ATYPICAL FUNCTIONAL ORGANIZATION
OF THE BRAIN IN DYSLEXIA
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ABSTRACT

Atypical functional organization in the brains of adult male dyslexics was investigated through the divided visual field (DVF) paradigm. By intentional manipulation, equal levels of overall performance between groups were obtained, which made clearer interpretation of the results possible. Both dyslexic and control subjects appeared to have left hemisphere specialization for nonsense words. Dyslexics exhibited no asymmetry for face recognition indicating bilateral representation of this function in their brains, while control subjects exhibited the expected left visual field advantage. The results are considered both as group means and as frequency data. The results provide modest support for the hypothesis that dyslexics have atypical functional organization.
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The notion that developmental dyslexics have atypical functional organization of their brains was first proposed by Samuel Orton in 1925. His hypothesis was based upon the then rather vague concept of cerebral dominance. Only in recent decades have non-intrusive techniques been used that permit testing his hypothesis. Today behavioural and neurological evidence exists that implicates atypical functional organization as a factor associated with developmental dyslexia. For a variety of reasons that should become clear to the reader, the evidence is not yet definitive, although as a body it is persuasive. Differences in functional organization do appear to exist in the dyslexic's brain.

The present research was pursued in an attempt to expand earlier experiments by Witelson (1977) that 1) implicated atypical organization in dyslexics of the spatial functions that are specialized to the right hemisphere in normal people, and 2) found that dyslexics are left lateralized for verbal functions, just as are normal people. Since publication of that work, there have been developments in theory and methodology that permit more rigorous scrutiny of left and right hemisphere
functions. The purpose of the present research is to reexamine those functions in dyslexics, with the benefit of current knowledge.

The evidence of atypical lateralization in dyslexics is reviewed in Chapter 1. The problems associated with defining dyslexia for research purposes are considered in Chapter 2. The third chapter presents a detailed review of the myriad problems that are inherent in divided visual field (DVF) research, both in general and especially when comparing normal and pathological groups. Chapter 4 addresses some questions about the appropriate way to handle the data that result from DVF experiments. Chapters 5 and 6 report the present experiment, and Chapter 7 is a discussion of the findings.
CHAPTER 1

Evidence of Atypical Functional Organization in Dyslexics

Behavioural Evidence

Abnormal functional organization in dyslexics, as reflected in behavioural asymmetries, has been demonstrated with a variety of non-intrusive methods. However, no consensus has yet been reached and no one definitive study done that clearly establishes atypical lateralization in dyslexics. This is likely due to one or more of the following problems in the existing research: 1) The use of variously defined subjects who are not necessarily dyslexic, 2) Inclusion of confounds such that the results reflect the effects of other factors in addition to or instead of lateralization, 3) Consideration of only the lateralization of verbal functions without consideration of the lateralization of spatial functions.

It seems like a modest requirement that research on lateralization in dyslexia be done with an experimental group composed of dyslexics only, that the generated data
be valid evidence of lateralization and that the data be sufficient to answer the questions of whether dyslexics are atypically lateralized or suffer from deficient functioning of a hemisphere. As is apparent below, those requirements have unfortunately not yet been fully met within any one experiment reported in the literature. If atypical behavioural asymmetries in dyslexics are found with measures of functional organization, it will be important evidence that there are neural regions in dyslexics' brains that are atypical.

**Divided Visual Field Studies**

The results of DVF studies with linguistic stimuli generally tend to support right visual field superiority in dyslexics, in undifferentiated poor readers, and in normals. There are numerous reports that deal with lateralization in good and poor readers, without necessarily limiting poor reader groups to dyslexics. A 'poor reader' can be a reader whose poor achievement is readily explained in some way (e.g. low I.Q., neurological damage, etc.). Poor readers are not necessarily dyslexic. However, some of these reports do provide information that is useful in the study of dyslexics, and so will be included here.

McKeever and Huling (1970) studied lateral...
asymmetries in good and poor readers. They used monocular presentation of horizontally oriented common 4-letter words. A central fixation number was reported first by the subject. A right visual field advantage (RVFA) of equal degree was found for both groups. Because the poor reader criteria did not exclude subjects with known causes of poor reading, it is not possible to generalize their results to dyslexics. The confounds of a) visual field with visual pathway inherent in monocular tests, b) easier scanning from fixation point of horizontal words in the RVF, and c) verbal report of fixation digit before response to stimuli, make it difficult to be confident of their interpretation of the results as evidence of a RVFA for words in both groups. (Explication of such methodological problems is given in Chapter 3.) However, only condition 'b' should have differential effects between good and poor readers, and since no differences were found in asymmetry, it is unlikely that greater scanning skill associated with greater reading ability was a factor here. Therefore, it is reasonable to conclude from their results that lateralization of verbal skills does not vary with reading achievement per se.

That interpretation stands in contrast to the report of Marcel, Katz & Smith (1974), who also studied lateralization in good readers and undifferentiated poor readers (not necessarily dyslexics). They measured not
only number of words correct in a visual half-field, but also provided subjects with the option of reporting letters in the word when they could not produce the whole word. Both groups showed more accurate performance for the RVF on both whole word and letter measures. Good readers showed a significantly greater RVFA for letters as compared to poor readers. The greater asymmetry of good readers for words approached significance. There are, however, a number of problems with this report. Although differences in overall accuracy between the two groups is not analyzed, visual inspection of the reported data indicates that the good readers probably performed significantly better overall than poor readers. (See chapter 5 for a discussion of why differences in overall accuracy present interpretive problems.) RVF minus LVF accuracy scores were used in the analysis of variance. It is quite possible that the poor readers were at or near a floor effect that did not permit the emergence of an asymmetry as strong as was possible with the good readers. In addition, poor readers were more likely to report letters, simply because they more often could not report complete words. The dependence of the letter score on the word score is a confound that makes interpretation impossible. Although the experiment confirms the existence of RVFA's for verbal material for good and poor readers, it does not establish that this advantage varies with reading achievement, and does not
address the situation in dyslexics.

Yeni-Komshian, Isenberg & Goldberg (1975) found a significant difference between good and poor readers for laterally presented words. The poor (not dyslexic) readers showed a RVFA for the words, but the good readers showed no VFA. Because the good reader group did not perform in a way consistent with what is known about hemispheric specialization in normal people, the proper interpretation of their work is unclear.

McKeever & Van Deventer (1975) used a group of good readers and a group of dyslexic readers (poor readers without any explanatory factors) in a study of lateralization of verbal functions employing both unilateral and bilateral presentations of words. Good readers showed significant RVFA's under both conditions. Dyslexics showed a trend toward a RVFA with bilateral presentation, which suggests normal left hemisphere lateralization for verbal functions. However they showed no asymmetry with unilateral presentation. With unilateral presentation the dyslexics were poorer than the good readers in the RVF but equal in the LVF. McKeever & VanDeventer interpreted these findings as likely indicative of normal left lateralization of verbal functions, but suggested left hemisphere dysfunction as a possible explanation of the unilateral trials results.

Unfortunately, as is frequently the case, the overall (LVF
+RVF) performance of the dyslexics was significantly below that of the good readers. It is difficult to interpret the data in such cases; lack of asymmetry could be due to a floor effect, and degree of asymmetry is not easily compared across groups of differing overall performance.

Kershner (1977) reported similar findings: dyslexic readers showed a RVFA for words, but of a lesser degree than that shown by good readers or gifted readers. Interestingly, when reading ability was statistically controlled for gifted and dyslexic readers, the cerebral dominance effect was eliminated. This might appear to be in contradiction to the earlier discussed work of McKeever and Huling, but in those cases the poor readers were not dyslexic. In Kershner's study, controlling for reading achievement is equivalent to controlling for dyslexia. Therefore, although differences in asymmetry may not be related to reading achievement per se, they do appear to be related to the condition of being or not being dyslexic.

Right visual field advantages in dyslexics for linguistic stimuli are also reported by Aylward (1984), Keefe & Swinney (1979), and Olson (1973).

The research reported thus far has focused on left hemisphere functioning. Witelson (1977) suggested that it is likely the longstanding conceptualization of the left hemisphere as the 'verbal hemisphere' and of reading as a verbal skill, constrained theorizing about atypical
lateralization in dyslexic subjects to left hemisphere functions alone. However, reading is likely to employ at least some of the right hemisphere processes, so there is reason to also look at the right hemisphere. If there is something abnormal about right hemisphere processes in dyslexics, it may have implications for left hemisphere processes. Studying both processes in the same subjects is valuable because this approach may allow disentanglement of generalized deficit from localized deficit, as well as specifying the nature of localized deficits and of functional organization.

Marcel & Rajan (1975) reported an experiment that conceptually replicates Marcel et al (1974) but adds a DVF faces test to assess right hemisphere functioning in good and poor (not necessarily dyslexic) readers. A RVFA for words and a LVFA for faces was obtained for both groups, indicating that performance on these DVF tests does not distinguish between their two groups of readers.

Only a few researchers have attempted to assess in dyslexics lateralization of the cognitive functions specialized to both hemispheres. Malatesha (1976) used two types of stimuli in DVF task, digits and dot patterns. The digit task was intended as a measure of left hemisphere functions while the dot task was intended as a measure of right hemisphere functions. A RVFA was found for digits in all normal and older (11-13) dyslexic children, while a
left visual field advantage (LVFA) was found in younger (6-8) dyslexics. The dot pattern task yielded LVFA's for all normal and older dyslexics, and no asymmetry for younger dyslexics. The problem in interpreting this data comes from not knowing which specialized functions such tasks measure in any subjects. The use of lateralized digit stimuli has led to variable results in normal subjects (eg. Carmon, Nachshon & Starinsky, 1976; Reitsma, 1975; Kershner, Thomae & Calloway, 1977), and it is likely that different strategies can be applied to the task. Lateralized dot stimuli have likewise produced variable results, (LVFA's: Young & Bion, 1979; no asymmetries: McKeever & VanDeventer, 1975; Dyer & Harcum, 1961; and RVFA's: Braine, 1968). Therefore, because the tasks did not appear to be valid measures of both left and right hemisphere functions respectively in normal people or because the tasks permitted either or both processes to be employed, the data do not inform us about the nature of functional organization in dyslexics.

Pirozzolo & Rayner (1979) also employed word and face stimuli in a DVF study of reading disability. Both normal and disabled readers exhibited a LVFA for faces. Normals exhibited a RVFA for words while the disabled readers showed no asymmetry for words. However, exposure durations had been manipulated for each individual to 50% accuracy on the condition (faces or words) received first,
and then maintained at that level for the subsequent task. Surprisingly, although both groups had the same mean threshold for faces, the disabled readers had lower thresholds for words. They therefore were presented words at a shorter exposure duration than were the normal readers. Thus their poor performance on word trials may have been due to the signal strength discrepancy between groups rather than to atypical functional organization. Furthermore, Pirozzolo & Rayner are vague about disabled reader selection criteria; it is doubtful that these subjects represent the dyslexic population.

Witelson (1977b) tested stringently selected dyslexic boys, rejecting subjects whose reading problem could be explained by the presence of any factor known to be a cause of reading failure. Tests of functional organization in three modalities, visual, aural, and tactile were employed. The DVF tests used human figures for the right hemisphere task. A normal control group showed a LVFA, albeit weak, but the dyslexics showed no asymmetry. This evidence for bilateral representation of normal right hemisphere functions was supported by the converging evidence of a tactile test with nonsense shapes. The DVF test originally intended to tap left hemisphere processing consisted of lateralized presentation of upper case letter pairs to which subjects responded 'same' or 'different'. Before completion of the work, it became
clear that this task could permit a physical match without employing linguistic processing. Therefore the test cannot be regarded as a test of normally left lateralized verbal functions. However, a dichotic digits test revealed no differences between normals and dyslexics—both had a REA, although dyslexics’ overall performance was significantly lower than normals’. Based on these findings, Witelson proposed that 1) bilateral representation of the spatial function normally specialized to the right hemisphere may exist in dyslexics, and 2) such bilateral representation may interfere with the dyslexics’ normally lateralized linguistic functions of the left hemisphere. The hypothesized left hemisphere impairment would be consistent with dyslexics’ depressed performance levels on linguistic tasks. That performance on spatial tasks was equal to normals’ is evidence that dyslexics do not suffer from some generalized deficit.

A common finding throughout the DVF literature is that with verbal stimuli dyslexics perform less well overall than do normals. This could be interpreted as evidence for some generalized deficit in dyslexics, or it may be that there is some neural factor interfering specifically with their left hemisphere function. However most of the above research that provides evidence for normal lateralization in dyslexics for verbal functions cannot distinguish between the two possibilities because it
is limited to left hemisphere functions. By assessing both verbal and spatial processes in the same subjects, it may be possible to learn whether verbal processes are truly less lateralized than in normals or whether they are normally lateralized to a hemisphere they share with spatial processes, perhaps to the detriment of verbal functioning.

**Dichotic Listening Studies**

Zurif & Carson (1970) studied ear asymmetries in 14 dyslexic readers and 14 normal readers chosen from a larger group of grade four boys. The dyslexic boys read at the grade 2.7 level (range 1.1-3.5) and the normal boys read at the grade 4.7 level (range 4.0-8.0). Handedness was not controlled. Twenty series of three pairs of numbers were the stimuli. A boy would simultaneously hear two different digits, one in each ear. This was repeated (with new pairs) twice more. The three presentations of digit pairs constituted one trial. The subject was to report as many of the digits heard as possible, in whatever order he pleased. There was no correction for guessing. Dyslexic boys performed overall (right ear score + left ear score) significantly less well than normal readers. There was no significant overall asymmetry nor a significant group by ear interaction. There was a right ear superiority amongst normal boys which "closely approached significance," and
the dyslexic boys "tended" toward a left ear superiority. Because each group contained 8 subjects who exhibited a REA and 5 who exhibited a LEA, inter-subject variability was dismissed as causing the slight group differences. Instead, those normal subjects who exhibited a REA did so more strongly than did the dyslexic subjects who exhibited a REA.

These results are not very convincing however, because they do not represent statistically significant differences in asymmetries. That even a trend can be obtained with such a small sample size is of course intriguing, but several other factors in addition to small sample size make interpretation of these results difficult.

The study did not control for handedness. Five subjects in each group were classified as either ambidextrous or sinistral. Sinistrals have been found to show reduced dichotic listening laterality effects (Satz, Achenbach & Fennell, 1967; Satz, Achenbach, Pattishall & Fennell, 1965; Zurif & Bryden, 1969), likely reflecting the fact that left hemisphere speech representation is more prevalent in dextrals than in sinistrals, and right hemisphere speech representation is more prevalent in sinistrals than in dextrals. By including dextrals and sinistrals together in groups, there is a contamination that makes it difficult to predict what group performance normally should be, and thus difficult to define atypical
Another possible confound is that report order wasn’t controlled. Normal adults more frequently report right ear digits first (Bryden, 1963). Witelson and Rabinovitch (1972) found that reading clinic children did report left ear stimuli before right ear stimuli significantly more often than did normal control children. It is possible that such group differences in report order strategy could result in different dependent measure behavioural asymmetries between groups, without being reflections of different functional asymmetries. However, the existence of report order differences between groups is itself of some interest, and it may be that the report order strategy itself reflects functional organization.

Finally, there is no convincing evidence that the dyslexic group was composed only or even primarily of dyslexics. A boy would be included in this group if he were only 1/2 year delayed in reading, as measured by the Gates Reading Test. It would seem that this slight delay could be due to measurement error alone. Even if it were a true reflection of reading skill, a 1/2 year delay is insufficient a deficit to invoke dyslexia by even the most liberal criterion. There is insufficient spread in reading ability between the two groups to allow any conclusions about normal/dyslexic differences (or the lack of differences) because contamination of the dyslexic group by
normal readers is too great. Furthermore, delay is ill defined. It is not clear if it refers to delay from current grade placement or age appropriate grade placement, and whether time of testing during the school year and subjects' months of birth are considered in the calculation of years delayed.

What can be said for this study is that three of its flaws (small groups, uncontrolled handedness and loose dyslexia criterion) are likely to bias finding group differences, and yet slight differences were found. Unfortunately, we are left wondering whether these could have been caused by group differences in response strategy.

Numerous other dichotic listening studies have also investigated left hemisphere function in normal and (variously defined) dyslexic readers. Most dichotic listening research has reported REA's in normals and dyslexics (e.g.: Aylward, 1984; Keefe & Swinney, 1979; Leong, 1976; McKeever & VanDeventer, 1975; Satz, 1976; Satz, Rardin & Ross, 1971; Sparrow & Satz, 1970; Witelson, 1976, 1977b; Yeni-Komshian, Isenberg, & Goldberg, 1975), although Witelson & Rabinovitch (1972) reported REA's in 58% of reading disabled subjects (not necessarily dyslexic), with the other 42% of reading disabled showing a LEA. The normal readers were distributed 71% REA and 29% LEA. There was a significant Ear by Group interaction, but separate t-tests did not establish asymmetries within
either group.

The dichotic listening literature offers some evidence that dyslexics are atypically lateralized, but there is conflict in the particulars. Although dichotic listening experiments may augment DVF studies, because of the dichotic listening method's inherent difficulties in testing the functions of both hemispheres, it is not likely to be the best method for understanding hemispheric specialization in dyslexics.

RELATED RESEARCH AREAS

The finding of atypical behavioural specialization in dyslexics indicates that there is an atypical neural substrate. The following brief reports of atypical findings in the dyslexic brain provide corroboration for that idea.

Electrophysiological Evidence:

Abnormal behavioural asymmetries, when not artifacts of improper experimental procedure, may implicate underlying constitutional abnormalities. In dyslexics, such abnormalities have been found in neural regions that subserve cognitive functions involved in reading.

Hughes(1978) presents a review of 10 EEG studies of
dyslexics, in which he computed a weighted (for number of subjects) average incidence across studies of EEG abnormalities in dyslexics of 45%. In all studies that employed normal control groups, the incidence of abnormality amongst dyslexics was significantly higher than the control subject incidence.

Brain electrical activity mapping (BEAM) has revealed electrophysiological differences between normal and dyslexic boys in areas known to be involved in speech and reading. Duffy, Denkla, Bartels & Sandini, (1980) studied eight dyslexic boys and eight normal reader control subjects. Ten different experimental conditions were employed while collecting EEG data, in addition to three EP conditions. The conditions were designed to specifically evoke either left hemisphere processes, right hemisphere processes, or both hemispheres simultaneously. Significant differences between the groups were obtained from the data from mean image matrices on every state-dependent condition. Differences were obtained from Broca's area, Wernicke's area, and the left temporal region. These are areas involved in speech and reading.

**Anatomical Evidence**

Cytoarchitectonic study has revealed neuropathological anomalies associated with dyslexia in reading related brain regions (Drake, 1968; Galaburda & Kemper, 1979), although autopsy evidence on dyslexics is
rare. Drake's was the first autopsy report on a dyslexic child. Drake noted an abnormal convolution pattern bilaterally in the parietal region and thinness of the associated callosal region. Microscopic examination revealed ectopic neurons in white matter and spindle shaped nerve cells. Galaburda & Kemper's report presents more extensive data, including behavioural measures, although the subject experienced seizures at age 16, which makes clear interpretation of his reading disability difficult. The patient was left-handed, but strongly left lateralized for language functions on a dichotic listening test. Death was accidental at 20 years. The brain at autopsy was superficially normal, and serial sections revealed no anatomical abnormalities. The left hemisphere was larger than the right, but even so the planum temporale was not larger on the left, both sides being of equal size. The normal pattern is for the left planum to be larger (Geschwind and Levitsky, 1968). Abnormalities at a cellular level in the brain were revealed by microscopic examination. These were confined to the left hemisphere, and included polymicrogyria posterior to the planum temporale, fused molecular layers, dysplasia in the left temporal region, and absence of normal cytoarchitectonic landmarks. The presence of abnormalities in areas known to be involved in speech and reading in a patient who exhibited a reading disability, although not proof, is
strong evidence for a relationship between a structural and
a behavioural deficit. That the patient was nonetheless
strongly left lateralized for language functions hints that
abnormal lateralization of language functions may not be a
characteristic of dyslexics, or of some subgroup of
dyslexics.

Reversed anatomical asymmetries (ie., right
parietooccipital area greater than left) were found in 42%
of the 24 dyslexic brains studied by CT scan by Hier,
LeMay, Rosenberger & Perlo (1978). Among the normal
population such a reversal is found in only 9% of dextrals
and 27% of sinistrals (the percentages of reversed
asymmetry for the dyslexics by handedness was 56% of the
17 dextrals and 50% of the 6 sinistrals). These reversed
asymmetries correlated positively with delayed speech
acquisition and with Verbal IQ lower than Performance IQ.
Genetic evidence:

There is a greatly increased incidence of dyslexia
in males (Berger, Yule & Rutter, 1975). Sociological
factors could be involved in a sex based difference in
incidence. However, increased incidence of dyslexia among
siblings of dyslexics (Decker & DeFries, 1981) in addition
to the sex difference suggests a biological basis for this
disorder.
Conclusions

The roles of both the left and the right hemisphere processes in atypical functional organization deserve further study that include tests of both processes within one modality. Recently many DVF methodological improvements have been devised through research with normal subjects, and these will be applied in the investigation.

Most of the current literature on functional organization in dyslexics is based on studies of primary school age children. Little is known about the state of functional organization in adult dyslexics. Although current findings suggest that lateralization does not develop ontogenetically (Bryden, 1982, Kinsbourne & Hiscosk, 1984; Witelson, 1977, 1985), study of adult dyslexics nevertheless avoids the issue because lateralization is surely static by adulthood. Study of adult dyslexics also has other advantages: 1) By adulthood, it is clear that the inability to learn to read represents a specific problem and that the subject is not simply developing slowly. 2) With adults it is possible to study lateralization in subjects whose reading skills are stable. 3) Reading skills in adult dyslexics are usually sufficiently developed that the lateralization of reading skills at the same level can be studied.

Finally, there are three areas in research into
functional specialization in dyslexic readers that deserve scrutiny: subject selection, experimental techniques, and measurement of asymmetry. These will be dealt with in detail in the following chapters, to make clear the procedures employed in the experiment described in subsequent chapters.
Chapter Two

WHO ARE THE DYSLEXIC READERS?

Concepts of Expected Achievement and Underachievement

One factor that may account for the conflicting findings in dyslexia research is the use across studies of different criteria for inclusion in dyslexic reader groups. This chapter will explore some of the problems encountered when devising dyslexic reader criterion for research purposes. Do not expect that reading it will provide a simple, single answer to the chapter title's question. That is itself the purpose of this field of research. The dilemma of how to study dyslexia when it isn't clear who is dyslexic is perhaps best approached by attempting to use only those subjects who exhibit quite strongly the characteristics thought to be important, leaving to the future studies that will allow us to distinguish less clear
cases of reading failure.

There is one factor that unites virtually all definitions of dyslexia. That factor is the unexpectedness of the reading problems. A dyslexic exhibits a discrepancy between an expected achievement and actual achievement. This discrepancy is, by definition, not predicted by the factors that normally predict reading achievement. In order to understand any experimental definition of dyslexia based on these concepts, it is necessary to understand how reading achievement was assessed, how the expected level was determined, and how large a discrepancy between these two measures was needed to warrant inclusion in a dyslexic reader group.

Assessment of Reading Failure

Most evaluations employ instead the performance of a reference group as the criterion for evaluation. The appropriate reference group would be described by factors that are associated with (predictive of) a certain level of achievement, and those factors must also be present and quantifiable in the subject.

The most common reference group employed is the age peer group. This is a reasonable first approximation. That is, although age is not believed to "cause" reading, it is significantly correlated with it, and most
standardized reading tests use age-based norms. If a student’s reading skill is at the lower end of the age appropriate distribution he is considered poor at reading. In spite of the existence of a correlation between the two, it is a bit peculiar to expect a level of reading achievement on the bases of age alone. Surely there are other very obvious factors that should contribute more—and more directly—to the accuracy of the prediction. Intelligence and amount of education are candidates.

Causes of Failure of Prediction

The more that is known about the relevant factors that contribute to or are correlated with reading skill, the better the predictions can be, and the concept of underachievement can be seen to be a result of imperfect predictions. Attempting to improve prediction of reading skill is thus tantamount to attempting to understand all the relevant factors in reading. Thorndike (1963) describes four reasons for failure of prediction: errors of measurement, heterogeneity of the criterion, limited scope of the predictors and the impact of varied experience between time of prediction and criterion tests. These are discussed below with reference to predicting reading achievement.

Errors of Measurement: Sampling a specific behaviour of an individual is inevitably an undependable
representation of the person’s entire range of that particular behaviour. The problem is compounded when measurement error exists in both a predictor and a criterion, and attempting to explain discrepancies between predicted and obtained reading skill that arise from measurement error is a silly enterprise, although one that may be common in research that does not take account of regression effects. Measurement error cannot likely be eliminated, but it should not be permitted to influence an experiment in a systematic way, as might happen if the subjects in a group were primarily those people whose predicted/obtained discrepancies represented the extreme end of the distribution of measurement error.

Heterogeneity of the Criterion: This error could exist in dyslexia research if the criterion is grade level attained in school or some similar criterion that varies between subjects and even within subjects over time.

Limited Scope in the Predictors: To predict complexly determined behaviour requires a complex of predictors. The predictors should have a high correlation with the criterion, without being alternate measures of the criterion. For example, a very high correlation would exist between two versions of the same standardized reading test. But to use one to predict the other would not identify underachievement, it would only expose measurement error and parallel form reliability. The best predictors
are highly correlated with the criterion and are poorly correlated with each other (are independent).

**The Impact of Varied Experiences** between Dates of Prediction and Criterion Testing: Forecasts over time are subject to the effects of intervening variables (like special remedial training). Either simultaneous predictor and criterion testing should be done, or the presence of intervening variables should be controlled if possible.

**The Application of Prediction Theory to Studies of Dyslexia**

It is now clear that whenever the distribution of scores of a reference group is used to evaluate an individual's performance, we are predicting an expected level of performance for the individual. This is as true when the common age-based norms are used as when a multivariate prediction is made.

But if age were the only predictor used, the dyslexic group would be heavily populated by people with poor reading attributable to known causes. In order to distinguish between expected and unexpected reading achievement, it is next necessary to apply rules that exclude readers with known causes of reading failure (CNS damage, low IQ, etc.). The procedure would then exclude two groups who on the basis of multiply predicted reading scores versus obtained reading scores would be considered dyslexic: 1) readers who are of low intelligence but whose...
reading achievement is still substantially below that predicted by their intelligence would be excluded on the basis of their IQ, and 2) very intelligent readers who are reading substantially below the level expected on the basis of their IQ but whose reading places them at least at the middle of the distribution would be excluded on the basis of their reading achievement. Because the reasons for unexplained reading failure might be different in different IQ groups, it may be desirable to study dyslexic readers at various IQ levels and at various levels of reading skill. To do so requires that intelligence be considered in some way in the computation of expected achievement.

Employing a multiple regression equation, it is possible to derive the best combination and weighting of predictive factors. The result is the correlation with the criterion of all the predictor variables taken together. This correlation and the subject's scores on the predictor variables are then used to predict the criterion value. Predicted/obtained discrepancies are then calculated, and a confidence interval is computed using the standard deviation of the discrepancy scores, by the formula:
\[ S = S \left( 1 - r \right) \]
\[ D \]
\[ C \]
\[ pc \]

Where:

- \( S \) = std. dev. of a discrepancy score
- \( D \) =
- \( S \) = std. dev. of criterion scores
- \( C \) =
- \( r \) = correlation between criterion and predictor

(Thorndike, 1963)

Obtained scores on the criterion measure that are below the interval are significantly lower than predicted. A judgment must then be made regarding how much of a discrepancy is necessary for dyslexia to be invoked. The discrepancy must fall outside the confidence interval, of course. If the correlation of the predictor values with the criterion is low, the confidence interval will be sufficiently large that any significantly lower score will be of clinical significance. However, a low predictor/criterion correlation will also result in few readers' scores falling below the confidence interval.

There are two ways to use the multiple regression equation in prediction. The simpler consists of using the published population correlations between predictors and criterion and intercorrelations between predictors. These
are not readily available for most tests, limiting the
selection of standardized instruments.

Dyslexia: Normal Variation?

A vastly more complex approach is through
epidemiological study of reading achievement and various
covariates, like intelligence, age, familial incidence of
reading problems, education, social class, etc. Such
studies have been undertaken by Yule and his colleagues
(Rutter, Tizard & Whitmore, 1970; Yule, 1973; Berger, Yule
& Rutter, 1973). Because the required correlations are
computed from the data of the population studied, selection
of variables is not constrained as it is in the first
example above.

In addition to using the information obtained to
identify specific subjects who are reading below their
expected levels, epidemiological studies provide the
opportunity to test the concept of dyslexia itself. That
is, the distribution of discrepancies between predicted and
obtained scores should in theory be normal. If a 'hump' is
found on the curve at the lower end of the distribution it
may indicate that a factor or factors is operating on those
subjects that is not affecting the performance at other
areas of the distribution, that the readers represented are
not simply the lower end of the continuum of discrepancies.
The causal factor could be either biological or environmental. The 'hump' would not prove the existence of dyslexia, but its absence would be a serious challenge to the concept.

Yule et al. (1974) report eight epidemiological studies in which there were disproportionate numbers of readers at the lower end of the distribution, and no comparable excess at the other end of the distribution. Comparing these unexpected poor readers with a group of general poor readers, Yule et al. found that the M/F ratio was 3.3 to 1 among the former, and only 1.3 to 1 among the latter. The unexpected poor readers showed a lower incidence of neurologic disorder and greater incidence of motor and praxic abnormalities than the general poor readers. Thus, the prediction procedure identified a statistically significant group, and further study identified important clinical characteristics of the group.

Why is it, then, that regression equations are not more frequently employed to identify dyslexics for research purposes? Epidemiological studies are forbidding simply because of their size and the necessity of committing enormous resources to test a theory. Before embarking on an epidemiological study, it seems wise to attempt limited validation of a theory with a well-selected population. This does not, however, answer the question with regard to smaller scale studies.
It may be simple ignorance of the profound regression effects involved in prediction, and ignorance of ways to overcome them that lead researchers to use deterministic models of prediction (Ex.: normal IQ predicts normal reading score).

A more generous hypothesis is that the data required are frequently not available, constraining choice of variables. When these are available they represent scores which have been normalized, precluding definition of dyslexia by statistical characteristics. Furthermore, it is difficult to know whether the general population data that is available is appropriate for use with the population being studied.

The correlations between standardized reading tests and standardized tests of non-verbal intelligence are relatively low, about .5 to .6. This can present serious problems of prediction. For example, two predictors of reading achievement that could be used are the Object Assembly and the Block Design subtests of the WAIS. These have population correlations with WRAT reading subtest scores of .37 and .58 respectively, and an population intercorrelation of .69 (Jastak & Jastak, 1978). The subtests of the VIQ are more highly correlated, but more likely represent abilities that are measured by the WRAT. Thus using them would be close to using parallel form measures. When predictors have such low correlations as
the object assembly and block design subtests do with the
WRAT and a relatively high intercorrelation, the obtained
multiple correlation is only .58, and the standard
deviceation of the discrepancy scores is .81 z. Therefore
only scores that are at least -1.3 z below the predicted
score are significantly lower (p.<0.05) than the predicted
score. This illustrates the problem of trying to use
predictor variables with low correlations with the
criterion, and conversely the difficulty of finding
predictor variables with high correlations with the reading
test but which are not themselves a reflection of reading
skills or experience.

In addition to the problem of low correlations, IQ
tests present other problems with a dyslexic population.
Intelligence seems like a most obvious predictor of reading
achievement, but the problem of assessing intelligence in
dyslexic readers is a thorny one, whether in small-scale or
epidemiological studies. It is not clear that there is a
way to measure only those parts of intelligence that do not
contribute to reading, simply because it isn’t known
precisely what mental skills are employed in reading. The
use of the full scale IQ of the Wechsler series of tests
seems clearly inappropriate because of the contribution of
Verbal I.Q. to it. The dyslexic is clearly at a
disadvantage in that he usually has not had the opportunity
through reading to acquire the knowledge this scale taps.
Even use of Performance Scale scores is suspect because the subtests may still require verbal mediation. Use of an intelligence test which does this violates the caveat to avoid predictor variables that are alternate measures of the criterion. There is presently no way to be certain that an ability is free of reading-related factors.
CHAPTER 3

Methodological Concerns

The Problems in DVF Research with Dyslexics

There is the real possibility that a major reason there is no consensus concerning the functional organization of dyslexics is that there are so many uncontrolled extraneous variables affecting the results of experiments in this field. It may be that a good DVF research design has not yet been devised for the purpose. An exhaustive treatment of all the considerations in this area is beyond the scope of this thesis; the following is a review of decisions made regarding the present research, in only those areas where the decision might need explanation.

There were two overriding considerations in devising the present DVF experiment. The first was that the control subjects should perform in a way that is
consistent with what is known about normal functional organization and what is known about the task requirements. That is, controls must exhibit a LVFA for spatial stimuli and a RVFA for verbal stimuli. The second is that the DVF task should be limited to what has been shown to be processing in one hemisphere, so that atypical behaviour could not be attributed to differences in strategy between groups.

There are two kinds of exclusionary factors that are relevant to dyslexia research. They are 1) any factor that could be causal of reading failure (like inadequate intelligence, socio-cultural opportunity or education) and 2) any factor that may have led to functional reorganization (like head injury, CNS disease, psychosurgery).

Because dyslexia is more prevalent in males and because there appear to be sex differences in functional organization in normal people such that males show stronger behavioural asymmetries, it is preferable to study the sexes separately, and likely more fruitful to study males. That way it is more clear what the expected pattern of functional organization should be, and atypical organization therefore more recognizable.

Sex differences in behavioural asymmetries have been obtained with DVF tests for a variety of stimuli (e.g., Bradshaw, Gates & Nettleton, 1977; Bradshaw &
Gates, 1978; Davidoff, 1977; Hannay & Malone, 1976; Kail & Siegel, 1978; Kimura, 1969; McGlone & Davidson, 1973; McKeever & Jackson, 1979; Walter, Bryden & Allard, 1976, Witelson, 1977), although sex differences have not always been found (e.g., Bradshaw, Bradley & Patterson, 1976; Bryden & Allard, 1976; Hannay & Boyer, 1978). In general, when there are differences found, males appear to exhibit greater RVFA's than females for verbal stimuli, and LVFA's for spatial stimuli in instances where females show no asymmetry. Because the issue of sex differences in DVF test asymmetries is not resolved, it is clearly necessary to study the sexes separately.

It has frequently been observed that dyslexic boys outnumber dyslexic girls (e.g., Critchley & Critchley, 1978; Hinshelwood, 1900; Lovell, Shapton & Warren, 1964). Because dyslexia is hypothesized to be related to functional organization, and because there are sex differences in functional organization in normal people, it is clear that the sexes should be studied separately in this research, and the use of males is likely to improve the opportunity to obtain subjects.

In order to recognize atypical functional organization, it is necessary to have a notion of just what organization is normally expected for a subject. Handedness can be used to infer pattern of functional organization. Through sodium amytal testing, it has been
established that 96% of right handed people are left lateralized for speech, whereas only 70% of left handed people have only left hemisphere speech representation (Rasmussen & Milner, 1977). Therefore, by using only right handed subjects, the expected pattern of organization can be specified more accurately.

Handedness may be assessed in a variety of ways. Handedness inventories may simply ask which hand is used for an activity, or they may assign weights according to how consistently one hand is used for a particular activity (e.g., Annett, 1970; Crovitz & Zener, 1962; Oldfield, 1971).

The subject's statement of hand preference may be suspect, however. Raczkowski, Kalat & Nebes (1974) report that certain items common to many handedness inventories (e.g., which hand at top of broom) have relatively low retest reliability. Performance measures were found to be more reliable (subjects were more likely to perform consistently across two testing sessions than they were to report their preference consistently).

In addition to demonstrated preference or report-of-preference measures, proficiency measures of various kinds are sometimes used: dexterity, reaction time, speed of arm movements, finger tapping, aiming, arm hand steadiness, etc. Barnsley & Rabinovitch (1970) did an extensive analysis and found that these measures were
poorly intercorrelated. However, all except reaction time and arm movement speed differentiated between preferred and nonpreferred hand. Because there is not yet evidence specifying the best choice among the many options for measuring handedness, demonstrated preference, which is an easily administered measure, and is more reliable than reported preference, appears to be the best option.

Normal visual acuity must be ascertained for all subjects in DVF experiments, simply to ensure that no subject is tested who performs poorly because of a visual handicap. Acuity must be measured in each eye independently, to avoid confounding VF with visual pathways associated with varying levels of acuity.

In research investigating dyslexia, it is obvious that poor acuity must be ruled out as a possible cause of reading failure.

In order to ensure that lateralized stimuli are projected to the desired part of the hemiretinae, it is imperative that both of the subject's eyes (assuming binocular vision is employed) be focused on the same point in space. Subjects with uncorrected amblyopia or strabismus are therefore unsuitable for DVF research. Because mild degrees of these conditions may be difficult to assess simply by viewing the subject's eyes, a simple test of proper fusion should be administered. A test of depth perception that requires that the subject wear
polarized lenses to view special polarized pictures can identify subjects with improper fusion. If there is proper fusion, certain pictures appear three-dimensional. Although depth perception can be absent in the presence of proper fusion, the inverse is not true for these tests. Therefore, they are useful for assessing proper fusion, and should be employed.

**Stimuli**

Real words are not suitable as stimuli because the groups vary in their experience with them, likely leading to differences in overall performance that are not desirable (see Chapter 5). In addition, it may be that a different strategy is used to read a familiar word than is used to read a novel word, and these strategies might be differently lateralized. For example, familiar words might be recognized by use of a spatial strategy and novel words might be sequentially analyzed. Differences within and between groups in strategy would then confound the results. The only way to require the subject to read while still being confident that he is not familiar with the material read is to use pronounceable nonsense words. Experienced readers may be at an advantage in mentally scanning a horizontally presented string of letters, and this advantage may bias toward better RVF performance, so
it is desirable to present the letters in a vertical orientation. This has been found to be equally effective in obtaining the expected RVFA's for verbal material (Bryden, 1970, Day, 1979). Even typeface has been found to affect VFA's (Bryden & Allard, 1976), and so a typeface very similar to that found to encourage a RVFA was selected for use for the nonsense words.

Faces have been shown to provide the most reliable LVFA's in normals of all spatial stimuli (Beaumont, 1982). In order to prevent a verbal strategy in performance of the task, faces used in a trial should be matched for nameable features. Thus, all faces should have the same expression, eye colour, nose size, etc.

**Fixation Control**

It is necessary to maintain the subject’s fixation on a central fixation point during each trial, to insure that lateralized stimuli do not impinge upon a part of the retina that has bilateral projections. One commonly used method is to present a digit centrally simultaneously with presenting the lateralized stimuli. The subject reports the central fixation digit first as assurance that he was centrally fixated (McKeever & Huling, 1971). It has been argued that the reporting of the digit before reporting the stimuli might bias the results (Hines, 1972; Kershner,
Thomae & Calloway, 1977; Carter & Kinsbourne, 1979), yet it has not always been found to do so (Hines, 1978).

**Bilateral Presentation**

Bilateral presentation of two different stimuli may cause the two hemispheres to function as independent channels and so give a better measure of the capacities of each (Dimond, 1972). Because the requirement to respond to both of the two bilaterally presented stimuli may introduce various confounds (report order, memory) only one response should be scored. In order to prevent the subject from anticipating the side to which he must respond, a post-cue arrow can indicate the response side.

**Pre-testing Verbal Stimuli**

Because dyslexics and normal readers may differ on two factors (functional organization and reading achievement) it is important not to confound these in the experiment. If dyslexics do less well than controls when presented with verbal stimuli in a DVF task, it should not be because they could not do the task under far more favourable circumstances, yet this is frequently the procedure. It is more logical to present them with stimuli they have shown the ability to process. The
pre-testing, under ordinary reading conditions, of potential stimuli could eliminate this problem. For instance, all subjects can be given a large number of nonsense words to read aloud from a list. Only those words correctly read are chosen for use as stimuli in the DVF task. By cross indexing the correct words for all subjects, it is possible to maintain great similarity in the stimuli sets. Proper counterbalancing of order and lateral position of the words can help eliminate the problem of differing stimuli sets. In addition, dyslexics and controls can be matched so that each pair receives the identical set of nonsense words that were correctly read by each.

Stimuli Presentation

The order of events in a trial were carefully planned to eliminate differential effects on the two experimental groups. The stimulus duration was chosen because it was short enough to obtain asymmetries with normal subjects as shown through pilot testing, but long enough to permit dyslexics to perform adequately. Following presentation of the stimuli, a 500 msec. delay precedes the presentation of an arrow that cues target face. No mask is used in this experiment. Moscovitch, Scullion and Christie (1976) have shown that asymmetries
emerge only when a central mask is presented after about 90 msec. following the stimuli, presumably at a time when the differential abilities of the hemispheres begin to be tapped. If a mask is used when comparing normal and dyslexic subjects, and if the time required to obtain asymmetries is different for these two groups, the finding of differences between the groups could be due to those differences, rather than to differences in the functional specialization of the hemispheres. Instead, the 500 msec. delay between stimuli offset and presentation of the cuing arrow requires that both stimuli proceed to processing, on the assumption that, whatever any delay in dyslexics until asymmetries emerge, it does not exceed 1/2 second.

Conclusions

Undoubtedly other important extraneous variables exist that are not yet recognized; this must be true if only because the DVF technique is not absolutely reliable. Although it is preferable to eliminate as many of these as possible, it is not necessary to await that time before proceeding to apply the method to abnormal groups. The primary emphasis in this situation should be to eliminate extraneous variables that differentially affect the groups. In the present experiment, the most important
extraneous variable that probably has differential effects is the difference between groups in reading achievement. Thus, the most important methodological consideration is likely to be the attempt to equate both groups, through the nonsense word pre-test, on their accuracy when reading the nonsense words.
Chapter 4

UNDERSTANDING THE DATA:
INTERPRETATION OF BEHAVIOURAL ASYMMETRIES

The previous chapter reviewed factors that influence the validity of DVF tasks. Two important interrelated issues remain: 1) how to interpret behavioural asymmetries when comparing groups who differ in overall (LVF + RVF) accuracy, and 2) whether there are degrees of lateralization, and, if so, whether differences in degree of behavioural asymmetry reflect such differences in degree of functional organization.

Group Differences in Overall Performance

There is a serious problem of interpretation of differences in behavioural asymmetries when groups differ in overall accuracy. This problem is of immediate interest because it is usual to find such differences between control and dyslexic subjects for verbal stimuli on DVF tests. To understand the problem, consider the extreme...
case where one group performs near ceiling level and the other group performs in the middle of the range of possible levels. The first group is constrained to small asymmetries by their level of overall performance, whereas the other group retains the possibility of exhibiting a large asymmetry.

An example from the literature of this problem is Kimura's (1963) dichotic listening experiment that compared asymmetries in children of different ages. The magnitude of the right ear advantage decreased with increasing age. Such results defy interpretation by any current theory: no one subscribes to a theory of a developmentally decreasing lateralization. Finer examination of the data illuminates the cause of this apparent paradox: young children made many errors, older children made very few, likely constraining the magnitude of their asymmetry (Bryden & Sprott, 1981). Thus, the overall performance level was negatively correlated with the magnitude of the differences between left and right visual fields.

The example illustrates how using the raw data may be misleading when overall performance differences exist. Recognition of this problem has resulted in the development of a number of indices of lateralization that are not dependent upon overall performance (Bryden & Sprott, 1981; Harshman & Krashen, 1972; Hawles, 1969; Kuhn, 1973; Marshall, Caplan & Holmes, 1975; Repp, 1977;
Studdert-Kennedy & Shankweiler, 1970. These indices transform the LVF and RVF scores in an attempt to negate the constraining influence of overall performance level. Different indices can result in profoundly different interpretations of the same data (see Figure 1). Thus, the lack of firm foundation of lateralization theory upon which to base the choice of index presents a major problem. A theory is required that specifies the relationship of overall performance to asymmetry and which addresses the issue of degrees of lateralization (see next section for discussion of this issue).

Until such time as the relationship between overall accuracy and laterality can be theoretically and empirically established, the best condition under which to compare groups is one of equivalent overall performance because such comparisons are not confounded by the correlation between overall accuracy and the magnitude of the differences between the LVF and RVF.

Are there Degrees of Lateralization?

The traditional approach to analyzing between group differences in behavioural asymmetry is with ANOVA. There are two major problems associated with that approach. The first arises when considering a significant group X visual field interaction. When this interaction occurs in the
An illustration of the manner in which each of four popular laterality indices varies as a function of total performance (R+L). Considered separately are Case 1, in which the difference between right and left raw scores increases with increasing total performance; Case 2 in which differences between R and L remains constant as total performance increases, and Case 3 in which the difference between R and L decreases as total performance increases. The laterality indices depicted are: \(\frac{(R-L)}{(R+L)}\) (e.g, Studdert-Kennedy & Shankweiler 1970); Percent of Error (Harshman & Krashen 1972); the phi coefficient (Kuhn 1973) and \(f\), which is \(\frac{(R-L)}{(R+L)}\) for \((R+L)<50\%\) and \(\frac{(R-L)}{(T-(R+L))}\) for \((R+L)>50\%\), where \(T\) represents the maximum number of possible correct responses (Marshall, Caplan & Holmes 1975). Curves were generated with the following constraints: 60 trials, 2 responses per trial, mean R-L difference of 10. (Adapted from Kinsbourne & Hiscock, 1984, with permission of the authors.)
presence of a VFA in the same direction for both groups, it has been typically interpreted as indicating differences in degree of lateralization. There is criticism of such an interpretation, primarily because the relationship between behavioural asymmetry and lateralization is uncertain (Colbourn, 1978). An alternative interpretation of differences in degree of behavioural asymmetry is that they are attributable to the effects of extraneous factors discussed in the previous chapter. Nevertheless, the consideration of differences in asymmetry are important because 1) they can disconfirm the hypothesis of differences in degree of lateralization between groups, or 2) because they provides a starting point from which to evaluate extraneous factors which may contribute to differences between groups (Kinsbourne & Hiscock, 1984).

A second problem associated with comparisons based exclusively on group means is the obscuring of important factors related to the VFA distributions. Alternative measures are available that examine the data in terms of numbers of subjects in each group exhibiting a particular VFA. Such information might reveal different patterns of performance within and between groups that influence each group's mean performance. For example, a dyslexic group might be bimodally distributed, possibly indicating the presence of two distinct subgroups. Alternatively, strong asymmetries for a small proportion of subjects may inflate
their group mean in a VF, yet there may be no more subjects
in that group exhibiting that VFA than in another group
with a lower mean.

Although these difficulties are not unique to
lateralization research, because there is not a coherent
theory of lateralization that makes clear whether it is
only direction of asymmetry or whether magnitude of
asymmetry is also important that is crucial, it is
important to use additional measures in conjunction with
the comparison of group means by ANOVA to evaluate all
aspects of group differences.
METHOD

Subjects

Two groups of adult subjects were tested in this study: 10 dyslexics and 10 normal controls. To be included in this experiment, each subject had to meet the following criteria:

1. Male
2. Caucasian
3. Age 17 to 35
4. Right handed, defined as demonstrated preference for at least 9 of the 11 items of the Annett (1967) handedness inventory, with the stipulation that the right hand must have been used for the signature.
5. A score of 80 or above on the Performance scale of the Wechsler Adult Intelligence Scale - Revised (Wechsler, 1981).
6. Visual acuity of at least 20/30 in each eye as assessed by a standard eye chart test.
7. Normal stereopsis, the criterion being identification of the apparent three-dimensionality of at least 6 of the 9 stimuli on the Titmus Stereopsis Test.

8. Completion of at least nine years of formal education.

9. No evidence, record or subject report upon questioning of brain damage, diagnosed primary emotional disturbance, economic disadvantage or inadequate social experience.

Dyslexic subjects were recruited from two sources: 1) a larger group of dyslexic subjects who have been repeatedly seen in our laboratory since their childhood, and 2) referrals from community agencies that deal with reading disabled adults.

Control subjects were recruited from the local community, by appeals through instructors to part time university students, and through the local casual labour office of the government employment service. Where required, subjects in both groups were paid $4.00 per hour for participation.

The subjects were selected so that the groups did not differ significantly in age or WAIS-R Performance IQ (t= 1.51, d.f. = 18, p.>0.05) (See Table 1).
### TABLE 1

**GROUP DESCRIPTORS**

<table>
<thead>
<tr>
<th>Measure</th>
<th>Group</th>
<th>Mean</th>
<th>StdDev</th>
<th>Max</th>
<th>Min</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>Dys</td>
<td>22.6yr.</td>
<td>2.59</td>
<td>26.7yr.</td>
<td>17.9</td>
</tr>
<tr>
<td></td>
<td>Con</td>
<td>23.8yr.</td>
<td>4.07</td>
<td>31.3yr.</td>
<td>18.2</td>
</tr>
<tr>
<td>WAIS-R IQ</td>
<td>Dys</td>
<td>92.11</td>
<td>10.9</td>
<td>106</td>
<td>80</td>
</tr>
<tr>
<td></td>
<td>Con</td>
<td>106.1</td>
<td>11.5</td>
<td>122</td>
<td>79</td>
</tr>
<tr>
<td>WAIS-R VIQ</td>
<td>Dys</td>
<td>91.2</td>
<td>8.9</td>
<td>104</td>
<td>80</td>
</tr>
<tr>
<td></td>
<td>Con</td>
<td>104.1</td>
<td>10.6</td>
<td>121</td>
<td>82</td>
</tr>
<tr>
<td>WAIS-R PIQ</td>
<td>Dys</td>
<td>95.8</td>
<td>12.7</td>
<td>112</td>
<td>80</td>
</tr>
<tr>
<td></td>
<td>Con</td>
<td>106.7</td>
<td>11.7</td>
<td>118</td>
<td>80</td>
</tr>
<tr>
<td>WRAT-R</td>
<td>Dys</td>
<td>-1.4z</td>
<td>1.16</td>
<td>-.1z</td>
<td>-3.5z</td>
</tr>
<tr>
<td></td>
<td>Con</td>
<td>+0.6z</td>
<td>.99</td>
<td>1.5z</td>
<td>-0.2z</td>
</tr>
<tr>
<td>WRAT</td>
<td>Dys</td>
<td>-1.23z</td>
<td>.69</td>
<td>-.5z</td>
<td>-2.2z</td>
</tr>
</tbody>
</table>

a) The WRAT was administered only to the six subjects seen as children, and was given at their first testing in our laboratory.
Dyslexic group: Six of the ten dyslexic subjects had their reading first assessed in our lab when they were children (ages 7.2 years to 14.2 years) by the Wide Range Achievement Test (WRAT) (Jastak & Jastak, 1965). Their scores from that first test met the criterion of being at least 1.5 years behind the grade appropriate to their age at that time, or if the age appropriate grade was three or below, the criterion was that the subject was a minimal reader, having been unable to read more than a few words on the WAIS. The Wide Range Achievement Test-Revised (WRAT-R) (Jastak & Wilkinson, 1984) was also administered to these subjects during their current testing sessions. The current ages of these six subjects ranged from 17.9 years to 26.7 years old.

The other four subjects in the dyslexic group only became available to our laboratory as adults (ages 20.6 years to 26.7 years) and their reading was assessed at that time by the WRAT-R. These subjects were selected to read at or below the 8th percentile for their respective ages. (Grade level comparisons are not practicable with adults.)

Control Group: Control subjects ranged in age from 18.2 to 31.25. The control subjects were selected to read at or above the 42%ile for their respective ages, as assessed by the WRAT-R.

Other Subjects: Three other subjects were also studied, although the data from their tests were not
employed in testing the experimental hypothesis. These three subjects were selected from our laboratory group because they were available during the period of testing. Although diagnosed in childhood as having reading difficulty by their teachers or by clinicians, the scores from their first tests in our laboratory (which led to their being classified as "borderline dyslexic") did not meet the criteria of this study.

Tests and Materials

Selection tests


2. The Wide Range Achievement Test (Jastak & Jastak, 1965) and the Wide Range Achievement Test-Revised (WRAT-R), (Jastak & Wilkinson, 1984). These are individually administered tests of single word recognition in which the subject reads aloud. The results allow comparison with a same-age reference group for adult subjects as well as for children. The WRAT-R was selected because it taps basic, almost mechanical, reading skills that are not dependent upon context or syntax.

3. Snellen Eye Chart Test.

4. Handedness test, which consisted of demonstration of hand used for the following 12 activities:
a. signing name legibly
   b. brushing teeth
   c. hammering a nail
   d. throwing a ball to hit a target
   e. holding a tennis racket
   f. sweeping floor (hand at top of broom)
   g. shovelling (hand at top of shovel)
   h. threading a needle (hand that guides)
   i. striking a match (hand that holds match)
   j. unscrewing a jar lid (hand that twists)
   k. dealing playing cards
   l. cutting paper with scissors

(These are the activities used by Annett (1967) in her verbal report handedness questionnaire.)

5. Stereopsis test.

Descriptive Tests

6. Gates-MacGinitie Reading Tests, Level F, Form 1 (MacGinitie, 1980). This is a test of comprehension in silent reading of paragraphs, in which the subject responds in writing to printed questions about paragraph content. It does not permit same-age reference group comparisons for adults, but the highest age norm (Grade 12) does permit comparisons that provide estimates of attainment.

7. Gray Oral Reading Tests, Form A (Gray, 1967). This is an individually administered oral paragraph reading
test. It provides descriptive data about the subject's oral reading speed, accuracy, and comprehension.

8. Boder Test of Reading-Spelling Patterns (Boder & Jarrico, 1982). This test classifies readers into various normal reader and dyslexic reader subtypes based upon oral reading of single words and upon spelling errors.

**Experimental Tests**

9. List of 200 nonsense words printed vertically on 8 1/2 x 11 inch bond paper. The nonsense words were chosen from a larger list of computer generated CVC's. Only those were selected that were not real words, not reminiscent of real words, and not familiar acronyms, as judged by the writer and two colleagues.

10. A Scientific Prototype Corporation three-channel mirror tachistoscope, on loan to our laboratory through the kindness of Dr. A. B. Kristofferson. The tachistoscope was modified for the purposes of this experiment so that the subject's eyes were illuminated and could be seen by the experimenter during a trial through a telescope that had been mounted on the opposite side of the tachistoscope. A shelf just above the subject's lap level was attached to the table supporting the tachistoscope. This shelf was used to hold response cards.

11. Cards used for presentation of stimuli in the tachistoscope and as response cards. These cards were made from blank index card stock, cut to approximately 13 cm. by
17 cm. to fit the tachistoscope's frames.

Stimuli cards for the verbal divided visual field task displayed two vertically oriented nonsense words, a different one in each visual field. When presented in the tachistoscope, the distance from the fixation dot at the center of the card to the vertical axis of the nonsense word subtended 1 degree 20 minutes, and each nonsense word subtended 2 degrees 18 minutes vertically. The horizontal axis of the nonsense words was positioned on the horizontal axis of the cards. Geotype brand Helvetica Bold pressure sensitive letters were used to form the nonsense words (see Figure 2).

For presentation of face stimuli 45 sets of cards were prepared. Each set was composed of a sample card for presentation of stimuli in the tachistoscope, and a response card. In all, 190 different pictures of faces were employed, 4 per set (two on the sample card, with those two and two others on the response card).

The faces displayed on the cards consisted of black and white photographs of primary-school-age Caucasian children. Obsolete negatives of individual student pictures were generously donated for this research by a major school photographic company. The pictures were printed in our laboratory so that hair and ears were obscured, and each was the same size and had the same outer contour. Pictures with distinctive characteristics (e.g.
Figure 2
Example of a Stimuli Card for Nonsense Word Test
(actual size)
eyeglasses, birthmarks, strong expressions) were not used. The pictures of different faces that comprised a set of cards were selected to be so similar that verbal description of a face would provide inadequate information to allow correctly identifying it.

A sample card had two different pictures of faces, one on either side of a central fixation dot (see figure 3). When presented in the tachistoscope, the faces were positioned with their horizontal midlines on the horizontal midlines of the card, the inner edges of the faces were offset from center by 1 degree 10 minutes, and the faces subtended 1 degree 39 minutes horizontally and 1 degree 50 minutes vertically.

A response card displayed four faces, the two faces from the corresponding sample card and two other faces (see figure 3). The faces were positioned near the center of the card, one in each quadrant. The positions on the response card of the left and right sample faces were counterbalanced across sets.

In all, 190 different pictures of faces were employed, 4 per set (two on the sample card, with those two and two others on the response card).
Figure 3
Example of a Stimuli Card and Response Card for Faces Test (reduced size)
Procedure

Faces DVF Test

The subject was seated before the viewing box of the tachistoscope and instructed in the procedure (see appendix A). A single trial proceeded as follows: The experimenter would view the subject's eyes through the telescope mounted on the tachistoscope to visually ascertain that the subject was fixated on a central dot, would say "Ready," and would then activate a switch that began the sequence of stimuli presentations that composed a trial. The faces sample card was exposed for 150 msec, followed by the fixation dot for 500 msec, followed by a leftward or rightward pointing arrow for 500 msec. The return of the fixation dot completed the sequence. The subject would place his clasped hands on one of the four faces on the response card to indicate his choice and then move his hands to the left or to the right to indicate understanding of the arrow direction.

Two practice trials were routinely given. This was sufficient practice for all subjects to perform correctly. Questions about the procedure were answered and the procedure re-explained if necessary. Illumination of the stimuli was constant across all exposures.

A written record of face selected and arrow direction indicated was kept. There were 20 trials with
target in the left and in the right visual fields respectively. Forty trials without procedural error were performed per subject. Data were discarded from trials in which the subject's eyes deviated from central fixation or trials where the subject incorrectly identified arrow direction and replacement trials performed employing targets in the appropriate visual fields. This occurred infrequently, approximately once in three different subjects.

The arrow direction was random with the constraint that the arrow did not point in the same direction more than three times in succession and one half of the subjects began with a leftward pointing arrow and one half with a rightward pointing arrow.

Order of stimuli sets was counterbalanced, as was target face within a stimuli set. Dyslexic and control subjects were yoked so that each yoked pair received the identical order of sets and order of arrow direction. Target face within a stimuli set was counterbalanced across yoked pairs.

Nonsense Word Pre-test Procedure.

The subject was given a 4 page list of 180 typewritten nonsense words, vertically printed in 5 columns. It was explained that the nonsense words were not actually words, that they had no meaning, but nevertheless could be pronounced. The subject was directed to read each
nonsense word aloud and the experimenter kept a record of acceptable pronunciations. If, as occasionally happened, a subject indicated recognition of a nonsense word as having a specialized meaning, it was not selected for the DVF task.

An acceptable pronunciation was any that followed standard English grapheme phoneme correspondences. For example, a nonsense word that began with the letter C could be pronounced with the hard or soft sound. The first 80 acceptable pronunciations defined the basic list of nonsense words to be used in the DVF test for a dyslexic group subject. The next six acceptable pronunciations defined the spare words, to be used if data from a trial had to be discarded because of procedural error. The 80 nonsense words were randomly assigned to the sample cards (described below) and to the left or right positions. This procedure resulted in each subject receiving DVF trials only with words he had demonstrated the ability to read, and precluded the possibility of error due to inability to perform the mental task. It also resulted in minor differences in the stimuli sets presented to subjects.

Control subjects were yoked with dyslexic subjects so that for every individual stimuli set presented to a dyslexic subject, one control subject received the identical set. Care was taken to ensure that control subjects had also demonstrated the ability to correctly
read aloud the nonsense words in the stimuli set each received.

Reading is not a unitary mental function, but clearly composed of a number of skills. These component skills may or may not be differently lateralized. The nonsense word test given to the subjects in this experiment is not a reading test (not necessarily representative of reading in general.) Rather it is intended as a test of processes known to be left lateralized in normal people.

**Nonsense Words DVF Test Procedure**

The subject was again seated before the tachistoscope and instructed in the procedure. Two practice trials were given to ensure understanding, and questions were solicited and answered. The experimenter would ascertain that the subject was fixating the central dot and would then say "ready," as a warning to the subject. The experimenter next activated the switch that began the sequence of stimuli presentations. The sample card displaying the two vertically oriented nonsense words was exposed for 150 msec., followed by the fixation dot for 500 msec., followed by a leftward or rightward pointing arrow. The subject then pronounced the nonsense word indicated by the arrow and moved his clenched hands to the left or right to indicate understanding of arrow direction. The subject's response was recorded by the experimenter.

Forty trials were routinely performed. There were
20 trials with target in the left and in the right visual fields respectively. Deviation from central fixation or incorrect identification of arrow direction necessitated replacing a trial approximately once in three different subjects. Two additional trials were performed with dyslexic subjects. If the data from a trial of a yoked control subject was discarded, the corresponding data was discarded from the dyslexic’s record and replaced with the data corresponding to the control’s replacement trial. Thus, the data used in analyses was from identical trials for each yoked pair, and consisted of 20 trials with the target word in the left visual field and 20 in the right.

Order of Tests:

Testing of dyslexic subjects took place during two sessions of approximately 2 1/2 hours each, and averaged 7 days apart.

Session 1: Handedness, visual acuity and stereopsis were assessed. The entire WAIS-R was then administered, followed by the WRAT-R, the oral reading portion of the Boder Test of Reading Spelling Patterns, and oral reading of the vertical CVC list.

Session 2: The DVF Faces test was administered, followed by the Gates-MacGinitie Reading Test, the Gray Oral Reading Test, and the spelling test of the Boder Test
of Reading-Spelling Patterns. The DVF nonsense word test was then administered.

When time constraints of individual subjects dictated doing so, the test order would be maintained, but certain tests would be administered in a different session. In such cases, the one exception to the standard order was that the DVF Faces test always began the second session.

Control group subjects received approximately three hours of testing. They first were assessed for handedness, visual acuity, and stereopsis. They were administered the DVF Faces test, followed by the nonsense word pre-test, the WAIS-R, the WRAT-R reading subtest and the DVF nonsense word test.
Chapter 6

RESULTS

Nonsense Words DVF Test

The analyses in the nonsense words DVF section are based upon only 8 of the dyslexic subjects. Two of the 10 dyslexic subjects were unable to perform the nonsense word pretest. Neither could read more than one nonsense word correctly among the first 45 attempted, and the experimenter aborted the test after 5 minutes in each case to avoid undue stress on these subjects.

The dyslexic and control groups did not differ significantly in overall (RVF + LVF) accuracy (F < 1.0), by a 2 (groups) X 2 (visual fields) mixed design analysis of variance. That finding justified performing nonsense word test analyses on the raw scores, as opposed to transforming the scores by a laterality index. The variances of the overall accuracy scores of each group did not differ significantly (F=1.802, d.f. = 9,7) by a test for differences between variances for independent samples. The
ANOVA revealed a significant visual field effect (F = 20.79, d.f. = 1, p < .001) such that accuracy over groups was greater in the right visual field. There was no significant group X visual field interaction. (See Table 2 and Figure 4.)

The data were then categorized by group and VFA (RVFA vs. not-RVFA). RVFA's were obtained by 7 of the 8 dyslexic subjects and by 8 of the 10 control subjects. Binomial tests on the data of the individual groups established that the distribution of subjects' visual field advantages were skewed within each group, with more subjects exhibiting a RVFA than not RVFA in each group (dyslexics p = 0.035; controls p = 0.547).

There was no significant difference between the groups in the proportion of subjects exhibiting a RVFA, by the Fisher Exact Probability Test (p > .05). (See Figures 5 & 6)

A t-test for independent groups performed on the absolute values of subjects' LVF score minus RVF scores revealed that the groups did not differ in degree of asymmetries.

The two dyslexic group subjects who could not perform the nonsense word pre-test were given a modified version of the nonsense word DVF test. The nonsense words most frequently used in testing the other subjects were presented in the standard procedure, but instead of
### TABLE 2

Nonsense Words Test ANOVA Summary Table
Groups X Visual Fields

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<thead>
<tr>
<th>Source</th>
<th>S.S.</th>
<th>d.f.</th>
<th>MS</th>
<th>F</th>
<th>p</th>
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</thead>
<tbody>
<tr>
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<td></td>
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<tr>
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<td>1</td>
<td>4.672</td>
<td>.625</td>
<td>n.s.</td>
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<td>7.363</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Within Ss</strong></td>
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<td></td>
<td></td>
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<tr>
<td>VF</td>
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<td>226.689</td>
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Descriptive Statistics:

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<th>LVF</th>
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<td>I 10</td>
<td>I 10.20</td>
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<td>I 62.90</td>
</tr>
<tr>
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<td>I 8</td>
<td>I 11.88</td>
<td>I 5.88</td>
</tr>
<tr>
<td>Subjects</td>
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<td>I 3.44</td>
<td>I 54.88</td>
<td>I 82.87</td>
</tr>
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<td></td>
<td>11.04</td>
<td>5.99</td>
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**Key**

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<th>I</th>
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<th>overall mean</th>
<th>std. dev.</th>
<th>SS</th>
<th>I</th>
<th>VF mean</th>
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<tr>
<td>I</td>
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<td>I</td>
<td>mean</td>
<td>overall mean</td>
<td>std. dev.</td>
<td>SS</td>
<td>I</td>
<td>VF mean</td>
</tr>
</tbody>
</table>
FIGURE 4

Nonsense Words Test Graph
Groups X Visual Fields

Number correct in VF

12.0
11.5
11.0
10.5
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0

Dyslexics

Controls

RVF

LVF
FIGURE 5

Distribution by Groups of Subjects with LVFA's, RVFA's and no VFA's on the Nonsense Words Test.
Figure 6
Number of Subjects Within Each Group Showing RVFA's and non-RVFA's in the Nonsense Word Test

non-RVFA  RVFA

Dyslexics

Controls

10 8 6 4 2 0 2 4 6 8 10
pronouncing the nonsense word, the subjects were instructed to spell it. A response was scored correct only if the three letters of the target nonsense word were reported accurately and in the correct sequence. These subjects scored 14 & 13 overall, out of a total possible score of 40. Both of these subjects showed numerically higher RVF than LVF scores. One of these subjects scored 6 LVF and 8 RVF, out of a total score of 20 for each visual field. The other subject scored 5 in the LVF and 8 in the RVF, again out of total possible scores of 20 in each visual field.

**Faces DVF Test**

A 2 (groups) x 2 (visual fields) analysis of variances revealed no significant difference between groups in overall (LVF + RVF) accuracy in the faces test (F = 2.917, d.f. = 18). That finding justified performing all further faces test analyses on the raw scores, as opposed to transforming the scores by a laterality index. The variances of the overall accuracy scores of each group did not differ significantly (F=2.058, d.f. = 9,9) by a test for differences between variance for independent samples. The ANOVA revealed a significant visual field effect (F = 5.853, d.f. = 1, p. <.025) such that accuracy across groups was greater in the left visual field. The group X visual field interaction was significant at the p. = .07 level (F= 3.596, d.f. = 1). A Newman-Keuls multiple comparison test
compared to the RVF (p. < .01), whereas no such difference was found with dyslexics (see Table 3 and Figure 7). There was no significant difference between groups in their LVF scores, but the dyslexics performed significantly better in the RVF than did the controls (p. < .05).

The data were then categorized by group and VFA (LVFA vs. non-LVFA). LVFA's were obtained by 5 of the 10 dyslexic subjects and by 6 of the 10 control subjects. Binomial tests on the data of the individual groups did not reveal that the distribution of visual field advantages was skewed (see Figure 8).

There was no significant difference between the groups in the proportion of subjects exhibiting a LVFA, by the Fisher Exact Probability Test (p. > .05), as one would expect (see Figure 9).

A t-test for independent groups performed on the absolute values of LVF minus RVF revealed that the groups differed in degree of asymmetries (t = 1.82, d.f. 18, p. < .05), with the control subjects exhibiting larger asymmetries (see Figure 10).

Descriptive Reading Tests

No patterns of performance on the three descriptive reading tests (Bader Test, Gates Oral Reading, Gates McGinitie) were found to be related to behavioural asymmetries or overall performance on the tachistoscopic tests, by visual inspection of the reading data.
### TABLE 3

**Faces Test ANOVA Summary Table**

**Groups X Visual Fields**

<table>
<thead>
<tr>
<th>Source</th>
<th>S.S.</th>
<th>d.f.</th>
<th>MS</th>
<th>F</th>
<th>p.</th>
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<tbody>
<tr>
<td><strong>Between Ss</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Group</td>
<td>24.025</td>
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<td>24.025</td>
<td>2.917</td>
<td>n.s.</td>
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<tr>
<td>Error</td>
<td>148.250</td>
<td>18</td>
<td>8.236</td>
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<tr>
<td><strong>Within Ss</strong></td>
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<td></td>
</tr>
<tr>
<td>VF</td>
<td>34.225</td>
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<td><strong>Total</strong></td>
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**Descriptive Statistics:**

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<tr>
<td>I N</td>
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<td>I std.dev.</td>
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<td></td>
</tr>
<tr>
<td>I SS</td>
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</tr>
</tbody>
</table>

VF mean
FIGURE 7

Faces Test
Groups X Visual Fields

Number correct in a VF

RVF
LVF

p = N.S.

p < 0.05

dyslexics

p < 0.01

controls
FIGURE 8

Distribution by Groups of Subjects with LVFA's, RVFA's and no VFA's on the Faces Test.
Figure 9
Number of Subjects Within Each Group Showing LVFA's and non-LVFA's in the Faces Test

<table>
<thead>
<tr>
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<th>Dyslexics</th>
<th>Controls</th>
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</thead>
<tbody>
<tr>
<td>non-RVFA</td>
<td>6</td>
<td>8</td>
</tr>
<tr>
<td>RVFA</td>
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<td>6</td>
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<tr>
<td></td>
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<td>4</td>
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<td></td>
<td>0</td>
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</table>

10 8 6 4 2 0 2 4 6 8 10
FIGURE 10

Numbers of Subjects in Each Group at Different Degrees of Asymmetry, Faces Test

**Dyslexics**

![Bar graph showing the number of subjects in the dyslexic group at different LVF-RVF difference scores.]

**Controls**

![Bar graph showing the number of subjects in the control group at different LVF-RVF difference scores.]

LVF-RVF difference score
Discussion

It has sometimes been alleged that developmental dyslexia is not distinct from other well established reading disorders, and that dyslexics may merely represent the lower end of a continuum of achievement. The dyslexic subjects in this experiment were carefully selected to include only those with whom were associated no known causes of reading failure. The experiment was designed in intricate detail to avoid the spurious effects often associated with testing groups hypothesized to differ on one factor (functional organization) and known to differ on another factor (reading achievement). The results from this experiment suggest that dyslexics are qualitatively distinct from normal readers in the constitutional factor of functional organization of their brains.
**Left Hemisphere Specialization**

**Group Means Comparisons**

The nonsense words DVF task was designed to foster equal overall performance between groups. Most earlier experiments found differences between groups in the overall score, making interpretation of the results difficult. In the present experiment, as worked for, there was no significant difference in the overall scores of the controls and the dyslexics. The mean performance of the dyslexics was actually somewhat higher than controls’ performance.

DVF tests using verbal stimuli are commonly interpreted as indicating the lateralization for speech. RVFA’s are considered to indicate left hemisphere specialisation for speech and language functions. Both the dyslexic and control subjects in the present study exhibited a strong and significant RVFA. An informal indication of the strength of the asymmetry is that the mean RVF score over groups was nearly double the LVF score. Few DVF studies with verbal stimuli have obtained such strong asymmetries. The strong RVFA’s in both groups are interpreted as indicating that the left hemisphere is the major hemisphere for speech and language in both normal and dyslexic readers.
That interpretation must be tempered by realization that the DVF test with nonsense words likely tapped only one small aspect of the repertoire of language and speech skills in these subjects, and that different differences within and between groups might be obtained with different verbal tasks.

**Left Hemisphere Dysfunction**

Witelson (1977) proposed that dyslexics, although normally lateralized for verbal processes, might nevertheless have left hemispheres that are deficient in their processing. This hypothesis was based on Witelson's finding of 1) normal left hemisphere lateralization of verbal functions in a dichotic listening test and 2) impaired overall performance relative to normals. No such overall impairment was found in the present experiment. This is not surprising, however, as equating overall performance was a goal of the manipulations in this experiment, in order to make valid comparisons of asymmetries on the basis of raw scores, without using a laterality index. Equal levels of overall accuracy on the nonsense word test in the present experiment do not logically imply that dyslexics read as well as normal people! The results of their reading tests (see Table 1) establish that these subjects are indeed poor readers.
That information along with the finding of normal left hemisphere localization for a verbal process provide support for the hypothesis that the left hemisphere in the dyslexic brain may process deficiently.

**Frequency Comparisons**

No differences between the groups were found in the frequency comparisons (RVFA vs. notRVFA). Both groups showed the same distribution, skewed toward RVFA's. This confirms the conclusions based on group means of no differences between the groups for lateralization of verbal functions, and left hemisphere specialization for the processing of nonsense words.

**Right Hemisphere Specialization**

**Group Means Comparisons**

For the DVF Faces test no manipulations were employed that would help ensure equal levels of overall performance between groups, simply because there is no theoretical reason to expect differences; the literature provides empirical support for this assumption. There was not, in fact, any difference in the overall accuracy, again permitting a clear comparison of the asymmetries of the
groups, without the necessity of transforming the data by a laterality index.

Control subjects exhibited the expected LVFA, which is interpreted as evidence of right hemisphere specialization for the processing required to perform the task. Dyslexics exhibited no behavioural asymmetry. This is interpreted as evidence that the processing involved in this task is bilaterally represented in their brains.

Of interest is the fact that the control subjects and the dyslexic subjects performed at the same accuracy level with LVF stimuli, but the controls were significantly reduced in accuracy for RVF stimuli as compared to dyslexics. It appears that dyslexics may have the typical right hemisphere functions also represented in the left hemisphere, permitting performance with the RVF stimuli. Representation in one hemisphere of functions that are typically represented in two different hemispheres has been hypothesized to account for the deficient performance of the normally lateralized left hemisphere (Witelson, 1977). The results of the present experiment support that interpretation.

The performance of the control subjects raises a question about the relative roles of the hemispheres in the processing required for the faces task. The chance level of performance for the task is a score of 5 per VF. The mean level of performance in the RVF was 6.5 for controls.
This level is relatively close to the chance level; in no other visual field x group condition did the scores approach chance levels. If the procedure of presenting stimuli bilaterally results in each hemisphere being occupied with processing its respective stimuli, so that there is little or no resource left to process information channelled from the other hemisphere, the task may resemble the presentation of stimuli to split-brain patients. In this case, one would expect that the hemisphere that is not specialized for a type of processing would perform at chance levels. The results suggest that not only is the right hemisphere more involved in processing the face stimuli than the left hemisphere, but also that the left hemisphere may not be able to do it at all. Further studies with larger groups might address this issue statistically. If the speculation that the procedure mimics the split brain condition is true, the procedure is a valuable tool for investigation of functional specialization.

**Frequency Comparisons**

Frequency comparisons in which groups were compared for numbers of subjects exhibiting RVFA's vs. number not exhibiting RVFAs indicated no difference between the two groups for processing of faces. Inspection of the data
indicates a slight trend toward controls being represented more in the LVFA category, but the numbers are far from conclusive. Comparing the relative numbers in both groups in the faces test with the same relative numbers in both groups in the nonsense word test indicates that both groups show less asymmetry in the faces test. Right hemisphere effects have traditionally been difficult to find with normal subjects, and most investigators are content with showing less asymmetry for spatial than for verbal tasks. However, because the trend is present in the faces test, it would seem wise to pursue further study with larger groups to address the question through analysis of frequency data.

Conclusions

The results indicate that adult dyslexics may have atypical functional organization of their brains, with normal lateralization of verbal functions and atypical representation of spatial functions (to the extent that these functions are represented by the experimental tasks). The data provide some support for the hypothesis that the atypical representation of spatial functions in dyslexics may be implicated in deficient left hemisphere verbal processing. There is insufficient theoretical ground for choosing a method of analysis of the data, and different analytical perspectives led to somewhat different
conclusions regarding the present experiment. Increased numbers of subjects in each group, so that the frequency as well as the group means methods of analysis may be used with confidence, should provide more conclusive results.
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