ON THE RELATIONSHIP OF HEMISPHERIC SPECIALIZATION AND DEVELOPMENTAL DYSLEXIA

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The examination of hemispheric specialization has provided the focus for a great deal of the etiological investigation of developmental dyslexia (reading difficulty in persons who exhibit no other apparent intellectual, perceptual or learning deficits). It is, of course, not the only such focus; there have been a number of rather specific cognitive differences found to exist between dyslexic and normal readers (e.g., intersensory integration, Belmont and Birch, 1965; serial ordering deficits, Corkin, 1974). However, most of these specific differences constitute cases which- can, by some interpretation, be subsumed under explanations focusing on cerebral hemispheric processing differences. Unfortunately, while *some* type of relationship appears to exist between hemispheric specialization and dyslexia, the exact nature of this relationship is far from clear; the literature contains an astonishing list of contradictory findings and inconsistent results (cf. Satz, 1977). In what follows we propose, and present evidence for, a model which appears capable of resolving these conflicts.

Because reading is a process which necessarily requires both linguistic and visual-perceptual processing -- abilities commonly attributed to control by opposing cerebral hemispheres -- it is not surprising that many investigations of reading disorders have attempted to implicate either one or the other of the hemispheres. Clinical examinations of dyslexia first initiated interest in this topic with reports of inconsistent or poorly established dominance in functions which presumably involved each of the hemispheres (Orton, 1937; Bender, 1968). However, these clinical findings were elusive in early experimental investigations. For example, several investigators (Coleman and Deutsch, 1964; Benton and Kemble, 1960) could find no differences between normal and dyslexic children in various measures of spatial ability, despite clinical reports which predicted their existence.

The advent of dichotic listening and visual half-field (hemi-retinal) presentation procedures provided an opportunity for more precise experi-

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mental examination of both language and non-linguistic abilities in dyslexia. Perhaps suprisingly, studies employing each of these methods have lead to essentially the same sets of contradictory results, a fact which suggests that both methods may be tapping some similar - although confusing - aspects of dyslexic processing. The results from these various studies of hemispheric specialization in dyslexia can be grouped into three distinct patterns, each of which supports a different theory of lateralization in dyslexia. The first of these, which might reasonably be called the 'Left-Hemisphere-Deficit' position, is the most popular. It is based on the notion that while normal brain maturation involves increasing dominance of the left hemsiphere for language (or language-like) functions, dyslexics experience a maturational lag in the functional development of this hemisphere. An obvious corollary of this theory is that the source of the dyslexic disorder is to be found in processes responsible for linguistic (as opposed to visual-perception) functioning. Data supporting this view comes from many sources. Zurif and Carson (1970). for example, report data showing a trend for right ear deficit (albeit non-significant) in recall of dichotically presented numbers by dyslexic subjects. Similarly in a study employing hemiretinal presentation of words, Marcel, Katz and Smith (1974) found that poor readers showed a deficit for words presented to the Right Visual Field when compared to normals. (See also Satz, Radin and Ross, 1971; Marcel and Rajan, 1975, for further support of the Left-Hemisphere-Deficit hypothesis).

The second theory which is antithetical to the first, can be termed the 'Right-Hemisphere-Deficit' position. It holds that the left hemisphere participates sufficiently in the information processing of dyslexic children, but that the right hemisphere is deficient. The most straightforward support for this view comes from work by Yeni-Komshian, Isenberg and Goldberg (1975). Using hemi-retinal presentatiorr of numbers, it was found that dyslexic subjects had left visual half-field deficits in comparison to normal subjects; however, right half-field scores did not differ for these two groups.

The third position has two versions -- both of which can be considered to be 'Normal Dominance' hypotheses. Studies which fall in this category have found that the relative contribution of each hemisphere is the same for dyslexic and normal groups. Some of these studies have failed to find any performance differences at all between normal and dyslexic groups (e.g., McKeever and Ruling, 1970), while other studies found overall performance deficits for the dyslexic group without relative dominance differences (e.g. McKeever and Van Deventer, 1975).

Hopefully, the pattern is obvious; using essentially the same techniques different studies have found support for each of the possible different positions. We suggest that the results (of these individual studies do not represent valid descriptions of the dyslexic population. Moreover, we believe that most of the current studies appear to have obscured the relationship of hemispheric specialization to dyslexia by their methods of data examination. It is our contention that the discrepancies in the dyslexia literature are due to the fact that previous studies have failed to examine the performance of individual subjects; investigators have continually examined the developmental dyslexic population by treating it as a homogeneous group. If, as we believe, the dyslexic population is comprised of a heterogeneous mixture of those with left and right hemisphere deficits, then the conflicting pattern of results reported above can be resolved. Certainly, sets of small samples (as is the rule in these studies) taken from a heterogeneous population are likely to result in greatly divergent results -- depending on the predominant 'type' of subject sampled.

The present research subjects the Heterogenity Hypothesis to an examination involving both dichotic listening (Experiment 1) and hemi-retinal visual presentation (Experiment 2) techniques. The distribution of individual subjects' laterality indices are specifically examined for both dyslexic and normal subjects.

EXPERIMENT 1

Materials and Method

Subjects

The subjects were 38 right-handed boys: 19 'developmental dyslexic' and 19 normal reader. Only those children with no known, uncorrected perceptual impairments or diagnosed brain trauma were included in the study. Dyslexic readers were defined as those who read at least two years below their grade level as measured by the Gray Oral Reading Test. Normal readers were defined as children who read on or above their grade level. The mean reading score for the dyslexic subjects was two years, seven months behind their grade level. Right-handedness was determined by the subject's performance on manual tasks; the use of the right hand for at least eight of these tasks was criterial for inclusion in the study.

Subjects in the two groups were matched with respect to age (± five months) and intelligence (± one SD on the WISC Performance and on the PPVT). The mean age for both groups was 10.0 years. The mean IQ scores for the normal and dyslexic subjects were 106 and 105, respectively, on the WISC Performance Test and 108 and 106, respectively, on the PPVT.

Materials and Procedures

The materials for the dichotic listening test comprised the digits from one to ten, exclusive of the number seven. These digits were randomly paired to create 3 practice and 18 test trials, each trial consisting of three digit pairs. The members of each digit pair were recorded with simultaneous onset and offset on separate tracks of an audio tape, at a rate of two digit pairs per second. None of the digits on a given trial were either in repetition or ordinal sequence.

During presentation, tape channels were counterbalanced both within and between subjects. Materials were presented by a Sony TC 630 stereo rape recorder over Koss Pro-4AA headphones. Immediately following the presentation of each trial, the experimenter indicated the ear from which the subject was to recall the presented digits. Recall was required on nine trials for each car, so that the maximum score for either ear was 27. A lateralization index was calculated for each subject using the formula $\frac{R-L}{R+L} \times 100$ in which R represents the accuracy for the right ear and L represents the accuracy for the left ear. As accuracy scores were relatively mid-range this measure provides a relatively umbiased laterality coefficient; that is, no correction was required for the ceiling or floor effects that often. arise using this measure with more accurate responses (cf. Marshall, Caplan and Holmes, 1975).

Results

Mean ear accuracy scores were determined for each ear for each subject. The means for the Group by Ear interaction and the overall Group Lateralization Index scores are presented in Table I. In these, pre-converted accuracy

TABLE I

Normal and Dyslexic Group Means for Right and Left Ear Accuracy and Group Laterilization index Score; Dichotic Listening Test

	Right ear	Left car	Lateralization index
Normal	21.7	18.0	10.3
Dyslexic	19.5	15.7	11.2

scores were below 85% for all but four subjects in the right ear and one subject in the left ear. Average accuracy for normal subjects was 73% and for dyslexics was 66%. An analysis of variance examining the main effects of Groups and Ear accuracy indicates that (as Table I suggests) the normal group responded more accurately than the dyslexic group ($F = 6.14$; d.f. = 1, 36; $p < .01$) and that both groups showed a right ear superiority for recall ($F = 10.94$; d.f. = 1, 35; $p < .01$). There was no significant interaction of Groups and Ear accuracy. This result would appear to support the 'Normal Dominance' position in describing developmental dyslexia.

In addition, however, the lateralization index scores for each subject were examined independently. The resulting distributions (in frequency polygon form) for both groups can be seen in Figures la and lb. Note that the scores for the 'normal' group distribute themselves in a normal fashion, with a single mode which coincides with the interval containing the group mean (+ 5 to + 15). In contrast, the distribution of scores from the dyslexic sample exhibits bimodality; the highest frequency of dyslexic subjects actually occur in two places - one on either side of the interval containing the group mean (+ 5 to + 15). Thus the group mean scores derived from these data conceal subject distribution differences observed between the two groups.

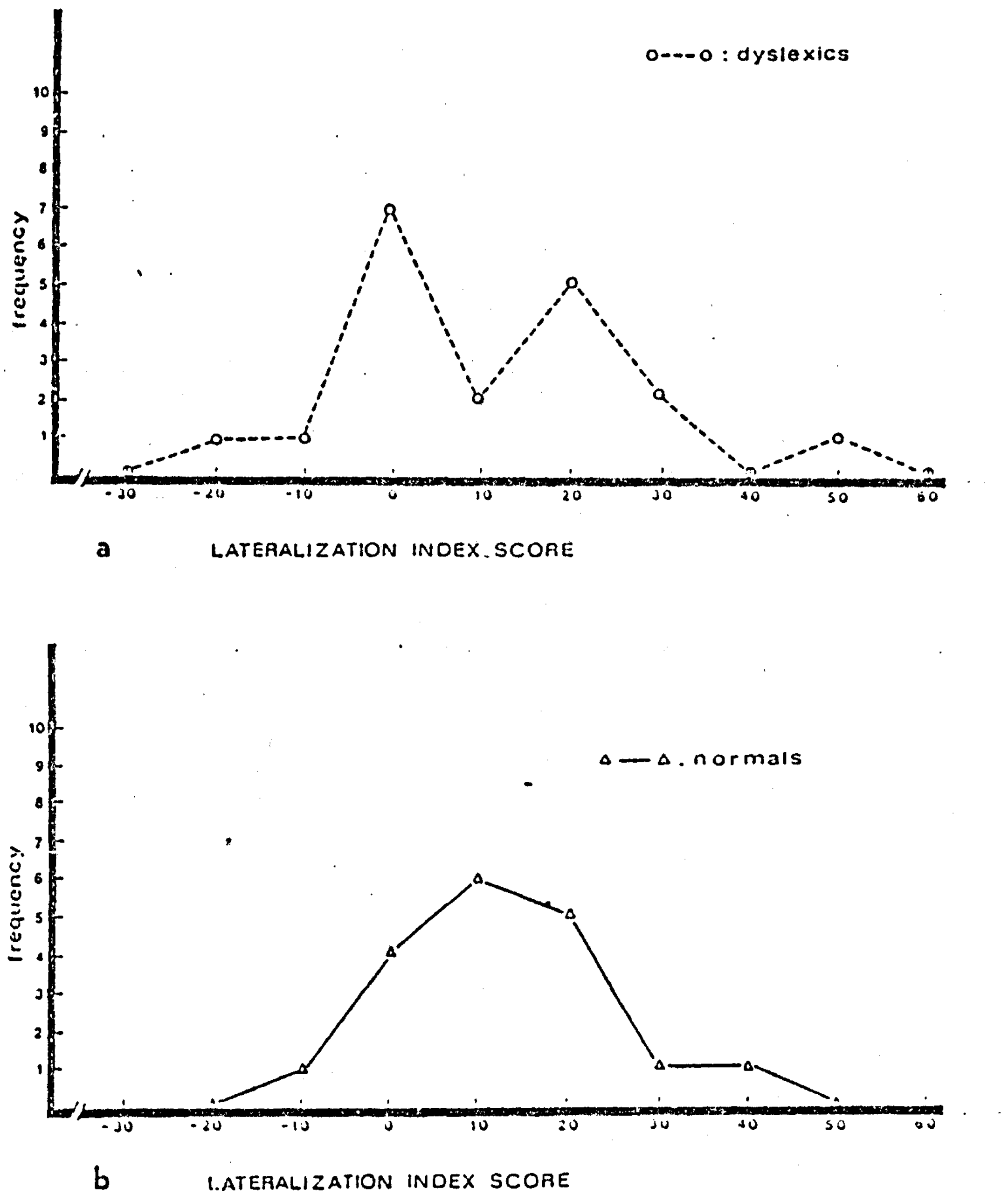

Fig. 1 -- (a) *Frequency polygon of distribution of individual Lateralization Index Scores of Dyslexic subjects on Dichotic Listening Test;* (b) *Frequency polygon of distribution of individual Laterilization Index Scores of Normal subjects on Dichotic Listening Test.*

Pearson Product Moment correlations were computed between the lateralization scores and the variables of age, IQ, and degree of reading disability, in order to investigate whether the bimodality of the dyslexic distribution could be attributable to these subject variables. There were no significant correlations between dyslexic lateralization scores and age (r = .12), WISC Performance IQ (r = .14), PPVT IQ (r = .10) or degree of reading disability (r = .05).

EXPERIMENT 2

Experiment 2 was undertaken in an attempt to see if the bimodal distribution observed in Experiment 1 would replicate with a different, but also commonly reported, technique of hemispheric dominance (hemi-retinal viewing). The number of subjects tested was increased in order to make any comparative variability in the distribution of individual performance within the normal and dyslexic groups more apparent.

Material and Method

Subjects

The subjects were 60 right-handed boys: 30 dyslexic readers and 30 normal readers. Guidelines for subject inclusion were identical to those for Experiment 1. The mean reading score for the normal subjects was one year, four months above their grade level, while that for the dyslexic subjects was two years seven months below their grade level. The normal subjects averaged 10-5 years of age, and the dyslexic subjects averaged 10-8 years. The difference in ages is non-significant (t = .03). No subjects (either dyslexic or normal) were included in the study who had a full scale WISC score of less than 90. Because there appear be secondary motivational and emotional problems associated with dyslexia that cause detriments in even purely performance tasks, it is highly likely that WISC performance scores underestimate the IQ of dvslexics. This fact, and the failure to find any correlation of WISC or PPVT scores and laterality indices in Experiment 1, lead us not to attempt to match subjects in Experiment 2 based on I.Q. scores.

Materials

The materials consisted of 20 test slides which utilized the capital letters: A H M O T U W X Y. Ten trigrams were created from these letters. Two trigrams appeared on each slide, equidistant from the center of the slide. To counterbalance for material effects, each ingrain occurred two tines on both the left and right side of different slides. None of the trigrams formed words. In addition, nine recognition cards were created; each card contained an example of one of the nine symmetrical letters.

Apparatus and Procedure

The apparatus comprised a Type W5MT Variac Autotransformer, a Kodak Carousel 800 projector, an Alphax projection shutter, and a rear projection screen with a fixation cross drawn in the center. The Variac Autotransformer was used to vary the intensity of the light produced by the slide projector. Subjects were placed so that the test stimuli, which appeared on each side of the fixation-point, were displaced from center by a visual angle of 2.5 degrees. Each teyt stimuli occupied 2.5 degrees horizontal and 1.5 degrees vertical visual angle.

Subjects were required to focus on the fixation cross prior to each trial. A test slide was then presented for 1/100 seconds. During this entire time, the subjects eye movements were visually monitored by the experimenter. As such surveilance has been shown to be sufficient for detecting eye movements and as the slide presentation duration was well below the latency necessary to initiate an eye movement to a stimulus (see, for example, White, 1969) eye scanning biases were prevented. Trials in which any eye movements were detected were discarded. Following slide presentation, the exprimenter immediately indicated which one of the two trigrams were to be reported by pointing to either the left or right side of the projection screen. In response, the subject pointed to the 3 recognition cards which corresponded to the 3 letters which he 'saw' on the indicated side of the projection screen.

A pretest was run on each subject to determine the light intensity levels necessary to prevent ceiling and floor effects. In addition. six practice trials were administered. The actual test consisted of ten trials taken from each Visual Half Field thus yielding a maximum correct score of 30 for any one VHF. A lateralization score was obtained for each subject using the formula described in Experiment 1, as this procedure, again, provides a relatively unbiased laterality measure given the midrange accuracy obtained in this study.

Results

Group means for right and left VHF accuracy scores and group lateralization indices are summarized in Table II. (The pre-indexed accuracy scores

TABLE II

Normal and Dyslexic Group Means for Right and Left VHF Accuracy and Group Laterlization Indices; Hemi-Retinal Presentation Test

	Right VHF	Left VHF	Lateralization index
Normal	17.6	16.5	3.1
Dyslexic	15.4	13.9	6.5

averaged about 55% of both normals and dyslexics, with 86% and 30% correct providing the range limits in both populations). An analysis of variance confirmed the pattern of results which are apparent from this table. The normal group responded more accurately than the dyslexic group ($F = 9.47$; d.f. = 1, 58; $p < .003$), both groups showed a right VHF superiority for recall ($F = 10.44$; d.f. = 1, 58; $p < .002$), and there is no significant interaction between groups and VHF scores ($p < .3$).

The distributions of subjects as a function of lateralization index scores (in frequency polygon form) are presented in Figures 2a and 2b. Again, the distribution of the dyslexic subjects is unimodal, with the group mean representing the best single descriptive measure of the sample. However, the distribution of the dyslexic subjects is bimodal, with the two modes falling in the intervals on either side of that containing the group mean (+ 5 to + 15). A Mood (non-parametric) test (Gibbons, 1971) showed that the dyslexic and normal subjects do, indeed, belong to differently distributed population ($Z = 1.81$, $p < .04$). Again, Pearson Product Moment correlations were not significant for comparisons of lateralization scores to age ($r = .06$) or degree of reading disability ($r = .04$) for dyslexic subjects.

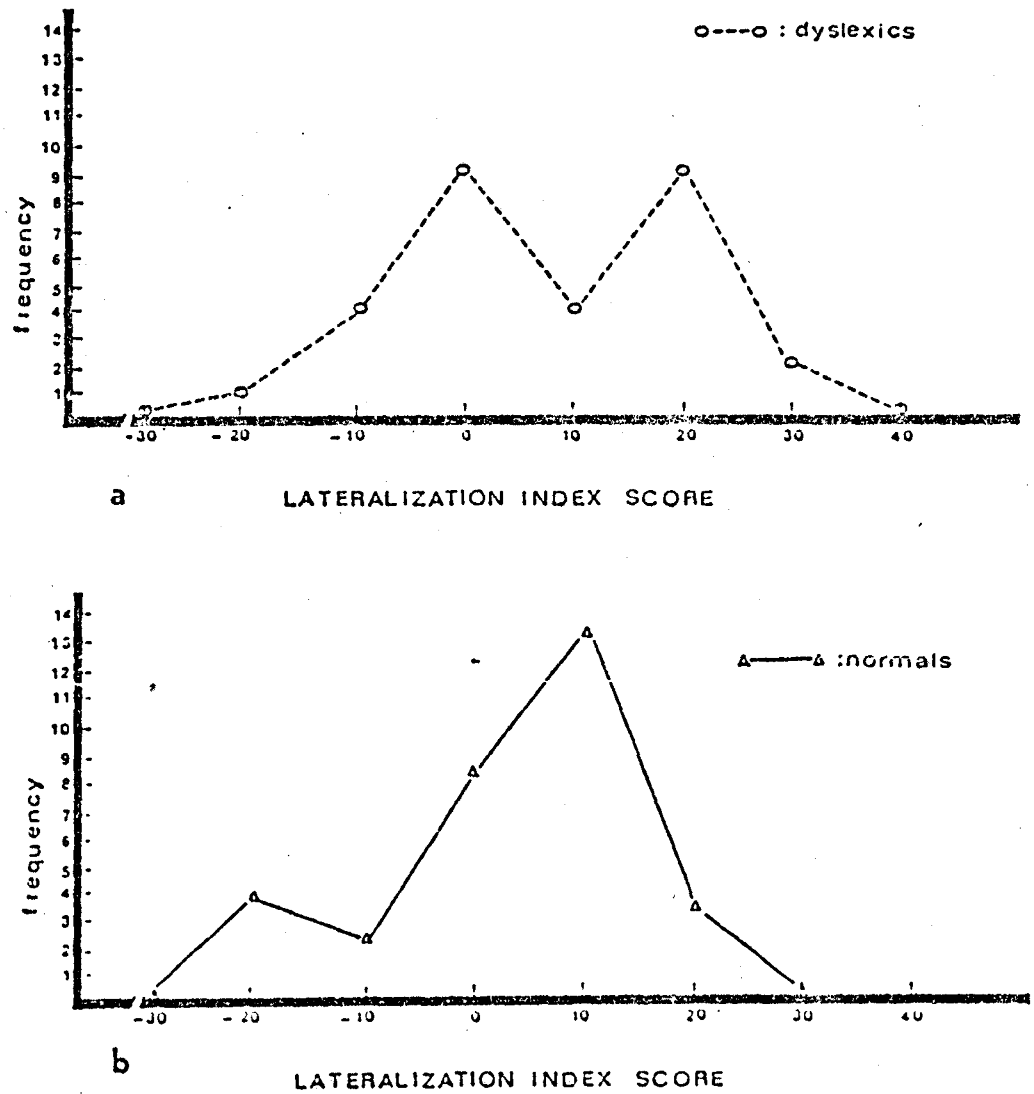

Fig. 2 -- (a) *Frequency polygon of distribution of individual Lateralization Index Scores of Dyslexic subjects on Hemi-Retinal Presentation Test;* (b) *Freqnency polygon of distribution of individual Lateralization Index Scores of Normal subjects on Hemi-Retinal Presentation Test.*

DISCUSSION

The results of this study appear to support our contention; the examination of individuals in a dyslexic population suggests that what phas been assumed to be a homogeneous population with regard to hemispheric lateralization is actually a heterogeneous one. These results appear capable of reducing the confusion surrounding the discrepant findings in the dyslexia literature. Note that in both Experiments 1 and 2, no difference was observed between the mean lateralization scores of normal and dyslexic subjects. This finding is congruent with those investigations which support the Normal Lateralization theory of dyslexia. However, inspection of the lateralization indexes for individual subjects indicates that the performance of normal and dyslexic groups *actually* differs; while the mean lateralization index for the normal group was fairly representative of the performance of the individual normal subjects, that is not at all the case for the dyslexic subjects. In fact, the distribution of dyslexic subjects as a function of lateralization indexes is bimodal with a cluster of subjects falling on either side of the group mean.

Thus, there appears to be at least two categories of dyslexic children with respect to hemispheric lateralization of linguistic material. One type demonstrates what might be labeled, at least in comparison to the normal controls, a Left-Hemisphere-Deficit and the other demonstrates, again by comparison, a Right-Hemisphere-Deficit; these results are interesting in view of the large number of studies which supported only one or the other of these etiological explanations. A methodological moral of sorts appears to arise from this experiment: examination of disordered populations cannot rely on simple group summary statistics alone. Knowledge derived from clinical observation and knowledge of normal processing requisits (in this case, for reading) need to be used to provide guide-lines for experimental examination.

The notion of heterogeneity in dyslexia could provide an explanation not only for the discrepancies already cited in the hemispheric specialization literature but also for other aspects of higher cognitive functioning in dyslexia. If, indeed, the various dyslexias have some relationship to other-than-normal cerebral functioning, then one would reasonably expect dyslexic children to demonstrate behavioral deficits which correspond with their specific cerebral abnormality. Diagnostic subtypes have, in fact, been reported by some investigators (see ivlattis, French and Rapin, 1975; Zangwill, 1962; Kinsbournc and Warrington, 1966; Boder, 1973). In general, two (and, occasionally, three) types of dyslexic children arc reported. The first type is said to be deficient in auditory and language (phonetic analysis) skills, while the second type is said to he deficient in visual and spatial (visual gestalt) skills. The first diagnostic subtype corresponds remarkably well to what would be expected from Left-Hemisphere-Deficit functioning, whereas the second subtype corresponds to Right-Hemisphere-Deficit functioning.

The experimental delineation of dyslexic subtypes in future research could be diagnostically and therapeutically significant for the field of dyslexia. Because no one deficit is displayed by all dyslexic children, no definitive criteria for dyslexia has ever been established. These dyslexic subtypes appear capable of providing a significant tool for distinguishing dyslexics not only from each other but also from other areas of learning disabilities.

SUMMARY

Hemispheric specialization for linguistic material was compared for normal and dyslexic subjects under dichotic listening (Experiment 1) and hemi-retinal presentation (Experiment 2) conditions. In both experiments, group data indicated that dyslexic subjects were, overall, less accurate in their performance than normals but that both groups showed similar right ear/visual field superiority. However, examination of individual subjects scores in both experiments indicated that the distribution of lateralization scores for dyslexic subjects was bimodal, whereas that for normal subjects was unimodal. These results suggest that the dyslexic 'population' is heterogeneous with regard to cerebral lateralization and that previous work treating it as homogeneous is most likely misleading. It appears important to both carefully examine *individual* subject data in such studies and to consider the consequences of there being diilerent types of cerebral lateralization etiologies for what has beat typically considered to be a homogeneous dyslexic population.

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REFFRENCES

BELMONT, L., and BIRCH, H. G. (1965) *Lateral dominance, lateral awareness and reading Disability*, Child Develop., *36*, 57-72.

BENDER, L. (1968) in *Dyslexia*, ed. by A. Kenney and V. Kenney. The C.V. Mosley Co., St. Louis.

BENTON, A. L., and KEMBLE, J. D. (1960) *Right -left orientation and reading disability*, Psych. Neurol., Basel, *139*, 49-60.

BODER, C. (1973) *Development dyslexia: A diagnostic approach based on three atypical reading-spelling patterns*, Develop. Med. Child. Neurol., *14*, 663-687.

COLEMAN, L. R., and DEUTSCH, C. P. (1964) *Lateral dominance and right-lelt discrimination: A comparison of normal and retarded readers*, Percept. Mot. Skills, *19*, 43-50.

CORKIN, S. (1974) Serial-ordering deficits in inferior readers, Neuropsychologia, *12*, 347-354.

GUBBONS, J. D. (1971) *Nonparametric Statistical Inference*, McGraw-Hill, New York.

KINSBOURNE, M., and WARRINGTON, E. K. (1966) in *The Disabled Reader: Education of the Dyslexic Child*, ed. by J. Money, Johns Hopkins Press, Baltimore.

MATTIS. S., FRENCH, J. H., and RAPIN, L. (1975) *Dyslexia in children and young adults: Three independent neuropsychological syndromes*, Develop. Med. Child Neurol., *17*, 150-163.

MARCEL, T., and RAJAN, P. (1975) *Literal spectalization for recognition of words and faces in good and poor readers*, Neuropsychologia, *13*, 489-497.

—— , KATZ, L., and. SMITH, M. (1974) *Laterality and reading proficiency*, Neuropsychologia, *12*, 131-139.

MARSHALL, J., CAPLAN, D., and HOLMES, J. (1975) *The measure of laterality*, Neuropsycologia, *13*, 315-321.

MCKEEVER, W. F., and HULING, M. D. (1970) *Literal dominace in tachistoscopic word recognition of children at two levels of ability*, J. Exp. Psychol., *22*, 600-604.

—— , and VAN DEVENTER, A. D. (1975) *Dyslexic adolescents: Evidence of impaired visual and auditory language processing associated with normal lateralization and visual responsivity*, Cortex, *11*, 361-378.

ORTON, S. T. (1937) *Reading, Writing and Speech Problems in Children*, W. W. Norton, New York.

SATZ, P. (1977) in *Neuropsychology of Learning Disorders*, ed. by Knights and Bakker.

——, RARDIN, D., and ROSS, J. (1971) *An evaluation of a theory of specific developmental dyslexia*, Child. Develop., *42*, 2009-2021.

WHITE, M. J. (1969) *Laterality differences in perception: A review*, Psychol. Bull., *70*, 387-405.

YENI-KOMSHIAN, G. H, ISENBERG, D., and GOLDBERG. H. (1975) *Cerebral dominance and reading disability: Left visual field deficit in poor readers*. Neuropsychologia, *13*, 33-94.

ZANGWILL, O. L. (1962) in *Reading Disability*, ed. by J. Money, Johns Hopkins Press, Baltimore.

ZURIF, E. B., and CARSON, G. (1970) *Dyslexia in relation to cerebral dominance and temporal analysis*, Neuropsychologia, *8*, 351-361.

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