5
	7	10	8	7	9
	8	10	9	6	9
	9	8	10	8	5
	10	8	6	8	5
	11	5	9	8	5
	12	10	10	9	6
	13	10	9	5	8
	14	10	10	6	8
	15	8	10	7	7
	16	10	10	5	9

Hits

Subaverage Readers

		Verbal		Nonverbal	
		Left Ear	Right Ear	Left Ear	Right Ear
Boys	**Subject**				
	1	7	10	9	8
	2	6	10	6	6
	3	6	10	7	7
	4	7	10	9	5
	5	7	7	4	5
	6	7	10	6	8
	7	8	9	6	7
	8	5	8	6	8
	9	9	9	7	4
	10	6	7	8	6
	11	9	10	5	7
	12	9	10	9	7
	13	7	8	6	7
	14	6	10	6	7
	15	8	7	3	6
	16	9	8	4	7
Girls					
	1	9	10	10	7
	2	9	9	9	7
	3	6	10	8	6
	4	6	10	7	5
	5	4	7	6	9
	6	8	8	6	5
	7	8	9	6	8
	8	3	5	6	7
	9	8	7	8	4
	10	4	6	6	6
	11	7	9	8	4
	12	7	5	9	6
	13	6	7	7	4
	14	5	8	6	8
	15	8	9	7	7
	16	5	8	7	8

TABLE 1

SOURCE TABLE FOR THE ANALYSIS OF VARIANCE ON THE HITS AS A FUNCTION OF READING ABILITY, SEX, STIMULUS TYPE, AND EAR

Source	df	MS	F
Between groups			
Reading Ability (RA)	1	10.97	3.04
Sex (S)	1	1.72	0.47
RA X S	1	0.88	0.24
Error	60	3.62	
Within groups			
Stimulus Type (ST)	1	114.22	72.17+++++
ST X RA	1	5.94	3.75
ST X S	1	3.75	2.37
ST X RA X S	1	9.38	5.92++
Error	60	1.58	
Ear (E)	1	1.13	0.53
E X RA	1	15.50	7.29+++
E X S	1	0.32	0.15
E X RA X S	1	4.79	2.25
Error	60	2.13	
ST X E	1	19.69	8.59++++
ST X E X RA	1	10.97	4.79+
ST X E X S	1	0.66	0.29
ST X E X RA X S	1	1.41	0.62
Error	60	2.29	

+$p < .050$
++$p < .025$
+++$p < .010$
++++$p < .005$
+++++$p < .001$

Hits

Superior Readers

		Verbal		Nonverbal	
		Series I	Series II	Series I	Series II
Boys	Subject				
	1	9	8	6	7
	2	8	5	8	7
	3	7	8	6	8
	4	9	9	5	8
	5	9	8	7	8
	6	10	10	7	7
	7	8	9	6	7
	8	9	10	5	8
	9	9	9	6	8
	10	8	10	7	8
	11	7	8	8	7
	12	7	8	6	7
	13	6	5	3	5
	14	8	8	7	8
	15	9	9	8	7
	16	9	10	6	7
Girls					
	1	6	7	6	5
	2	7	8	5	7
	3	8	9	7	7
	4	8	9	6	6
	5	9	9	7	7
	6	6	3	3	6
	7	9	9	9	7
	8	10	9	7	8
	9	9	9	6	7
	10	7	7	7	6
	11	7	7	6	7
	12	10	10	8	7
	13	10	9	6	7
	14	10	10	7	7
	15	8	10	7	7
	16	10	10	6	8

Hits

Subaverage Readers

		Verbal		Nonverbal	
		Series I	Series II	Series I	Series II
Boys	Subject				
	1	9	8	9	8
	2	7	9	5	7
	3	8	8	7	7
	4	8	9	9	5
	5	6	8	4	5
	6	9	8	6	8
	7	7	10	6	7
	8	7	6	7	7
	9	8	10	5	6
	10	7	6	7	7
	11	9	10	6	6
	12	10	9	7	9
	13	8	7	7	6
	14	7	9	6	7
	15	6	9	6	3
	16	8	9	5	6
Girls					
	1	9	10	8	9
	2	8	10	8	8
	3	7	9	7	7
	4	8	8	5	7
	5	5	6	7	8
	6	9	7	6	5
	7	8	9	7	7
	8	3	5	7	6
	9	7	8	5	7
	10	4	6	5	7
	11	8	8	6	6
	12	6	6	7	8
	13	6	7	5	6
	14	5	8	7	7
	15	10	7	7	7
	16	6	7	7	8

TABLE 2

SUMMARY SOURCE TABLE FOR THE ANALYSIS OF VARIANCE ON THE HITS AS A FUNCTION OF READING ABILITY, SEX, STIMULUS TYPE, AND SERIES

Source	df	MS	F
Within groups			
Series (Ser)	1	13.60	15.43++
Ser X Reading Ability (RA)	1	0.32	0.36
Ser X Sex (S)	1	0.04	0.04
Ser X RA X S	1	1.41	1.60
Error	60	0.88	
Stimulus Type (ST) X Ser	1	0.19	0.20
ST X Ser X RA	1	3.75	4.00+
ST X Ser X S	1	0.04	0.04
ST X Ser X RA X S	1	0.88	0.94
Error	60	0.94	

+$p < .05$
++$p < .001$

Sensitivity measures (d')

Superior Readers

		Verbal		Nonverbal	
		Series I	Series II	Series I	Series II
Boys	Subject				
	1	1.80	1.68	1.10	0.78
	2	2.12	1.28	1.68	0.00
	3	1.36	0.84	1.54	2.12
	4	1.80	2.56	0.26	3.16
	5	1.54	1.10	1.05	1.36
	6	3.60	3.60	1.05	1.05
	7	1.68	1.80	0.78	1.80
	8	1.54	2.84	0.52	1.10
	9	2.12	1.80	0.00	1.10
	10	0.58	2.84	1.05	1.10
	11	2.84	1.10	1.68	1.05
	12	1.80	3.16	0.00	1.36
	13	0.26	0.26	-0.78	0.52
	14	3.16	3.16	1.36	1.36
	15	2.12	1.80	2.12	1.80
	16	2.56	3.60	0.51	1.05
Girls					
	1	1.10	1.80	1.10	2.32
	2	1.36	2.12	1.28	1.80
	3	1.36	2.12	1.36	1.80
	4	3.16	1.54	1.10	0.51
	5	2.12	2.56	1.05	1.36
	6	0.26	0.78	-1.05	0.26
	7	2.56	3.60	2.56	2.84
	8	2.84	1.28	0.52	0.58
	9	3.60	3.60	0.78	1.05
	10	1.80	1.05	1.36	1.10
	11	1.05	1.80	0.78	1.80
	12	2.84	2.32	0.84	1.05
	13	3.60	2.56	0.00	0.27
	14	2.84	3.16	1.05	0.78
	15	1.68	2.84	0.00	1.05
	16	2.84	3.16	0.78	1.68

Sensitivity measures (d')

Subaverage Readers

		Verbal		Nonverbal	
		Series I	Series II	Series I	Series II
Boys	Subject				
	1	2.12	1.36	0.76	0.00
	2	1.80	1.54	-0.26	0.52
	3	1.10	2.12	1.36	1.05
	4	1.10	1.80	1.28	-0.52
	5	1.10	2.12	2.06	0.52
	6	1.80	1.10	0.78	3.16
	7	1.80	4.64	0.00	1.05
	8	1.36	1.54	0.78	0.52
	9	2.12	3.60	0.84	2.58
	10	1.36	1.10	1.80	1.80
	11	2.56	2.84	0.00	-0.58
	12	3.60	2.56	0.78	1.28
	13	2.12	2.84	1.36	1.10
	14	0.27	2.12	1.54	0.00
	15	2.58	2.12	1.54	0.32
	16	1.36	1.54	1.28	1.54
Girls					
	1	2.56	3.60	1.68	1.80
	2	1.36	2.32	0.84	0.58
	3	1.80	1.54	0.78	0.27
	4	3.16	2.12	0.84	1.80
	5	1.28	1.54	0.78	0.58
	6	2.12	2.84	1.54	2.32
	7	1.68	2.12	1.80	0.78
	8	-0.52	-0.52	0.52	0.26
	9	1.05	3.16	0.84	1.05
	10	2.06	1.54	2.32	1.36
	11	1.36	1.68	1.10	2.58
	12	0.51	1.54	1.05	1.10
	13	0.00	0.00	-0.84	0.00
	14	1.28	1.68	0.27	0.52
	15	2.84	1.80	1.05	0.52
	16	2.58	1.36	1.36	1.36

TABLE 3

SOURCE TABLE FOR THE ANALYSIS OF VARIANCE ON THE SENSITIVITY MEASURES AS A FUNCTION OF READING ABILITY, SEX, STIMULUS TYPE, AND SERIES

Source	df	MS	F
Between groups			
Reading Ability (RA)	1	203.95	1.46
Sex (S)	1	2.46	0.02
RA X S	1	53.02	0.38
Error	60	140.07	
Within groups			
Stimulus Type (ST)	1	5543.73	67.40++
ST X RA	1	57.86	0.70
ST X S	1	13.64	0.17
ST X RA X S	1	134.17	1.63
Error	60	82.25	
Series (Ser)	1	247.47	4.79+
Ser X RA	1	16.05	0.31
Ser X S	1	6.09	0.12
Ser X RA X S	1	1.25	0.02
Error	60	51.63	
ST X Ser	1	0.18	0.005
ST X Ser X RA	1	186.83	5.25+
ST X Ser X S	1	30.73	0.86
ST X Ser X RA X S	1	4.33	0.12
Error	60	35.58	

+$p < .05$
++$p < .001$

Median Response Latencies: Hits

Superior Readers

		Verbal		Nonverbal	
		Left Ear	Right Ear	Left Ear	Right Ear
Boys	Subject				
	1	3.00	5.00	2.25	3.00
	2	5.00	4.00	3.70	3.00
	3	5.00	4.00	6.00	5.00
	4	4.50	3.25	3.50	4.00
	5	3.50	3.00	3.00	2.83
	6	5.50	4.50	2.25	2.25
	7	5.00	4.10	3.00	3.00
	8	5.50	3.00	4.00	4.17
	9	4.50	8.50	3.17	6.50
	10	4.75	4.25	4.00	3.25
	11	6.50	5.00	4.17	4.00
	12	2.83	4.00	4.00	4.00
	13	5.00	5.83	5.50	2.50
	14	4.33	5.50	5.00	3.50
	15	3.83	3.21	2.00	3.25
	16	4.00	3.00	2.00	2.30
Girls					
	1	4.10	4.00	4.00	2.83
	2	4.00	4.00	4.00	3.00
	3	6.00	5.00	3.50	3.00
	4	4.75	5.00	2.00	5.00
	5	6.00	5.00	1.25	1.75
	6	5.00	5.50	4.00	5.00
	7	4.30	4.83	3.00	5.00
	8	3.83	5.00	3.83	4.00
	9	3.17	2.93	2.25	2.00
	10	5.00	5.50	3.50	4.00
	11	7.00	5.00	3.90	4.00
	12	5.90	5.17	5.00	5.83
	13	5.10	5.00	3.00	2.83
	14	3.06	3.00	2.00	2.00
	15	3.50	4.08	3.00	3.00
	16	3.90	5.50	4.00	3.00

Median Response Latencies: Hits

Subaverage Readers

		Verbal		Nonverbal	
		Left Ear	Right Ear	Left Ear	Right Ear
Boys	Subject				
	1	3.00	3.10	4.00	3.00
	2	3.83	3.70	3.83	3.83
	3	5.83	3.50	3.00	3.00
	4	4.00	4.50	5.00	6.00
	5	5.00	5.00	4.50	4.00
	6	4.00	5.25	3.50	4.00
	7	2.25	2.00	2.50	2.00
	8	4.00	4.17	2.25	2.25
	9	5.00	5.00	3.00	4.17
	10	5.50	5.00	2.70	4.00
	11	4.00	5.00	3.00	4.00
	12	4.00	4.25	3.00	4.00
	13	4.00	3.50	3.83	3.00
	14	5.83	4.75	5.00	3.00
	15	4.75	3.00	6.00	4.50
	16	4.00	5.83	4.00	3.00
Girls					
	1	7.00	5.30	4.00	4.00
	2	4.00	5.00	3.00	3.00
	3	4.83	4.10	1.90	2.50
	4	6.50	4.00	3.00	4.00
	5	3.50	3.00	1.50	2.00
	6	4.83	4.25	2.83	3.00
	7	5.50	6.00	4.00	2.50
	8	6.00	4.00	8.50	5.00
	9	2.83	4.00	2.00	2.50
	10	5.50	4.50	2.90	5.50
	11	4.00	5.00	1.75	2.00
	12	4.00	4.00	5.00	4.50
	13	4.50	4.00	4.00	8.00
	14	4.00	2.00	2.00	2.00
	15	[illegible].10	4.00	3.00	2.00
	16	4.00	2.10	4.00	2.90

TABLE 4

SOURCE TABLE FOR THE ANALYSIS OF VARIANCE ON THE MEDIAN RESPONSE LATENCIES AS A FUNCTION OF READING ABILITY, SEX, STIMULUS TYPE, AND EAR

Source	df	MS	F
Between groups			
Reading Ability (RA)	1	0.66	0.24
Sex (S)	1	0.08	0.03
RA X S	1	0.14	0.05
Error	60	2.72	
Within groups			
Stimulus Type (ST)	1	55.95	46.40+
ST X RA	1	1.44	1.19
ST X S	1	2.02	1.68
ST X RA X S	1	0.00	0.00
Error	60	1.21	
Ear (E)	1	0.34	0.36
E X RA	1	0.39	0.41
E X S	1	0.05	0.05
E X RA X S	1	0.52	0.55
Error	60	0.95	
ST X E	1	1.08	1.67
ST X E X RA	1	0.11	0.16
ST X E X S	1	0.69	1.06
ST X E X RA X S	1	0.27	0.41
Error	60	0.65	

+$p < .001$