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PURDUE PEGBOARD PERFORMANCE AND REACTION TIME IN RESPONSE TO LATERALIZED VISUAL STIMULI IN READING DISABLED AND NORMAL CHILDREN

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PURDUE PEGBOARD PERFORMANCE AND REACTION TIME IN RESPONSE TO LATERALIZED VISUAL STIMULI IN READING DISABLED AND NORMAL CHILDREN

by

SUSAN CHERYL LESLIE

A dissertation submitted to the Graduate Faculty in Psychology in partial fulfillment of the requirements for the degree of Doctor of Philosophy, The City University of New York.

1987

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Abstract

PURDUE PEGBOARD PERFORMANCE AND REACTION TIME IN RESPONSE TO LATERALIZED VISUAL STIMULI IN READING DISABLED AND NORMAL CHILDREN

by

Susan Cheryl Leslie

Advisor: Professor Howard Ehrlichman

The purpose of the present study was to apply measures of motor behavior and behavioral estimates of interhemispheric transmission time (IHTT) derived from simple manual reaction time to the study of differences between reading disabled and normal readers. The first phase of this study examined the performance of 25 carefully selected reading disabled and 25 male control subjects, ages 9-12 years, on the peg placement section of the Purdue Pegboard Test (PPT). A significant Group x Condition interaction was obtained and indicated that disabled readers performed worse than controls in the unimanual, but not in the bimanual condition. Simple manual reaction time was also obtained from each group in response to checkerboards, which were randomly presented to each visual field. The conditions were blocked by the hand of response. An estimate of interhemispheric transmission time (IHTT) was derived by subtracting the median reaction time obtained in the ipsilateral hand-visual field condition from the median reaction time obtained in the contralateral condition. The results indicated no overall difference in reaction time between the groups. As expected, a significant Hand x Visual field interaction emerged, demonstrating faster reaction times in the anatomically predicted direction. No other significant interactions were obtained. Correlational data indicated that longer IHTTs were associated with better reading performance, particularly for the dyslexics. The implications of these data for hypotheses that argue for left hemisphere dysfunction, as well as those that posit interhemispheric transfer deficits in reading disabled children are discussed.

The second phase of this study examined test-retest reliability of the PPT and group differences in subtle motor behaviors that were demonstrated during PPT performance. A subsample of 19 disabled and 19 normal readers returned to participate in a re-administration and videotaping of the PPT. Test-retest reliabilities were moderately high and most were significant. The Group x Condition interaction that was found in the first administration was not significant upon readministration. However, group differences did emerge in more subtle indices of behavioral performance, which, importantly, were not reflected in the overall PPT score.

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This manuscript represents only one aspect of a larger four year multifaceted study on reading disabilities that was conducted in the Laboratory of Cognitive Psychobiology at SUNY Purchase, under the supervision of Dr. Richard Davidson. As such, it is naturally the case that this project would not have been possible without the concerted effort of many people. I owe special thanks to Orit Batey for her contribution to the development of our psychometric battery and for her role in screening and testing our subjects. I would like to also thank Marshall Gladstone for his help in testing subjects. I would also like to extend a very special thank you to my colleague and friend, Clifford Saron, for his major (and often lonely) role in creating and orchestrating the implementation of laboratory procedures. I would also like to express my deep respect and appreciation to James Long who, by utilizing his expertise in the writing of software programs, simplified, routinized and thus organized the process of data acquisition. Special thanks to those SUNY Purchase undergraduates who helped to code and analyze the data. In particular, I will always be indebted to my dear friend, Carol Shilliday, for having undertaken a major role in running subjects and analyzing data. In addition, she most graciously extended herself well above and beyond the call of professional duty by helping to type, proof and xerox this manuscript.

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CHAPTER I

Introduction

During the last few decades, the literature on the relation between reading disabilities and the cerebral hemispheres has expanded at an exceedingly rapid rate. Several hypotheses have been formulated from this massive amount of data to account for the neurological bases of specific reading disabilities, and generally fall into three basic categories: 1. Incomplete/delayed cerebral lateralization; 2. Left hemisphere dysfunction and/or; 3. A deficit in interhemispheric communication.

Incomplete/delayed lateralization

Orton (1937) was the first to posit a relation between cerebral functional lateralization and reading disability. Based on his clinical observations of an increased incidence of left-handedness, incomplete handedness and/or crossed hand and eye dominance in reading disabled populations, he hypothesized that lateralization of language in the left hemisphere of poor readers is incomplete and results in competition for expression between the two hemispheres. Orton proposed that the right hemisphere's normally inhibited store of inverted symbols becomes expressed as a function of this competition and leads to letter and word reversals. Although Orton's notion of suppressed reversed memory images in the right hemisphere during reading is implausible today, he did recognize that inhibitory processes may be important for skill acquisition (Dennis, 1983).

One major flaw in Orton's theory was the heavy reliance on the extent of peripheral laterality preferences (e.g., handedness, eyedness and footedness) for making inferences concerning central laterality (Dennis, 1983). Similar to warnings that have been issued concerning the use of the magnitude of a perceptual laterality effect (dichotic listening and visual half field measures) as an index of the degree of hemispheric specialization (Kinsbourne and Hiscock, 1978), several theorists have argued that variables in addition to cerebral laterality may influence the extent of peripheral lateral preferences (e.g., Bryden, 1982). Orton claimed that poorly established motor preferences signalled a diffuse representation of language in the cerebral hemispheres. However, as Dennis (1983) points out, the incidence of bilateral speech representation as assessed by sodium amytal techniques is much lower than would be predicted on the basis of peripheral measures of laterality.

Despite the rejection of several aspects of Orton's theory, the notion of incomplete lateralization in reading disabled children has remained in the literature and has been attributed by some authors to a "lag" in the "normal" developmental progression of hemispheric specialization. This particular extension of the incomplete lateralization theory originally gained popularity when Lenneberg (1967) advanced his theory on the maturation of cerebral dominance

(Kershner, Henninger and Cooke, 1984). Lenneberg claimed that the cerebral hemispheres were equipotential at birth and that lateralization of language functions to the left hemisphere progressed throughout childhood. Lenneberg's theory was based primarily on Basser's (1962) findings of a higher incidence of dysphasia in children (35%) than in adults (1-3%) following right hemisphere damage. Also children as compared to adults have been shown to have a faster and more complete recovery following left hemisphere aphasia - producing insults.

However, too few cases of dysphasia in children subsequent to right hemisphere damage have been reported for conclusions to be made concerning the development of lateralization. As Bryden (1982) points out, the diagnosis of aphasia varies from study to study and the possibility of undetected damage to the left hemisphere cannot be ruled out. Also, evidence from individuals who sustained early brain damage and subsequently demonstrated less severe cognitive impairments as compared to their adult counterparts, could be interpreted as reflecting age-related decreasing neural plasticity rather than increasing hemispheric specialization. As Witelson (1985b) points out, the concepts of specialization and plasticity have often been confounded theoretically, when in fact they are distinct features of the brain. Although both neural characteristics are present at birth, specialization is believed to remain constant throughout life while plasticity decreases with age. Evidence of developmental changes in the normal course of lateralization must be demonstrated before claims of a delay in the lateralization of language in poor readers can be made.

In contrast to Lenneberg's notion of equipotentiality at birth, various sources of evidence have demonstrated the presence of structural as well as functional cerebral asymmetries in the neonate. Morphological studies, for example, have uncovered hemispheric differences in language-mediating areas (temporal planum) in newborns (Witelson and Pallie, 1973), which are similar to asymmetries found in adults (Geschwind and Levitsky, 1968). Findings from electrophysiological and behavioral techniques have demonstrated a greater left hemispheric response to speech in infants (Entus, 1976; Gardiner and Walter, 1977; Molfese, 1977). Early removal of the left hemisphere has been found to result in language deficits that are not present following early right hemisphere removal (Dennis and Whitaker, 1977). Taken together, the findings suggest that there is cerebral specialization in the newborn and that the functional potential of the two hemispheres for language are not equal. After having reviewed studies involving auditory and visual perception, motor performance and electrophysiological measures with children of all ages, Witelson (1977) in agreement with others (e.g., Kinsbourne and Hiscock, 1978; Bryden, 1982) concludes that lateralization of language functions does not progress throughout development. According to Witelson (1977), what does progress is the child's cognitive repertoire rather than the degree of lateralization.

In sum, there is presently little evidence to suggest that hemispheric specialization of language functions is a developmental process. In spite of this, however, it is still argued that reading disabilities result from a lag in the development of functional lateralization. Proponents of this developmental lag hypothesis base their claim largely on findings which demonstrate magnitude differences in the right ear advantage (REA) on dichotic digit tasks between older (age 11-12) groups of normal and disabled readers. According to the developmental lag hypothesis, group differences in the magnitude of the asymmetry effect do not become apparent until around early puberty when hemispheric speech lateralization is almost complete (Satz, 1976). However, very little evidence implicates puberty as the critical time at which language functions are established (Bryden 1982), and most importantly, in contrast to the maturational lag hypothesis, magnitude differences between younger groups (e.g. aged 7-8) of disabled and normal readers have been found (Marcel, Katz, and Smith, 1974).

While it is unlikely that a reading disability stems from a maturational anomaly, it may still be possible that initially poor hemispheric specialization contributes to the dysfunction. However, results from studies investigating the presence and magnitude of asymmetry effects in reading disabled children are highly inconsistent. Several perceptual laterality studies have in fact failed to find the typical left hemisphere advantage in poor readers when processing verbal material (e.g., Leong, 1976; Thomson, 1976;

Witelson and Rabinovitch, 1972), suggesting poorly lateralized functions. On the other hand, others have found behavioral asymmetries among dyslexics that are comparable in magnitude to, or larger than, those observed in normal readers (Bryden 1970; Yeni-Komshian et al, 1975; Witleson, 1976), suggesting that language functions are normally lateralized in poor readers. This inconsistency in the literature is largely due to methodological problems that are associated with the various perceptual techniques used to assess cerebral dominance (See Naylor, 1980 and Satz, 1976). In Bryden's (1982) critique of perceptual laterality measures, he pinpoints several factors that may influence the direction and/or magnitude of observed laterality effects, and underscores the need to control for these factors. In dichotic listening studies, for example, variables such as order of report, biases in attention allocation, and lateral differences in perceptual acuity and perhaps in memory storage have been identified as possible confounds. Given these methodological problems, it is difficult to evaluate the claim that disabled readers are poorly lateralized for language functions.

Left hemisphere dysfunction

Several studies have found that dyslexics perform more poorly compared with controls on measures which purportedly reflect the integrity of the left hemisphere (See Doehring, 1976). Findings from these studies have been interpreted by many to suggest that a left hemisphere dysfunction rather than incomplete cerebral lateralization underlies certain types of reading disabilities. For example, reading disabled children have been found to perform more poorly compared with controls on tasks which require naming of visually presented objects (Denckla and Rudel, 1976; Denckla, Rudel and Broman, 1981), processing verbal material at the semantic, syntactic and phonological levels (e.g., Vellutino, 1978) and perceiving temporal order in verbal stimuli (Bakker, 1972).

Gordon (1980) has claimed to contribute evidence to the left hemisphere deficit hypothesis by demonstrating that dyslexic children perform better on tests of right hemisphere function as compared to performance on tests of left hemisphere function. He also found reading ability to be correlated with overall cognitive performance in the dyslexic group but not in the control group. Gordon has interpreted these findings as suggesting that dyslexics are "locked into a right hemisphere mode of processing" (p. 653). In Gordon's study, a maximum of five "left hemisphere" tasks were administered. Twelve dyslexic children (ten males and two females) and 13 control children (apparently all male) were included in the study. Not all subjects, however, took all tests. Unfortunately the number of subjects included in each average score was not reported. When percentile scores are calculated from the reported average z-scores, it is easily seen, as Gordon reports, that dyslexics perform better on right hemisphere tests than on left hemisphere tests. In contrast, performance level appears to be equal on left and right hemisphere tests for the control group. Between group differences appear to emerge on the right hemisphere tests where dyslexics generally score higher than the controls. However the pattern of performance level among the left hemisphere tasks is not consistent between the two groups. According to the reported values, two of the left hemisphere tasks did not discriminate between the dyslexic and control samples (i.e., circles test and word production). Mean z-scores for a third left hemisphere test (digit span-numbers) were not reported. The left hemisphere test that discriminated the best between the dyslexic and control group was the serial sounds test, which involves the presentation of eight easily recognizable sounds in varying sequences. The subject is required to list (or report verbally if unable to write) the sounds in the order presented. As Rudel (1985) points out, while sequencing is a skill that is better performed by the left hemisphere, recognizing environmental sounds is better performed by the right hemisphere. Rudel thus suggests that poor performance on this particular task may be due to either a unilateral dysfunction and/or to interference with right to left interhemispheric transfer. Results from Gordon's study, therefore, do not clearly indicate the presence of a unilateral left hemisphere dysfunction in dyslexic children.

Evidence from the motor domain has also been used to support a left hemisphere deficit hypothesis in reading disabled children. A number of workers have reported that dyslexic children perform more poorly compared with controls on tasks requiring motor sequencing and fine manual dexterity (Gardner and Broman, 1979; Leslie, Davidson and Batey, 1985; Rourke, Yanni, MacDonald and Young, 1973; Zurif and Carson, 1970). As described below, these functions have also been found to be under the control of the left hemisphere in adults.

Left hemisphere and motor skills

Hugo Liepmann, in the early part of this century, was the first to describe disorders that resulted from destruction of the corpus callosum (see Geschwind, 1975). He observed a patient who in the presence of normal comprehension and adequate motor strength bilaterally, was unable to perform skilled movements to verbal commands with his left hand. His right hand, however, demonstrated intact motor function. Based upon a series of similar clinical observations, Liepmann hypothesized that the left hemisphere of right handed individuals possessed a specialized capacity for motor programming and that damage to the corpus callosum prevented the left hemisphere from exerting any influence over the left hand via the right hemisphere (See Taylor and Heilman, 1980). Liepmann also observed that this patient failed to improve on imitation with his left hand, and concluded that the left hemisphere of right handed individuals contained the memories or engrams of skilled movements (See Heilman, Schwartz and Geschwind, 1975).

Various motor skills in normal and clinical samples have been investigated in an attempt to evaluate the theory of left hemisphere motor dominance. Wyke (1968), for example, studied arm-hand movements that require adequate timing and precision in patients with either left- or right-sided lesions and in a healthy control group. Her subjects were required to touch targets with an electric stylus as they appeared 1 cm equidistant from each other on a revolving turntable. The results demonstrated that left arm-hand performance of patients with right-sided lesions and no visual field defects was inferior to the controls' left arm-hand performance. This finding is in accordance with anatomical predictions since the distal musculature is controlled predominantly by the contralateral hemisphere (Brinkman and Kuypers, 1973). Bilateral impairment, however, occured in patients with left hemisphere damage, indicating bilateral dominance of fine movements by the left hemisphere.

Additional support for Liepmann's notion that the left hemisphere has control of certain motor skills has been demonstrated by Kimura and Archibald (1974). These investigators have shown impaired bilateral performance in a group of left hemisphere damaged patients relative to right hemisphere damaged patients on a task requiring the copying of unfamiliar sequences of hand movements.

Findings from normal subjects have also been marshalled in support of Liepmann's hypothesis. Taylor and Heilman (1980) have shown that normal dextral subjects exhibit superior right as compared to left hand performance on a sequential key pressing task. These data were interpreted as reflecting left hemisphere dominance for sequential motor skills. Taken together, these findings from clinical and normal populations have contributed to the claim that the left hemisphere has bilateral control of motor sequencing and dexterity (Heilman, 1979; Geschwind, 1975; Taylor and Heilman, 1980).

Left hemisphere dominance, however, is not implicated for all motor skills. Kimura and Archibald (1974), for example, found that although their left hemisphere damaged group was impaired in copying sequences of hand movements (as reported above), this group was not deficient compared to the right hemisphere damaged group on finger flexion and copying of static hand posture tasks. The presence of dissociative effects of left hemisphere damage on various motor tasks implies that generalized statements concerning the left hemisphere's role in motor functioning need to be issued with caution. Geschwind (1975) has described multiple motor systems of the brain, each with its own site of origin and differential involvement in particular motor behaviors. Motor functioning is thus the integration of complex behaviors which may stem from independent systems.

Factor analytic studies of psychomotor skills have supported the view of multiple motor systems. Fleishman and Hempel (1956), for example, extracted ten factors from the intercorrelations among twenty-three selected psychomotor test variables. Their two largest factors were interpreted as representing: I) the ability to control fine movements; and II) coordination of gross movements. Interestingly, a separate factor emerged (i.e., factor V - "integration") which represented the ability to perform tasks that require simultaneous movements with more than one body member (e.g., two hands). The significance of this finding will be discussed in a later section.

Possible asymmetric effects of hemispheric damage

Normally, the brain functions as a dynamic, hierarchically structured, interdependent system which gives rise to a continuous flow and exchange of information. Behavior is the result of the concerted action of multiple neural subsystems (Luria, 1973). Behavior subsequent to injury represents not only a disconnection of specific neural substrates (Geschwind, 1975), but also a reorganization of the unimpaired functional systems (Luria, 1973). Given this highly interconnected system, it is expected that lesions to a particular region would effect the functioning of areas to which the damaged neurons send and/or receive impulses.

Few investigations have addressed the issue of neuronal degeneration in response to injury and the potential effects of this process on observable behavior. Geschwind (1974) has warned that neuronal degeneration is more prevalent in the central nervous system than previously thought. Retrograde and orthograde degeneration have been demonstrated in various parts of the central nervous system using staining procedures (e.g., Nauta; Horseradish peroxidase) and autoradiographic techniques. Orthograde transneuronal degeneration was first observed in the visual cortex of primates. It had been demonstrated that following section of the optic nerve, retinal terminals in the lateral geniculate nucleus of the thalamus degenerated rapidly. Transneuronal degeneration has also been shown to work in a retrograde direction. For example, lesions in the visual cortex will cause neurons in the lateral geniculate nucleus to degenerate severely. Importantly, degeneration does not occur in all brain pathways and the extent and speed with which a neuron degenerates varies (See Kelly, 1981).

Interestingly, data have shown differences between the right and left cerebral hemispheres with respect to their neuronal connections. A higher gray to white matter ratio has been found in left prefrontal areas than in right prefrontal areas (Gur, Packer, Hungerbueler, Reivich, Obrist, Amarnek and Sackeim, 1980). Goldberg and Costa (1981) have interpreted these findings as representing greater interregional connections in the right hemisphere and greater intraregional connections in the left. They suggest that multimodal representation of information in the right hemisphere makes it well suited for the coding of novel information. On the other hand, greater intramodal representation predisposes the left hemisphere to superiority in tasks requiring a single mode of representation or execution. Skill acquisition, therefore, is proposed to operate from a right to left gradient. These authors are thus suggesting that the structure of the neuronal network directly influences the functional nature of the hemisphere's contribution to the processing of information.

Morphological evidence has recently been reported which also suggests a relation between neuronal connectivity and hemispheric functioning. Witelson (1985a), based on postmortem examinations, demonstrated differences in the size of specific areas (not including the splenium) of the corpus callosum among various handedness groups. Variables such as handedness (e.g., Bryden, 1982), familial sinistrality (e.g., McKeever, 1979), sex (McGlone, 1980) and hand posture (e.g., Levy and Reid, 1976) have previously been identified as possible contributors to variation in patterns of hemispheric specialization. Witelson's morphological data suggest that the neural bases for individual differences in hemispheric specialization may lie in the degree to which the cerebral hemispheres are anatomically connected to each other.

If there are differences between the cerebral hemispheres in terms of their connectivity to each other and to other systems, then one might expect hemispheric asymmetries in the degenerative process with respect to the extent and severity of the response to injury. In other words, it is possible that identical lesions in homologous areas of the cortex may have asymmetrical degenerative effects on other structures due to perhaps the withdrawal of trophic factors. For example, damage to the left hemisphere may differentially affect the corpus callosum due to the underlying network of anatomical connections. Behavioral deficits such as impaired sequential motor skills subsequent to this injury might then be due to the combined effect of left hemisphere damage and disturbance of the corpus callosum. Thus, behavior subsequent to discrete unilateral damage would therefore be the result <u>not</u> only of loss of input from the specialized hemisphere but also of 1. disruption or destruction of input from connected areas; as well as 2. a reorganization of the remaining intact areas. An example of this latter case may be witnessed from the crude approximations of discrete movements in individual limbs of patients subsequent to loss of input from the pyramidal system. Geschwind (1975) suggests that these approximations represent the nonpyramidal system's attempt to compensate for the inactive system.

In sum, poor performance by reading disabled children on purportedly left hemisphere skills has been interpreted as reflecting a left hemisphere dysfunction. However, the functional integrity of other anatomically related systems should be evaluated before any statements regarding causality can be made.

Hemispheric specialization versus hemispheric activation

The notion of hemispheric specialization is a complex one with many unresolved questions (See Bradshaw and Nettleton, 1981). One problem has been the lack of dissociation in studies between the concepts of hemispheric specialization and hemispheric activation. Hemispheric specialization typically refers to the degree to which the hemispheres are differentially competent in subserving various cognitive functions. According to Pribram and McGuinness (1975), activation refers to the system's physiological readiness to respond. With few exceptions, these concepts have typically been investigated independently, although both have been invoked to explain similar phenomenon (i.e., perceptual asymmetries and behavior subsequent to unilateral brain damage).

The hypothesis of hemispheric asymmetry in activation has been put forth in an attempt to explain reaction time differences found between unilateral brain damaged groups. Heilman and Van Den Abell (1979), for instance, have hypothesized that the finding of slower simple manual reaction times with right as compared to left hemisphere damaged groups (e.g., Howes and Boller, 1975) is indicative of right hemisphere dominance of activation. They tested this hypothesis in normal right handed subjects by administering a lateralized warning stimulus prior to central reaction time stimuli. It was assumed that a warning stimulus prepares an individual for action (or facilitates activation) and would therefore reduce reaction times. Their results demonstrated that warning stimuli presented to the right hemisphere reduced reaction times of the ipsilateral hand more than warning stimuli presented to the left hemisphere. Furthermore, right hand reaction times were found to be shorter when warning stimuli were presented to the right hemisphere rather than directly to the left hemisphere. Heilman and Van Den Abell (1979) have interpreted these results as indicating that the right hemisphere dominates activation.

In contrast, Tucker and Williamson (1984), based upon asymmetries in neurotransmitter activity, have suggested that activation is intimately related to the left hemisphere, whereas arousal is more associated with right hemisphere operations. They suggest that a warning stimulus, such as the one used in Heilman and Van Den Abell's (1979) study, involves an orienting response similar to what Pribram and McGuinness (1975) term "arousal" rather than "activation". The arousal system is described as producing a phasic response to input and orients the brain to novel stimuli. Activation conversely, maintains a tonic readiness for action (vigilance) in the absence of external stimuli. Heilman and Van Den Abell's findings are therefore interpreted as representing right hemispheric specialization for arousal. Interestingly, Tucker and Williamson conceptualize hemispheric specialization for attention in terms of left hemispheric specialization for motor readiness (activation) and right hemispheric specialization for perceptual responsiveness (arousal).

It is not within the scope of the present report to evaluate the literature on attention, activation and hemispheric specialization. However, the point to be stressed is that any study investigating differences in hemispheric specialization should simultaneously consider possible task and state related differences in hemispheric activation. It is quite possible that either a positive or negative finding of group differences in performance of a particular task may be related to differences in hemispheric activation in addition to differences in hemispheric specialization.

Differences in activation asymmetry have been addressed at the individual level. In a recent study, Sackeim, Weiman and Grega (1984) examined the relation between predictors of hemispheric specialization (e.g., handedness, sex, familial sinistrality, writing posture, and sighting dominance) and a predictor of characteristic activation (e.g., conjugate lateral eye movements). These investigators found that each predictor of hemispheric specialization accounted for at least some portion of the variance in the direction of LEMs following verbal and spatial questions. It has therefore been suggested that patterns of characteristic activation asymmetry should be examined prior to attributing asymmetrical performance solely to differences in functional specialization.

Levy (1985) has suggested that individual differences in patterns of hemispheric specialization may, in fact, be dependent upon the normal regulation of attention and arousal between the cerebral hemispheres. Based upon evidence from acallosal, split-brain, and normal subjects, Levy has theorized that the balance of arousal and allocation of attention between the hemispheres is an important function of the corpus callosum. She speculates that the corpus callosum serves both an inhibitory and facilitory role in the organization of each hemisphere's specialization. It is proposed that initially each hemisphere is equipped with primary and secondary programs of functional specialization. Normally, as the corpus callosum matures, increased integration between the two hemispheres serves to cause an elaboration of each primary program while the secondary program regresses into a more supportive role. Anatomical data suggesting naturally occuring commissural neuronal degeneration (e.g., cell death and axonal elimination) during neurogenesis has in fact been demonstrated in newborn kittens

(Innocenti, 1979). Whether or not this neuronal regression is intimately related to functional specialization is unknown. However, the notion of neuronal connectivity exerting direct influence over hemispheric specialization, as already mentioned, has been proposed (i.e., Goldberg and Costa, 1981; Witelson, 1985a). What Levy's model offers is the additional suggestion that the functions of the corpus callosum, such as regulating arousal and allocating attention, may be directly related to the patterning of hemispheric specialization.

It is generally accepted that the left hemisphere is specialized for certain motor skills, particularly those involving sequential movements. However, the majority of studies investigating left hemisphere specialization of these skills have not examined the possible influences of hemispheric activation on motor performance. Perhaps left hemisphere damage not only affects the skills for which this hemisphere is specialized, but in addition, serves to disrupt through differential neuronal connectivity the regulatory capacities of the corpus callosum. Although this is all speculation, the point to be stressed is that caution must be taken when interpreting findings from clinical populations solely with reference to hemispheric specialization.

Motor and language functions

Motor functioning and language skills have been linked conceptually by many investigators (e.g., Bradshaw and Nettleton, 1981; Levy, 1969). Corballis (1983) has suggested that left-hemispheric specialization for language and manual skills may have a common origin in a basic specialization for sequencing and fine temporal programming. Studdert-Kennedy (1981) has hypothesized that left hemispheric specialization of language arose from an initial specialization of coordinated hand movements. He suggested that the neural substrate required for motor functioning was identical to that type of circuitry necessary for control of a bilaterally innervated speech mechanism. Similarly, Kimura (1979), in a discussion of the evolution of vocal and manual communication systems in humans, has suggested that the left hemisphere became specialized for precise sequential limb positioning in conjunction with asymmetrical manual activity related to tool usage. She postulates that, if as indeed the evidence suggests, vocal communication was a later evolutionary development, it would come under the control of the already specialized motor apparatus of the left hemisphere.

Evidence from a variety of sources has in fact suggested that certain manual activities and language functions may utilize common neural substrates in the left hemisphere. Lomas and Kimura (1976), for example, demonstrated a bilateral decrement in performance by normal subjects on a single finger tapping task when concurrently speaking. A concurrent non-speech humming task, however, had no effect on the performance of either hand. Presumably, the concurrent verbal task as opposed to the non-verbal task interfered with motor performance because of its reliance on left hemisphere mechanisms. This finding was interpreted as reflecting an interaction between speech movements and bilateral hand representation at the level of discrete movement control in the left hemisphere.

An alternative interpretation, however, may be put forth to account for these data, which is based on the frequent failure to control for capacity interference in task interference paradigms. That is, performance levels may drop because the primary (e.g., finger tapping) and interference (e.g., speaking or humming) tasks performed together may exceed the overall capacity of the information processing system (Bryden, 1982). Lomas and Kimura's (1976) finding that finger tapping decreased bilaterally when concurrently speaking in contrast to humming may simply reflect differences in task difficulty rather than differences in the underlying functional asymmetries. In other words, finger tapping while speaking may be more difficult and therefore exceeds the system's capacity more so than finger tapping while humming. Clearly task difficulty must be controlled for in dual-task experiments before interpretations regarding underlying asymmetries are made.

Nevertheless, Kimura has contributed additional support for the notion of a close association between the neural substrates in the left hemisphere involved in the control of producing specific manual and oral movements. In another study, Kimura (1977) compared aphasic and nonaphasic adult patients with left hemisphere damage on a manual sequencing task. Her results indicated that while performance by both groups was impaired compared to the performance of a right hemisphere damaged group, the aphasic left hemisphere group performed more poorly than the non-aphasic group.

The relation between the representation of motor and language processes in the left hemisphere may also be evaluated by studies investigating apraxia. Almost all cases of apraxia in right handed adults are associated with left rather than right hemisphere lesions (Geschwind, 1965; Goodglass and Kaplan, 1963). It has also been well established that the left hemisphere is dominant for language functions in the majority of right handers. The occurrence of apraxia, therefore, is often associated with the occurrence of aphasia, and it is probable that for at least certain apraxias and aphasias the neural substrates overlap. However, apraxia and aphasia have also been shown to occur independently of each other (e.g., Goodglass and Kaplan, 1963; Heilman, Coyle, Gonyea, and Geschwind, 1973; Heilman, 1975), making the relation between language and motor systems in the adult less clear. This finding does suggest that the right hemisphere has the ability to substitute for the left hemisphere's visuokinesthetic engrams for skilled movements (Heilman, 1975). This also highlights the fact that neither aphasia nor apraxia is a unitary disorder and may have only some overlap in discrete parts of the adult cortex.

In sum, observations from normal and clinical adult populations have shown that the left hemisphere has control in programming at least certain motor abilities. In addition, the neural bases of particular language and motor skills in the left hemisphere appear to be closely associated, although the exact nature of this relation remains unclear. These findings regarding the organization of the left hemisphere in the adult have been extended to children and inferences have been made concerning the neural bases of reading disabilities in children with motor deficits. Specifically, as previously mentioned, the finding of motor dysfunctions in reading disabled children, especially those with a language-based reading disability, has been used to support the hypothesis of a left hemisphere deficit. One potential flaw in this line of reasoning, however, is the inherent danger in applying adult models of brain organization to children (Dennis, 1983). In generalizing from a mature nervous system to an immature system, parallels are drawn between the neural substrates involved in an acquired versus developing process. Luria (1973) states very specifically that the cerebral organization subserving a particular process changes in the course of development. In reference to the development of higher mental functions in ontogeny, he writes "...participation of the auditory and visual areas of the cortex, essential in the early stages of formation....[of a particular process]...no longer is necessary in its later stages and the activity starts to depend on a different system of concertedly working zones." (1973, p. 32). The organization and neural systems involved in the acquisition of a particular skill, therefore, are believed to differ from those which are involved in the performance of an acquired skill. This principle has been applied to both the motor (Bernstein, 1967) and language domains (Goldberg and Costa, 1981).

Nevertheless, while findings from the motor and cognitive domain generally support the interpretation of a left hemisphere dysfunction, neuroanatomical evidence (Galaburda and Kemper, 1979) and results from topographic mapping of brain electrical activity (Duffy, Denckla, Bartels, Sandini, and Kiessling, 1980) have demonstrated abnormalities in both the left and right hemispheres of dyslexic children. In addition to being cautious in drawing parallels between the neural patterning in adults and children it is also necessary to demonstrate an intact right hemisphere before inferences are made concerning the organization and integrity of the left hemisphere. Very few studies have attempted to demonstrate unimpaired right hemisphere functioning in the presence of left hemisphere dysfunction. This evidence is needed before conclusions are reached regarding the role of the left hemisphere in the etiology of dyslexia.

Interhemispheric communication deficit

More recently, several workers have hypothesized that poor readers may suffer from dysfunctions in transferring information between the cerebral hemispheres. In a series of studies, Wolff and colleagues (Badian and Wolff, 1977; Klicpera, Wolff and Drake, 1981; Wolff, Cohen and Drake, 1984) compared the performance of reading disabled boys to controls in various hand conditions of a metronome entraining task. In general, the conditions that involved tapping to the metronome with either hand alone or both hands simultaneously did not discriminate between the two subject groups. However, reading disabled children were found to perform more poorly compared to controls on tapping tasks involving temporal sequences of hand alternations. Performance of hand alternations was particularly poor for the left hand. Klicpera and colleagues (1981) reasoned that a left hemisphere dysfunction hypothesis would not account for their data since tapping with either hand alone or with both hands simultaneously was not deficient in the reading disabled group. Implicit in this line of reasoning is the assumption that performance of unimanual tapping and synchronous bimanual tapping is reflective of the integrity of the left hemisphere. This assumption may not always hold true for certain areas of damage as will be demonstrated below. The authors did interpret the findings of a between group difference in performance on the hand alternation task as reflecting a deficit in interhemispheric communication, possibly due to faulty callosal functioning. Implicit in this interpretation is the assumption that performance of asynchronous alternating bimanual finger movements is more indicative of callosal functioning. This interpretation is based on findings from commissurotomized patients, which suggested that certain types of bimanual coordination may be dependent upon the integrity of the corpus callosum (Kreuter, Kinsbourne and Trevarthen, 1972). Other studies have also investigated the role played by the corpus callosum in particular bimanual coordination tasks and will be discussed below.

Bimanual coordination tasks and the corpus callosum

Kreuter, Kinsbourne and Trevarthen (1972), demonstrated that commissurotomized subjects as compared to normals obtained lower rates of finger tapping in finger alternation as well as in finger synchronization conditions. In fact, the lowest rates were obtained when these patients tapped the right and left fingers simultaneously. The implication of these findings is that both types of bimanual coordination movements (i.e., synchronous and alternating finger tapping) are dependent, in part, upon the integrity of the corpus callosum. However, the possibility that brain damage, as Kreuter et al. (1972) warn, contributed to performance differences between the controls and commissurotomized subjects in the bimanual conditions (i.e., synchronous and asynchronous) cannot be ruled out. In fact, all five of the commissurotomized patients were epileptic. It is also noteworthy that while two of the five commissurotomized patients (A.A. and C.C.) were observed to have signs of considerable left hemisphere damage, their single right hand tapping scores were almost identical to their left hand tapping scores, and had tapping rates for each hand that were within the range of those scores that were obtained by the other three commissurotomized patients. This implies that the unimanual tapping rates may not have accurately reflected the extent of the cortical damage. Kreuter and coworkers interpret their finding of deficient synchronous and asynchronous tapping rates in commissurotomized subjects as reflecting a disconnection between the left hemisphere's specialized ability for higher rates of finger tapping and the left hand. However, it is unclear whether this functional disconnection is due exclusively to the physical separation of the two hemispheres or also due to damage of the left hemisphere. Perhaps the addition of a left hemisphere damage control group would have aided in the dissociation of the extent to which the left hemisphere and the corpus callosum play a role in producing high rates of synchronous and asynchronous bimanual finger taps.

The results from Kreuter and coworkers (1972) study have several implications for the aforementioned study by Klicpera et al. (1981) which investigated bimanual motor coordination in reading disabled and control children. To begin with, in light of the findings based upon the commissurotomized subjects, inefficient callosal functioning would be predicted to disrupt both asynchronous as well as synchronous bimanual finger tapping skills. However, as previously mentioned, performance differences between the poor and normal readers emerged only in the asynchronous finger tapping condition. That is, no difference in tapping rates when using both hands simultaneously occurred between the subject groups. It could be argued that the particular type of callosal deficit, if present in the reading disabled group, affects performance on perhaps more difficult types of bimanual coordination tasks (e.g., alternation tapping). But at the present time this is speculation and would need to be explored further. An additional implication for Klicpera and collegues' interpretation concerns their rejection of a left hemisphere deficit hypothesis on the basis of no between group differences in the unimanual tapping conditions. As previously demonstrated, unimanual tapping did not accurately reflect the extent of the cortical damage in at least two commissurotomized subjects. This suggests that the finding of no difference in unimanual tapping between reading disabled and control children does not necessarily rule out the presence of unilateral dysfunction. In other words, a left hemisphere deficit could have contributed to poor finger alternation tapping in the reading disabled sample. Perhaps the administration of more than one measure is necessary for an accurate portrayal of a hemisphere's functional status.

Additional evidence supporting the importance of the role of the corpus callosum in bimanual motor coordination has been demonstrated. Preilowski (1972) studied bilateral motor coordination in two patients in whom the anterior commissure and the anterior two thirds of the corpus callosum had been sectioned to control intractable epilepsy. These patients demonstrated inferior performance compared to controls on a task that required the drawing of a straight line in a narrow track on an X-Y plotter. Successful performance of this task required coordination between the hands in moving the vertical and horizontal handles attached to the pen. Simultaneous movement of these handles produced pen movements in any direction. Preilowski suggested that the sectioned structures are directly involved in the interhemispheric interaction of motor coordination. Similarly, patients with agenesis of the corpus callosum have been found to be deficient in the acquisition of novel bimanual skills (Ferriss and Dorsen, 1975). Unfortunately, neither of these studies, as in the aforementioned Kreuter et al. (1972) study, included a left hemisphere damaged group for comparison purposes. If bimanual coordination depends solely upon adequate functioning of the corpus callosum, then presumably a left hemisphere damaged noncommissurotomized group would perform at a slightly higher level than the groups with damage to or absence of the corpus callosum.

Studies on commissurotomized and acallosal subjects have thus suggested that bimanual coordination appears to be dependent, in part, upon the functional integrity of the corpus callosum. One crucial function of the corpus callosum is to regulate the flow of information between the cerebral hemispheres. Deficits in bimanual coordination have thus been interpreted as reflecting deficient interhemispheric communication.

It is likely, however, that interhemispheric communication depends upon, in addition to the cerebral commissures, the functional integrity of other neural structures. If so, then this would imply that a disturbance other than a structural lesion in the corpus callosum may disrupt communication between the hemispheres. Disruption in the left hemisphere, for example, may disturb interhemispheric communication if specialized input from the left hemisphere is not received. It is also conceivable that a dysfunction in the left hemisphere, while still able to function adequately, disrupts callosal efficiency due to it's neuronal connections. In other words, a disturbance in one system may lead to a functional disruption of another. Thus, to describe deficient performance on a particular task as reflecting poor interhemispheric integration, is not necessarily identifying the underlying neural substrates responsible for the deficiency. More accurate understanding of the neural processes involved in particular tasks, such as various types of bimanual coordination, is needed.

Interestingly, Wyke (1971) performed a study investigating bimanual coordination which provides an example of how damage to areas other than the corpus callosum may contribute to a deficit in interhemispheric communication. Wyke found adult patients with left hemisphere damage to be inferior to patients with right hemisphere damage in acquiring (i.e., over five successive trials) and performing a bimanual coordination task. Patients with right hemisphere damage made significantly more errors than normal controls, but only on the first two trials. There was no difference in performance level between the right hemisphere damaged group and the control group on trials four and five. In contrast, the left hemisphere damage group performed worse than the right hemisphere damaged group and controls on all five trials. The bimanual coordination task used in this study involved simultaneous manipulation by each hand of two moveable bars that were mounted to a pen. The subject was required to coordinate the movements of the two arms together but in different directions and at different speeds in order to obtain the desired drawing. Wyke interpreted her results as suggesting "that the left cerebral hemisphere is dominant in the control of voluntary movements involving mutual dependence and continuous interaction of the left and right arm" (p. 68). Alternatively, it may be argued that damage to the left hemisphere, due to the underlying neuronal network, affected callosal efficiency to a greater extent than did damage to the right hemisphere. Again, the roles played by the left hemisphere and the corpus callosum need to be disentangled before conclusions can be made concerning the significance of deficient performance on various bimanual tasks.

Findings outside the motor domain have also been marshalled in support of an interhemispheric communication deficit hypothesis in reading disabled children. Other investigators have reported that dyslexic children perform more poorly compared with controls in response to information presented directly to the right hemisphere to which a verbal response has to be made. Yeni-Komshian et al. (1975), for example, found that although the two groups performed at the same level of accuracy on a verbal recognition task when linguistic stimuli (numerals and words) were presented to the RVF, the poor readers had significant difficulties when the same material was presented to the LVF. Presumably this latter condition requires both: 1) intact right hemisphere functioning; as well as 2) interhemispheric transfer since the input to which subjects must respond is presented to the hemisphere that is not directly involved in the control of the verbal response. These authors interpret their data as indicating the presence of a right hemisphere dysfunction and/or a deficit in interhemispheric communication in the reading disabled group. In another study, Gross, Rothenberg, Schottenfeld and Drake (1978) demonstrated that identification of briefly flashed single letters to the visual fields separately resulted in higher visual threshold asymmetries for the dyslexics compared to the controls. The mean duration threshold for the dyslexic sample was significantly higher for left hemifield stimuli as compared to right hemifield stimuli. In contrast, no difference in mean duration thresholds for left and right hemifield stimuli emerged for the control group. Gross-Glenn and Rothenberg (1984) replicated these findings in a subgroup of their dyslexic sample and interpreted their results as reflecting a deficit in interhemispheric transfer of information in dyslexic boys. Similarly, in a dichotic listening study, Obrzut et al. (1981) demonstrated an inability for poor readers, unlike normal controls, to obtain a right ear advantage when attention was directed to the left ear. However, they did obtain the expected right ear advantage when attention was not directed. These findings have been interpreted as reflecting a deficit in callosal functioning in reading disabled children that interferes with their ability to process information simultaneously. These investigators reasoned that a deficit in callosal functioning results in minimal communication between the hemispheres.

Consequently, the normally inhibiting dominant left hemisphere is prevented from suppressing linguistic information coming from the nondominant ear. As a result, when attention is directed to the left ear, the nondominant hemisphere operates relatively independently of the left hemisphere's influence, and gives rise to a left ear advantage.

Interhemispheric deficit -What is it?

While a deficit in interhemispheric communication has been postulated to underlie particular reading problems, the precise mechanism contributing to this biobehavioral dysfunction has not yet been specified. One way in which the hemispheres would fail to efficiently communicate with each other is if information decays as it is crossing the commissures. This type of dysfunction might result in either a slowing of a required response, since the necessary information is presumably incomplete, and it might increase the likelihood of errors. Another potentially disruptive source of efficient interhemispheric communication is in the timing mechanism. It is possible that information is received by a particular hemisphere outside a critical time period, which would disrupt the integration of information. In other words, it is conceivable that the system is timed so precisely that either an acceleration or a slowing of information transfer could result in interhemispheric processing deficiencies. The behavioral manifestation of this type of dysfunction, as similar to that predicted by the decay model, would be an increase in errors and/or a slowing of response since the ability to consolidate information from various functional systems would be interrupted. It may be the case that both a timing dysfunction as well as information degradation contribute to inefficient communication between the hemispheres. These two possible mechanisms may not be mutually exclusive and may coexist in perhaps parallel or sequential form. It is not within the aim of the present study to clearly identify the mechanisms which may be operating in an interhemispheric transfer deficit. However, a timing malfunction, if present, might affect the speed of signal transmission across the commissures. There is no reason to expect that a deficit involving the degradation of information would also affect the speed with which the information is being transferred. Also, the present study is not designed to determine the cause of either an information degradation problem or a timing malfunction. That is, whether these dysfunctions are a product of a structural lesion in the callosum itself or in areas which are connected via complex neuronal networks should be addressed more directly in future research. However, if dyslexics have a generalized deficit in interhemispheric communication, then they would be expected to show slower response times and perhaps greater errors as compared to controls on tasks that require this process. In addition, if a timing dysfunction is present, then dyslexics would be expected to show interhemispheric transmission times (IHTT) that are different (i.e., either slower or faster) from normal controls when signals necessary for task performance must be transferred.

Inconsistencies in the literature

Despite the amount of research that has been conducted, an adequate model explaining the neural substrates of dyslexia has not yet been developed. One reason for this is due to the inconsistency with which dyslexia is defined from study to study (Benton, 1975; Vellutino, 1978). Several investigators have emphasized that dyslexia is not a unitary syndrome and that due to the complexity of the reading process different etiologies may underlie a reading disability (Boder, 1970; Doehring, 1976; Mattis, French and Rapin, 1975). If so, variability in subject selection criteria would contribute to the problem of non-replicable findings across studies.

Methodological issues have also contributed to the inconsistency in results from studies investigating the hemispheric dysfunctions in dyslexia (Naylor, 1980; Satz, 1976). One issue has to do with the fact that measures used to assess cerebral lateralization are often administered in different ways, making data from different studies noncomparable. For example, dichotic listening tasks have been administered using a free recall procedure (see Bryden, 1982) in some studies and a fixed ear order procedure in other studies (e.g., Yeni-Komshian, et al., 1975). Given the recent findings suggesting possible attentional differences between dyslexics and controls (Obrzut, Hynd, Obrzut and Pirozzolo, 1981) these different procedures will likely produce inconsistent results.

Similarly, divided visual field tasks have been administered using a horizontal orientation of verbal stimuli in some studies (e.g., Marcel, Katz and Smith, 1974) and a vertical orientation of verbal stimuli in other studies (e.g., Yeni-Komshian, 1975). Since there has been some suggestion that dyslexics may differ from controls in ocular scanning patterns (Zangwill and Blakemore, 1972), these procedural differences are likely to produce variable results among studies.

The present experiment

This study was designed to test for the presence of a left hemisphere dysfunction and a deficit in interhemispheric transfer in a group of carefully selected disabled readers, whose difficulties are primarily language based. This particular group was selected for two reasons: 1) language disabled children, exhibiting naming deficits especially, account for the largest percentage of reading disabled children compared with all other identified subgroups (Denckla, 1977; Doehring, Hoshko and Bryans, 1979; Mattis, French, and Rapin, 1975); and 2) due to the problems associated with perceptual measures of laterality, it was desirable to examine hemispheric functioning through the motor domain. Based on the theoretical arguments stated previously, the neural bases of particular language and motor skills in the left hemisphere appear to be closely related. Deficits in motor performance, therefore, would be expected in a group of children with language based reading difficulties. In contrast, although not tested in the present study, no difference in motor performance would be expected between normal readers and readers with perceptually based difficulties.

The Purdue Pegboard Test (PPT) is a measure of fine manual dexterity and coordination. It was chosen to examine various aspects of motor ability due to it's effectiveness in differentiating various clinical populations from normal controls. Costa and colleagues (Costa, Vaughan, Levita and Farber, 1963), for example, have demonstrated the utility of this measure as an indicator of the presence and laterality of brain damage in adults. This measure has also been used to discriminate brain damaged, retarded (Rapin, Tourk and Costa, 1966) and learning disabled (Gardner and Broman, 1979) children from normal control children.

The PPT has been shown to correlate with other indices of sensorimotor performance, and unlike other perceptual and cognitive tasks, is relatively independent of educational level in normals (Costa et al., 1963). It appears, therefore, to be a potentially useful instrument for exploring differences in hemispheric functioning between reading disabled and control groups.

Gardner and Broman (1979) have in fact found differences between a group of MBD children and normal controls on all PPT conditions. However, apparently only a previously existing diagnosis of MBD was required for subject inclusion. It is likely, therefore, that their sample of experimental subjects represented a heterogeneous group of learning disabled children with differing underlying etiologies. It is not yet known whether fine motor sequencing skills are deficient for all learning disabled groups or for only specific subtypes.

In addition, questions regarding the specific differences between learning disabled and normal control children in the relations among the three hand conditions (dominant, non-dominant and bimanual) have not yet been explored. Since different neural mechanisms might be invoked in the performance of each of the three hand conditions, it would be important to compare the two groups in their specific patterns of performance among the conditions. If dyslexics do have a left hemisphere dysfunction, then it is expected that performance will be worse compared to the controls in the dominant and nondominant hand conditions since the left hemisphere presumably specializes in the programming of fine manual dexterity and sequential manual skills.[1] It is unclear to what extent the bimanual hand condition is under primary control of the left hemisphere. As previously mentioned, the performance of various bimanual tasks have been hypothesized to depend upon the integrity of other neural structures (e.g., corpus callosum). Although, the bimanual condition, like the unimanual conditions, involves sequencing skills and fine manual dexterity, this condition also involves repetitive synchronization of mirrored hand movements. It is conceivable that a subtle left hemisphere deficit would not be reflected in performance of this task due to perhaps a greater reliance on the other structures that might be involved. Therefore, no prediction will be made concerning between group differences on the bimanual condition. If, however, an interhemispheric transfer deficit related to a callosal dysfunction underlies language based reading disabilities, then it is predicted that: 1) the right hand condition will not discriminate between the poor readers and controls since the distal musculature of the right hand is directly under left hemisphere control and therefore is not dependent upon interhemispheric communication; and 2) dyslexics will perform more poorly than controls on the left hand condition. This prediction is based on the notion that left hemisphere motor commands are required to cross the corpus callosum in order to activate the motor area in the right hemisphere that controls left hand movements. Again, no prediction will be made concerning the performance of the dyslexics compared to the controls on the bimanual condition.

Aside from the left hand Purdue condition which is hypothesized to require interhemispheric transfer, another and perhaps more systematically studied measure of interhemispheric transfer was administered. Manual reaction time was assessed in response to simple visual stimuli (checkerboards) that were randomly presented to the left and right visual fields. Although it is unclear which aspect of interhemispheric transfer is being assessed in the PPT (e.g., speed or signal quality), it is assumed that the time it takes (i.e., speed) to transfer the command is assessed when interhemispheric transfer is measured using reaction time. The assumption underlying simple manual reaction time as an index of interhemispheric transfer time (IHTT) is that information presented initially to the left visual field (LVF) will be responded to more quickly by the left rather than the right hand. This is based on the fact that LVF information is directly projected to the right hemisphere. The right hemisphere also has direct access to the distal musculature of the left hand. The left hand, therefore, would receive the command to respond more quickly than the right hand. In contrast, stimuli that are presented directly to the right visual field (RVF) will be responded to more quickly by the right rather than the left hand. In other words, ipsilateral hand-visual field combinations are associated with faster reaction times compared to contralateral hand-visual field combinations (e.g., Berlucchi, Heron, Hyman, Rizzolatti and Umilta, 1971). The mean difference in reaction time between the ipsilateral and contralateral combinations are indicative of the estimated time it takes for information to cross the cerebral commissures (IHTT). This mean difference in adults for simple manual reaction time is reported to be approximately 2.5 msec (Bashore, 1981; Berlucchi et al., 1971; Milner and Lines, 1982). Longer and more variable estimates of IHTT are reported when they are derived from measures of simple vocal reaction time. According to Milner and Lines (1982), values of IHTT based upon vocal reaction time have ranged from 7 msec to 33 msec. The discrepancy between vocal and manual estimates of IHTT are presumed to reflect transmission across different callosal routes. Milner and Lines (1982) demonstrated that manual reaction time estimates of IHTT, in contrast to vocal reaction time estimates, are not sensitive to variations in stimulus intensity. They therefore propose that manual reaction time involves interhemispheric relay across the more anterior motor regions, whereas vocal reaction time tasks involve transmission through a "sensory" route. Longer IHTT estimates based upon vocal as opposed to manual reaction time is believed to be due to slower signal transmission across the visual relative to the motor regions.

Since it is assumed that the interhemispheric transfer condition of the PPT involves the motor regions primarily, manual reaction time was believed to be an appropriate additional measure for comparison purposes. To date, the PPT has not been related to reaction time measures of IHTT. As described above, estimates of IHTT based upon RT assesses the speed with which information is transferred between the hemispheres. The component of interhemispheric transmission that is assessed in the left hand condition of the PPT is less clear. Perhaps this assessment of interhemispheric communication reflects information concerning initiation and precision of the hand movements. If speed is also a factor that is assessed by the left hand condition of the PPT, then this condition should be correlated with the contralateral hand-visual field reaction time conditions. This relation is expected to be particularly strong in the condition where visual stimuli are presented to the RVF and a response is required from the left hand.

This condition requires information transfer from the left to right hemisphere, which is similar to the hypothesized requirements involved in the left hand condition of the PPT.

Some have argued that spatial compatability plays some role in the improvement in reaction time associated with the ipsilateral hand-visual field conditions (e.g., Broadbent, 1974). In order to evaluate the effects of spatial compatability, many studies have been performed that have systematically manipulated the side of the body on which the subject is instructed to place his hand. Several studies have found that when this is done in simple reaction time tasks, the anatomically predicted effects are still obtained. That is, irrespective of where the hand is actually placed in space, faster reaction times are obtained with ipsilateral visual field-hand combinations (Anzola, Bertoloni, Buchtel and Rizzolatti, 1977; Berlucchi, Crea, DiStefano and Tassinari, 1977). In order to evaluate the effects of spatial compatability in the present experiment, the position of the responding hand was manipulated. Stimuli were presented to the visual fields separately while the responding hand was placed either straight out in front of the subject or across the midline to the opposite side of the body.

In sum, it is hypothesized that:

A. If dyslexics have a left hemisphere dysfunction which affects at least certain motor subsystems, then:

1. Between group differences on the PPT would be expected such that dyslexics perform poorly in the dominant and nondominant

conditions as compared to the controls. This hypothesis is based on the literature which suggests that the left hemisphere controls the programming of sequential motor abilities. A left hemisphere dysfunction would presumably disrupt certain left hemisphere skills. No prediction will be made concerning the effect of a left hemisphere deficit in the bimanual condition.

2. Between group differences in reaction time would be expected when simple visual stimuli are presented directly to the left hemisphere (RVF), irrespective of the responding hand. Similarly, a between group difference would be expected when simple visual stimuli are presented directly to the right hemisphere (LVF) and a right hand response is required. It is hypothesized that a dysfunction in the left hemisphere would interfere with, to some degree, this hemisphere's ability to perceive, program and execute the desired manual response. No between group differences in reaction time are expected when stimuli are presented to the right hemisphere and the left hand is responding. This hypothesis is based on the fact that the reaction time task in the present experiment involves a finger lift in response to the presentation of simple visual stimuli. This type of manual response predominantly involves the distal musculature. Since the distal musculature is subserved primarily by the contralateral hemisphere, then the right hemisphere is hypothesized to be dominant in this particular condition (i.e., LVF - left hand).

B. If dyslexics have an interhemispheric transfer deficit, then:

1. Based on the previous discussion, dyslexics are expected to perform more poorly than controls on the left hand condition of the PPT. However, no between group differences are expected in the dominant hand condition.

2. IHTTs as computed from reaction time are expected to differ for the dyslexics and controls if the underlying deficit is related to a timing dysfunction.

3. Left hand performance on the PPT is expected to be correlated with IHTT values. The direction of this relation will not be predicted since it is unknown whether faster or slower transfer time is associated with better PPT performance.

CHAPTER II

METHOD

Subjects

Fifty males from an initial group of 118 subjects were selected on the basis of their performance on a battery of neuropsychological tests to participate in a larger ongoing laboratory study of interhemispheric transfer time. (See Appendix A for a description of the psychometric tests). Subjects were included only if they scored 70% or higher in the right-handed direction on the Harris test of Lateral Dominance (Harris, 1958) and were between the ages of 9 and 12 years. Half of the subjects were reading disabled (N=25, M age=11.19, SD=1.16) and half were normal readers (N=25, M age=11.18, SD=1.11). Subjects came from school districts in Westchester County, New York. All children were from either middle or upper middle income families.

All subjects had to obtain a full scale IQ of 90 or above on the WISC-R (Wechsler, 1974) in order to participate. In addition, all subjects were required to score 85 or above on performance IQ and achieve a scaled score of 7 or above on the Block Design subtest. The PIQ and Block Design criteria were established to exclude those children with perceptually based learning disabilities. Other criteria common to both groups included: 1. Scoring at or above the 17th percentile on the quiet condition of the Goldman, Fristoe and Woodcock Test of Auditory Discrimination

(Goldman, Fristoe and Woodcock, 1970). This criterion served to screen out any subject with gross auditory impairment; 2. Eliminating any subject with obvious emotional or neurological problems (e.g., seizures, meningitis, encephalitis) or with a history of such problems; 3. Eliminating those subjects who took medication with known CNS effects for longer than 6 months or those subjects who were currently taking such medication; and 4. Eliminating any subject who was adopted due to lack of adequate historical information.

To select a sample of reading disabled children whose disorder was primarily language-based, only those dyslexics were included who scored one standard deviation or more below the mean on at least one of two naming tests: the Visual Naming subtest from the Neurosensory Comprehensive Examination for Aphasia (Spreen and Benton, 1977) and/or any of the four subtests of the Rapid Automatized Naming Test (Denckla and Rudel, 1976).

A child was considered reading disabled if he scored .85 or below on the reading quotient proposed by Myklebust (1968): (2 x Reading Age)/(Mental Age + Chronological Age). A child qualified as a control subject if he scored .95 or above on the same reading quotient and if he also scored less than one year below actual grade level on all of the reading tests which were administered. The mental age used in the Myklebust formula was derived from the WISC-R and the reading age was derived from the Word Identification subtest from the Woodcock Reading Mastery Tests (Woodcock, 1973).

In an effort to determine whether the dyslexics had an attentional dysfunction in addition to their reading disability, the performance of each group on the noise subtest of the Goldman, Fristoe and Woodcock (1970) Test of Auditory Discrimination was compared. This test provides a measure of the degree to which auditory attention is compromised by the presence of background noise. On this test, dyslexics were found to perform similarly to controls (M for dyslexics=45th percentile, M for controls=45th percentile, $t<1$). The dyslexic sample, therefore, did not show any gross dysfunction in attentional performance. Table 1 presents the psychometric data for the dyslexic and control samples. (All tables are presented in Appendix B).

These criteria, then, were devised to select only those reading disabled children who exhibited both naming and decoding deficits. It is important to note that this sample may represent only a subset of those children who exhibit decoding problems. Generalizations, therefore, from this sample to other groups of children with language based deficits should be made with caution.

Procedure

The PPT was administered during the first of two three hour psychometric sessions, which were held on separate days. The peg placement section of the Purdue was administered according to the instructions in the test manual (Tiffin, 1968). The number of pegs the subject placed, first using his preferred hand (i.e., the right hand) then his non-preferred hand and finally both hands simultaneously, was recorded. The order in which the three hand conditions were administered was identical to that used by Gardner and Broman (1979).

Simple manual reaction time was obtained from the subject in a separate session on a different day. Due to the possible effects of spatial compatability as previously mentioned, the simple stimuli were presented in both straight and crossed hand conditions. A total of 4 conditions were run which involved responses to checkerboards: 1. straight right hand; 2. straight left hand; 3. crossed right hand (the right hand is crossed in front of the body toward the subject's left side); and 4. crossed left hand (the left hand is crossed in front of the body toward the subject's right side). In the crossed hand conditions, the arms were actually crossed with the responding arm placed over the other arm. The order in which each of these four conditions were presented was counterbalanced across subjects.

The visual stimuli were 3.6° vertical by 3° checkerboard flashes presented 2.9° from a central fixation target for 10 msec. The stimuli were rear-projected using Kodak Carousel projectors fitted with Gerbrands electronic shutters and controlled by Coulbourn digital logic. White noise of 90db SPL (at one foot) was used in the projection room to mask the sound of the shutters. The subject was seated 50 inches from the rear projection screen upon which the stimuli were presented. In order to insure consistent location of stimulus presentation, subjects were required to place their heads in a chin rest, with a forehead restraint. The intensity of the visual stimuli was 4.75 ft candles. The background illumination of the screen was .75 ft candles. The ambient light at the subject's eyes was 9 foot candles. Each condition consisted of the presentation of 200 trials, half randomly presented to the RVF and half to the LVF. Each condition was preceded by approximately 25 practice trials. The inter-trial interval varied randomly between 1.5 and 3.5 seconds. An experimenter was in the subject room at all times and stopped the trial presentation if the subject was not attentive. The experimenter also allowed periodic breaks, dictated by the subject's state. The subjects were required to fixate on a central point. Eye movements were monitored with a video camera which provided a close-up image of the subject's eyes. The monitor was viewed by the experimenter in the subject room and he/she depressed a button whenever the subject was not centrally fixating. This button press automatically flagged the data from that trial (on the data acquisition computer) only if the eye movement was coincident with the stimulus presentation and eliminated the trial from analysis.

Subjects were required to respond to the stimulus by lifting their index finger off a momentary contact switch. The decision to use a finger lift as the motor response was based on previous research which used this particular response to produce estimates of IHTT (Milner and Lines, 1982). Subjects were instructed to return the button to the pressed position immediately after they made their response. The button was individually placed for each subject to accommodate a range of different arm and finger lengths. Individual placement of the button was accomplished by using a table with holes cut out every 2 cm. Placement of the left and right hand buttons were determined separately for the straight and crossed hand conditions.

An IBM PC acquired the reaction time data on-line. The computer determined the time from the stimulus presentation to the finger lift to an accuracy of .1 msec. The computer calculated the mean and median reaction time for each of the experimental conditions. It also plotted a histogram of the response latencies so that the shape of the distribution could be examined. Evaluation of these histograms revealed positively skewed distributions. Therefore, median rather than mean reaction time values were subjected to analysis. Trials on which the reaction time was less than 100 msec were eliminated as these were considered to have been initiated prior to actually perceiving the stimulus.

The data were reduced by computing medians of the reaction time for each of the hand-visual field combinations. Estimates of IHTT were derived by subtracting the reaction time in response to one visual field from the reaction time in response to the other visual field for each hand condition.

PPT Readministration

In an effort to examine test-retest reliability, the PPT was readministered to a subgroup of the original 50 subjects approximately one year following the initial testing. An attempt was also made during this time to systematically identify and evaluate patterns of motor behavior that might not be reflected in the standardized PPT score. To this end, performance of the PPT was videotaped during the readministration (Leslie and Davidson, 1985).

Subjects

Nineteen reading disabled (M age=12.08 years, SD=1.3) and 19 normal readers (M age=12.31 years, SD=1.4) from the original sample of fifty males returned to the laboratory approximately one year later to participate in an additional testing session.[2] The descriptive psychometric data that were obtained during the initial testing session from only this subsample of 38 subjects are presented in Table 2.

Procedure

The peg placement section of the PPT was re-administered during a two hour experimental session. The number of pegs the subject placed, first using his preferred hand (i.e., the right hand), then his nonpreferred hand, and finally both hands simultaneously, was recorded. PPT performance was videotaped by positioning a video camera 50 cm away from the subject. It should be noted that unlike the PPT, language and reading measures were not readministered.

Videotape Scoring

A coding system was developed for two general types of movements:

1) Fine motor errors - Three possible errors of this type were identified: a) spilling one or more pegs out of the cup as the subject reached for a single peg was counted as one error; b) if more than one peg was picked up from the cup at the same time and the subject either dropped the extra peg(s) or brought the peg(s) back to the cup prior to placing the targeted peg, then an error was counted; and c) if the peg was unintentionally dropped in the process of placement then an error was scored. Therefore, a total of three errors was possible on any given trial. The number of errors was summed across each trial so that one error score was derived for each hand condition. Each of the unimanual conditions (i.e., dominant and non-dominant) and the left and right hands separately for the bimanual condition were coded for errors. Thus, four conditions were independently coded (dominant, non-dominant, right bimanual, and left bimanual).[3] Higher values reflected a greater number of fine manual errors. The three possible types of fine manual errors are illustrated in Figure 1.

2) Symmetrical movements - This behavioral analysis applied only to the bimanual condition, where the subjects were instructed to pick up one peg from each cup using both hands simultaneously, and to

then place the pegs down the rows. The behavior of interest in this condition was the extent to which the two hands mirrored each other while performing the task. In the absence of symmetrical movements, the question of which hand led the other was also addressed. In order to quantify the relative hand symmetry among subjects, two points during performance of a particular trial were targeted for coding: a. the point at which the hands were leaving their respective cups with the pegs; and b. the point at which the hands were leaving the placed pegs. For each of these designated points, a score of one for a symmetrical movement was recored if the hands were equidistant to their goal. If the hands were in different positions such that one hand relative to the other was closer to the goal, then a score of one for an asymmetrical movement was recorded, and the leading hand was noted. In other words, each trial, consisting of the placement of a pair of pegs by both hands together, earned two scores. The scores reflected any of the possible ratings: symmetrical, asymmetrical left lead or asymmetrical right lead movements. Figure 2 illustrates the three types of movements at each target point. The scores for symmetrical movements, asymmetrical left leads and asymmetrical right leads were summed across the trials separately, for each subject. The possible value of each of these three scores on any given trial ranged from 0 (i.e., the movement was absent from that trial) to 2 (i.e., the identical movement occurred at both coding points). For each subject, the grand sum of the three scores equalled: the number of pegs placed in the bimanual condition x 2.

The video tapes were coded by two independent raters. Inter-rater reliabilities for all scores were calculated. Values for coding fine motor errors in all four conditions (i.e., dominant, non-dominant, bimanual left, and bimanual right) ranged from r=.69 to r=.85.[4] Inter-rater reliabilities for coding symmetrical/ asymmetrical right and left lead movements on the bimanual task ranged from r=.75 to r=.96. Once reliabilities were calculated, the raters jointly reviewed the videos in order to replace each inconsistent rating with a mutually agreed upon rating. In addition, inter-rater reliabilities were also computed for only those subjects who had fine manual error free performance on the bimanual condition (N=7). The values ranged from r=.79 to r=.99. This calculation was performed to insure that the high inter-rater reliabilities initially obtained were not due to the occurrence of reliable fine motor errors rather than to the presence of consistently observable gross motor movement.

CHAPTER III

RESULTS

Purdue Pegboard

A 2 x 3 analysis of variance (ANOVA) for balanced groups was performed on the raw scores with Group (dyslexic versus control) and Condition (dominant versus nondominant versus bimanual) as between- and within-group factors, respectively. A significant main effect for Condition [F(2,96)=121.07,p<.0001] was obtained (M for right hand=13.54; M for left hand=12.90; M for bimanual=10.66). The difference between the right hand versus the bimanual condition and the left hand versus the bimanual condition were both significant (p<.01 for both)[5]. In addition, performance in the right hand condition was better than performance in the left hand condition (p<.01). These results support previous findings which indicate that the best performance is displayed by the right hand and that the unilateral conditions result in better performance compared with the bimanual condition. The main effect for Group only approached significance [F(1,48)=3.50, p<.07], and demonstrated that the controls tended to earn overall higher raw scores than the dyslexics (M for controls=12.71, M for dyslexics=12.03). The Group x Condition interaction was significant [F(2,96)=6.69, p=.002] and indicated that dyslexics placed fewer pegs compared with controls in both the dominant (p<.01) and nondominant (p<.01) conditions. No differences in peg placement emerged between the controls and dyslexics in the bimanual condition (see Fig. 3). These data, therefore, only partially replicate Gardner and Broman's (1979) findings of better performance by controls as compared to a sample of MBD children in the unimanual as well as the bimanual conditions. It had previously been hypothesized that a left hemisphere deficit would become manifested in Purdue performance in terms of between group differences in each of the unimanual conditions. This prediction was supported, and raises the possibility of the presence of a left hemisphere deficit in the dyslexic group. It had also been hypothesized that a deficit in interhemispheric communication, if present, would contribute to between group performance differences only in the nondominant condition. This prediction was not supported since a between group difference in the dominant hand condition was also found. However, it is possible that both a left hemisphere dysfunction as well as an interhemispheric communication deficit may have contributed to the poor performance that was demonstrated in the unimanual conditions (see Appendix C). The relation between unimanual PPT conditions and other measures of interhemispheric transmission and of left hemisphere function need to be assessed in order to ascertain the underlying mechanisms that contributed to the poor performance in each of the unimanual conditions. These relations will be presented below.

Within the dyslexic group, each PPT condition was reliably different from every other condition (all comparisons, $p<.01$) with best performance observed during the dominant hand condition ($M=13.08$, $SD=1.26$), worst performance during the bimanual condition

(M=10.72, SD=1.10), and an intermediate level of performance during the nondominant hand condition (M=12.28, SD=1.70). Within the control group, performance in both dominant (M=14.00, SD=1.76) and nondominant (M=13.52, SD=1.64) conditions was superior to that in the bimanual condition (M=10.60, SD=1.50) ($p<.01$ for both). No significant difference was found between the two unimanual conditions in this group.

The effect of age on PPT performance has been documented in both preschoolers (Wilson et al., 1982) and in Gardner and Broman's (1979) normative sample, which ranged in age between 5 years, 0 months and 15 years, 11 months. In order to evaluate the effect of age in the present sample, Pearson product-moment correlations were computed between the age of the subjects and PPT raw scores, from each condition and group separately. For the dyslexics, very little association was demonstrated between age and PPT performance in all three hand conditions (dominant $r=.08$; nondominant $r=.08$; bimanual $r=-.24$). Although not significantly different from the dyslexics as tested by Fisher's Zr transformations, slightly higher positive relations were obtained between age and PPT performance for the controls (dominant $r=.36$, $p<.07$; nondominant $r=.37$, $p<.07$; bimanual $r=.47$, $p<.02$). Thus, due to the potential effects of age on performance, raw scores were converted to percentile scores using Gardner and Broman's norms in order to compare each subject to a larger group of age-matched normal children. (See Appendix D for a sample of Gardner and Broman's normative data, and the data from the present sample separated by age).

A 2 x 3 ANOVA for balanced groups was performed on the percentile scores, again with Group and Condition as the between- and within- group factors. The main effect for Condition was not significant [F(2,96)=1.96]. A significant main effect for Group was obtained [F(1,48)=3.91, p=.05], in which the controls showed a higher percentile score compared with dyslexics (M for controls=41.65; M for dyslexics=30.08). A significant Group x Condition interaction [F(2,96)=4.36, p=.02] was obtained, and as with the raw scores, demonstrates differences in performance between the dyslexics and controls in the dominant (p<.01) and nondominant (p<.01) conditions (see Fig.4). The bimanual condition, however, again did not discriminate between these two groups. When performance within each group was examined, a slightly different pattern emerged for the dyslexics as compared to the controls. The dyslexics showed no difference among the three hand conditions, whereas, the controls performed better on the left hand condition compared with the bimanual condition (p<.05). No other within group comparisons reached significance.

Pearson product-moment correlations based on the percentile scores were computed among the three PPT conditions for each group separately. For both groups, these correlations were high and positive, suggesting that performance in all three conditions was highly interrelated. Values for the control group ranged from .56 to .74, and values for the dyslexic group ranged from .41 to

.55 (See Table 3). Pearson product-moment correlations based on the raw scores were also computed and the results were almost identical to those obtained using percentile scores (see Table 4).

In sum, performance on the PPT revealed that dyslexics performed more poorly than the controls in the unimanual conditions, whereas no difference in performance emerged between these groups in the bimanual condition. This finding was obtained for both the percentile and raw PPT scores. As is the case with most neuropsychological tests, the actual scores derived from the PPT revealed little about the processes involved to perform the task. A subsidiary investigation was therefore performed, evaluating the more subtle aspects of motor behavior exhibited during PPT performance. The purpose of this evaluation was an attempt to examine the different processes that might be contributing to performance in the three PPT hand conditions (i.e., dominant, non-dominant and bimanual). The PPT was re-administered approximately one year after the initial testing session and performance was video taped. The procedure and results of this additional session is reported following the presentation of the remaining data that were collected during the initial testing sessions.

Manual reaction time

An analysis of variance (ANOVA) with Group (dyslexic/control) as a between subjects factor and Hand (left/right), Orientation of hand (straight/crossed) and Visual field (left/right) as repeated factors was performed on median RT.[6] No main effect for Group was present [F(1,48)=.02], indicating no overall difference between groups in reaction time to these simple stimuli. No other main effect was significant. Previous studies have demonstrated faster reaction times in the ipsilateral than in the contralateral hand-visual field combinations. These findings were replicated in the present study. The Hand x Visual field interaction [F(1,48)=6.07,p=.02] was significant and demonstrated faster reaction times in response to ipsilateral as compared to contralateral visual field presentations with respect to the left and right hands (p<.01 for both). Table 5 presents the means and standard deviations for this interaction. No other interaction was significant. The means and standard deviations for the Hand x Visual field x Group interaction [F(1,48)=.39] are presented in Table 6. Table 7 displays these data split by orientation of hand. As can be seen from this table, the same general pattern of responses is obtained in the straight and crossed hand conditions, suggesting that spatial compatability has a minimal role in these findings. The anatomical connections between the visual field and the responding hand likely account for these results. The one exception to this is in the dyslexic group, where a shorter contralateral as opposed to ipsilateral hand-visual field reaction time was obtained in the straight right hand condition. The factors involved in a negative IHTT such as this are unclear. Table 8 displays the percentage of subjects in each group who obtained faster reaction times in the anatomically predicted direction. As can be seen from this table, faster reaction times were obtained by the straight left hand in response to LVF versus RVF presentations in 64% of both the dyslexic and control groups (i.e., 16 out of 25). Reaction times were faster in response to RVF presentations as compared to LVF presentations in the straight right hand condition in 36% (i.e., 9 out of 25) of the dyslexic group and in 52% (i.e., 13 out of 25) of the control group. In the crossed hand conditions, 64% (i.e., 16 out of 25) of the dyslexic group and 56% (i.e., 14 out of 25) of the control group obtained faster reaction times in response to LVF as compared to RVF presentations when the left hand was employed. Forty-eight percent of the dyslexics (i.e., 12 out of 25) and 56% of the controls (i.e., 14 out of 25) obtained faster reaction times in response to RVF as compared to LVF presentations when the right hand was employed. Eight (32%) of the dyslexics and 10 (40%) of the controls showed consistently faster reaction times in the ipsilateral than contralateral hand-visual field combinations in at least three out of the four conditions.

IHTT

An ANOVA on the median IHTT scores was computed with Group, Hand and Orientation as factors. It had been predicted that IHTT differences between the groups would emerge if a malfunction in the timing mechanism resulting in an interhemispheric communication deficit was present in the poor readers. This hypothesis was not supported. As expected based upon the RT data reported above, no significant main effects or interactions were obtained in this analysis.[7] The means and standard deviations are presented in Table 9. As can be seen from Table 9, IHTT values appear to be more consistent for the left hand than for the right hand. The one exception to this is the IHTT that was obtained by the controls in the crossed left hand condition. This value of 1.31 msec is slightly less than other values which have been reported in the literature (e.g., 2.5 msec).

In an attempt to create a more stable measure of IHTT, the possibility of combining particular IHTT values was evaluated. First, the possibility of combining IHTT values derived from the straight and crossed hand conditions was considered. Pearson product-moment correlations were computed between median IHTT values derived from straight and crossed hand conditions, separately for each hand and group. For the dyslexic group, the relation between straight versus crossed IHTT values in the right hand conditions was low and positive (r=.24). A stronger relation emerged between straight and crossed hand IHTT values in the left hand conditions (r=.45, p=.03). For the controls, a low correlation emerged between the straight and crossed hand IHTT values in both hand conditions (for the right hand r=.28; for the left hand r=.30). The results of these correlations suggest that only a small part of the variance is shared between IHTT values that are obtained from straight and crossed hand performance, and therefore should be treated as measures which reflect distinct processes.

The relation between left and right hand IHTT values was also evaluated separately by orientation and group. Pearson product-moment correlations revealed for the dyslexics, almost no association between left and right straight hand IHTT values (r=.05). The relation between left and right IHTT values obtained in the crossed hand conditions was low and negative (r=-.22). For the controls these relations were negative and slightly higher (for the straight hand condition r=-.29; for the crossed hand condition r=-.39, p=.06), although still not significant. Thus, similar to IHTT values based on different hand orientations, given the low correlations, IHTT values derived from the left and right hands warrant separate evaluation.

Relation between RT and IHTT

While not directly related to the major hypotheses of this study, an additional set of analyses were performed to examine the relation between reaction time and IHTT for each group. These analyses were expected to reveal group differences, if present, in particular aspects of the information transfer - response time process. Pearson product-moment correlations were computed between IHTT and the sum of the LVF and RVF reaction times upon which it was based, separately for each condition (i.e., straight left hand, straight right hand, crossed left hand, crossed right hand) and group. As displayed in Table 10, the results of these correlations demonstrated that for the controls in the straight and crossed right hand conditions, a positive relation emerged between IHTT and overall reaction time. That is, longer IHTT values were associated with longer response times. No association between IHTT and reaction time emerged in either of the right hand conditions for the dyslexics. Conversely, negative correlations were obtained between IHTT and reaction time in the left hand conditions for both subject groups. In other words, longer IHTT values tended to correlate with faster left hand response times.

It is often assumed that faster (i.e., shorter) reaction times are due to the transmission of information through direct anatomical pathways whereas longer reaction times are due to transmission along more indirect pathways. These assumptions were evaluated by computing correlations between IHTT and reaction time separately for each visual field, hand orientation and group. These correlations are displayed in Table 11. For the control group, the results of this analysis demonstrated a positive association in both right hand conditions (i.e., straight and crossed) between IHTT and reaction time when information is presented to each of the visual fields. As expected, these correlations tended to be stronger when stimuli were presented to the LVF as compared to the RVF. In contrast, only weak relations emerged for the dyslexic group between IHTT right hand conditions and reaction time obtained from LVF and RVF presentations. Interestingly, a negative relation emerged in the left hand conditions between IHTT and reaction time obtained from LVF and RVF presentations for both subject groups. Again, these correlations tended to be stronger when stimuli were presented to the LVF as opposed to the RVF.

Relation between IHTT versus non-dominant PPT score

It had been predicted that scores obtained in the nondominant Purdue condition would be correlated with IHTT values, since performance of the nondominant condition was hypothesized to require interhemispheric transfer. Pearson product-moment correlations were computed between the raw scores from the nondominant PPT condition and median IHTT values, separately for each hand orientation and group. These correlations resulted in low values for the straight hand conditions (for dyslexics straight right hand r=-.01, straight left hand r=.29; for controls straight right hand r=-.16; straight left hand r=.14). Slightly higher relations emerged in the crossed hand conditions as compared to the straight hand conditions for the dyslexics, but not for the controls (for dyslexics crossed right hand r=-.30, crossed left hand r=.43; for controls crossed right hand r=.12, crossed left hand r=-.16). The interpretation of these correlations are ambiguous because of the high correlations among the PPT conditions. It is possible that a unique reflection of interhemispheric transfer in the nondominant score would become masked given the amount of variance shared with the other PPT conditions. An attempt was made, therefore, to establish a "purer" measure of interhemispheric transfer by removing the variability of at least the dominant hand condition (since this as compared to the bimanual condition most clearly represents left hemisphere functioning) from the nondominant PPT score. Partial correlations were computed between the nondominant PPT raw score and median IHTT values, separately for each hand orientation and group. For the dyslexics, removing the linear effect of the dominant hand score resulted in stronger positive relations between IHTT and PPT nondominant hand values in both left hand conditions (left straight hand r=.47; left crossed hand r=.51). Correlations between nondominant PPT scores and IHTT in the right hand conditions were unaffected by the removal of the contribution of the dominant hand score (straight right hand=-.04, crossed right hand=-.35). For the controls, the correlations between PPT nondominant scores and IHTT improved in the crossed but not in the straight hand conditions when the effects of the dominant right hand score was removed (right straight r=.07, left straight r=.15, right crossed r=.28, left crossed r=-.31). Fisher's Zr transformations were performed on the correlations obtained by each group in the left hand conditions. Results from this analysis demonstrated a significant difference between the correlations involving the crossed hand condition only (p<.01). Table 12 presents both the partial and total correlations[8] between IHTT and the PPT nondominant hand raw score for each group.

Relation between PPT scores and IHTT versus psychometrics

As previously mentioned, it has been suggested in the literature that manual skills and various language processes may utilize common neural mechanisms. In order to examine the relation between these abilities, Pearson product-moment correlations were computed between PPT raw scores and selected language variables across and between subject groups. As can be seen from Table 13, better unimanual PPT performance was related to faster naming speed and to higher reading scores on several of the measures. Interestingly, no relation emerged between bimanual PPT performance and any of the reading or language variables. When the correlations between PPT performance and various language and reading measures were examined for each group separately, it can be seen from Table 14 that higher scores in all three PPT conditions for the controls were associated with faster response (i.e., naming) rates on all four RAN subtests (see Appendix A for a description of the RAN). The values ranged from r=-.30 to r=-.69 and the scatterplots corresponding to the significant correlations are displayed in Appendix E. This pattern, however, was not obtained for the dyslexics, whose values ranged from r=-.20 to r=+.20. Fisher's Zr transformations were performed to test whether the correlation coefficients obtained by each group were significantly different from each other. Table 14.1 displays the results of this analysis, and demonstrates that except for correlations between the nondominant PPT score and RAN subtests, the correlation coefficients obtained by each group are, in general, significantly different from each other. These findings contribute additional support to the notion of a close link between certain language skills (e.g., speed of naming) and motor ability in normals and suggest that this link may be more variable in language disabled children. The association between other language measures and PPT scores were examined and resulted in generally low correlations for both groups (see

Table 14).

An attempt was made to examine the amount of variance in a reading score that was accounted for by PPT raw scores (dom, nondom and bimanual) relative to selected language variables (Sentence Repetition, Word Fluency). Multiple regressions were performed with the Myklebust Quotient (MQ) as the dependent measure. These regressions were computed both across group as well as separately for each group. The across group regression indicated that the best single predictor of the MQ was Word Fluency ($r^2=.24, p=.0004$). The addition of PPT's nondominant score accounted for slightly more variance in the MQ ($r^2=.35, p=.0001$). Sentence Repetition was the next variable that was added to the equation and accounted for additional variance ($r^2=.41, p=.0001$). The remaining PPT variables (i.e., dominant and bimanual scores) added little to the total amount of variance accounted for in the MQ. When this regression was computed separately for the dyslexic group, the data revealed that the single best predictor of the MQ was Sentence Repetition ($r^2=.24, p<.01$). The remaining variables did not account for any additional variance. In contrast to the reading disabled group, the best single predictor of the MQ for the control group was Word Fluency ($r^2=.16, p<.05$). While the addition of the dominant hand score accounted for more variance ($r^2=.23, p<.06$), none of the remaining variables did.

It had been hypothesized that a deficit in interhemispheric communication might be associated with specific types of reading disabilities. In order to examine this hypothesis more closely, Pearson product-moment correlations were computed between median IHTT from the straight and crossed left and right hand conditions and certain language measures. With only a few exceptions, these correlations resulted in generally lower values for the crossed hand conditions compared to the straight hand conditions. Therefore, only the correlations from the straight hand conditions are presented in Table 15. As can be seen from this table, typically low correlations between IHTT and the RAN subtests emerged for both groups. Significant correlations did emerge between each of three reading tests and IHTT in the dyslexic group and indicate an association between better reading performance and longer IHTT values. Evaluation of the scatterplots indicate that these high correlations are not due to spurious scores (see Appendix F). However, given the large number of correlations performed, these findings should be considered tentative. The significance of the difference between the groups' right hand IHTT versus reading test correlation coefficients was tested using Fisher's Zr transformation. The only significant between group difference in correlation coefficients revealed by this analysis was that based on right hand IHTT and Gray Oral scores (for dyslexics $r=.45$ and for controls $r=-.14$, $p<.05$). The correlation coefficients based on right hand IHTT versus Word Attack, Word Identification and MQ did not significantly differ between the groups. No other consistent pattern of relations emerged for either group. Correlations between psychometrics and IHTT values obtained from the left and right, straight and crossed hand conditions were computed collapsing across the subject groups. Again, no difference in the relation between IHTT and selected psychometric variables occurred between the straight and crossed hand conditions. Therefore, only the correlations for the straight hand conditions are presented in Table 16. As can be seen from this table, extremely weak correlations emerged between IHTT and naming speed. However, the direction of these correlations indicate that longer IHTT values tend to be associated with faster naming speed. This relation appears to be stronger for the left hand conditions as compared to the right hand conditions. In addition, low positive relations emerged between IHTT obtained in the straight right hand condition and reading measures. These correlations indicate that longer IHTT tends to be correlated with better performance on various reading measures.

PPT Test-Retest

Test-retest reliabilities on both the raw and percentile scores were computed separately for the dominant, nondominant and bimanual conditions. The values ranged from r=.37 to r=.57 for the dyslexic group and r=.41 to r=.72 for the control group. Table 17 presents the correlations for each condition and group separately.

A 2 x 3 analysis of variance (ANOVA) for balanced groups was performed on the raw retest scores with Group (dyslexic versus control) and Condition (dominant versus nondominant versus bimanual) as between- and within-group factors, respectively. Similar to the previous findings, a significant main effect for Condition [F(2,72)=59.88,p=.0001] emerged (M for right hand=14.42; M for left hand=13.55; M for bimanual=11.45) and demonstrated better performance in the right hand condition as compared to the left and bimanual conditions (p<.01 for both). In addition, performance in the left hand condition was better than performance in the bimanual condition (p<.01). These results again support the claim that best performance is displayed by the right hand and that the unilateral conditions result in better performance compared with the bimanual condition. The main effect for Group [F(1,36)=.26] was not significant. In contrast to the previous findings, the Group x Condition interaction was also not significant [F(2,72)=.04].

Raw scores were again converted to percentile scores using Gardner and Broman's (1979) norms in order to compare each subject to a large group of age-matched normal children. A 2 x 3 ANOVA for balanced groups was performed on the percentile scores, with Group and Condition as between and within group factors. Similar to the previous findings, the main effect for Condition was not significant [F(2,72)=.22]. However, in contrast to the initial report, the main effect for Group [F(1,36)=.37] and the Group x Condition interaction [F(2,72)=.02] were not significant. The most inportant finding from the initial study had been revealed in the Group x Condition interaction for both the raw and percentile scores. To briefly review, this interaction demonstrated significant between group differences in the unimanual conditions and no between group difference in the bimanual condition. Results from this analysis showed an inability to replicate the pattern of PPT scores in a subgroup (N=19 dyslexics; 19 controls) of the initial sample (N=25 dyslexics; 25 controls) one year later.[9] Examination of the data revealed that the major difference between testing time 1 and testing time 2 was in the dyslexic's unimanual scores. This was demonstrated in an ANOVA, performed separately on the raw and percentile scores, with Group as a between factor and Time (time 1 versus time 2) and Condition (Dominant versus Nondominant) as within factors. Results from the analysis on the raw scores revealed significant main effects for Condition [F(1,36)=9.19,p<.005] and Time [F(1,36)=8.52,p=.006]. These main effects demonstrated higher scores for the combined groups at time 2 as compared to time 1 (M for time 1 = 13.38, SD=1.70; and M for time 2 = 13.99, SD=1.97) and overall higher scores in the dominant as compared to the nondominant hand conditions (M for dominant=14.05, SD=1.82; and M for nondominant=13.32, SD=1.83). The main effect for Group was not significant [F(1,36)=2.46]. Most importantly was the emergence of a significant Group x Time interaction [F(1,36)=4.12,p<.05], which indicated that dyslexics placed a greater number of pegs in the unimanual conditions at time 2 as compared to time 1 (p<.01). There was no difference in the control group between time 1 and time 2 in the number of pegs placed. The Group x Time x Condition was not significant [F(1,36)=.09]. Although no main effects based on the percentile scores were obtained, the Group x Time interaction was marginally significant [F(1,36)=3.41,p<.07]. As found using the raw scores, this interaction demonstrated overall higher unimanual scores obtained from time 2 as compared to time 1 for the dyslexics (p<.05), but not for the controls. The means and standard deviations for the interactions based on the raw and percentile scores are presented in Table 18. In sum, only the dyslexic group showed improved performance at time 2 as compared to time 1 in the unimanual conditions, which, in effect, eliminated the between group differences that were shown in the initial session. Tables 19 and 20 present the PPT means and standard deviations based on raw and percentile scores, respectively, from the first and second administrations.

Pearson product-moment correlations based on the percentile scores from the second administration were computed among the three PPT conditions for each group separately. Similar to the findings based on the scores from the first administration, the correlations were high and positive for both groups. Values for the dyslexic group ranged from r=.53 to r=.78. Values for the control group ranged from r=.47 to r=.76. Pearson product-moment correlations based on the raw scores were also computed and the results were similar to those obtained using percentile scores (see Tables 21 and 22).

Fine motor errors

The video recording for three of the subjects was distorted, so their data were eliminated from this analysis. A total of 35 subjects were therefore included in this analysis (N=18 dyslexics; 17 controls).

A 2 x 4 ANOVA for unbalanced groups was performed on the fine motor error scores with Group (dyslexic versus control) and Condition (dominant versus non-dominant versus right bimanual versus left bimanual) as between and within group factors, respectively. The main effect for Condition [F(3,99)=2.93,p=.04] was significant (M for unimanual right hand=1.71; for unimanual left hand=1.69; for bimanual right hand=1.11; for bimanual left hand= 1.17) and demonstrated that more errors occurred in each of the unimanual as compared to each of the bimanual conditions (p<.01 for all). The main effect for Group was not significant [F(1,33)=.51]. The Group x Condition interaction was also not significant [F(3,99)=1.10]. The number of fine manual errors, therefore, did not significantly discriminate between the two groups in any of the conditions. One reason for these negative findings may be due to the generally small number of errors that were made while placing the pegs. For example, although the dyslexic group placed a mean of 14.26 pegs (SD=1.97) in the dominant hand condition, the average number of errors (for the 16 out of 18 Ss who made errors) was only 2.1 (SD=1.4). The control group placed a mean of 14.58 pegs (SD=2.06) in the dominant hand condition, but on the average (for the 13 out of the 17 Ss who made errors) made only 1.4 fine motor errors (SD=1.3). Although these numbers are suggestive of group differences in fine motor behavior, the range of values appears to be too small to significantly discriminate between the groups.

Symmetrical/Asymmetrical movements

No significant difference emerged between the groups in the number of symmetrical movements made during the bimanual condition (M for the controls=11.12, SD=4.85; M for the dyslexics=9.33, SD=4.78; p<.3). A 2 x 2 ANOVA for unbalanced groups was performed on the asymmetrical movement scores[10] with Group (dyslexic versus control) and Direction (left lead versus right lead) as between and within subject factors, respectively. This analysis revealed a significant main effect for Direction [F(1,33)=8.87,p<.005] and demonstrated that overall, a greater number of right hand lead movements were made relative to left lead movements (M for right leads=7.86, SD=5.30; M for left leads=4.60, SD=2.91). The main effect for Group was not significant [F(1,33)=1.13]. The Group x Direction interaction was significant [F(1,33)=4.63,p<.04] and revealed that dyslexics exhibited significantly more right lead movements than left lead movements (p<.01). No difference occurred between the number of right and left lead movements for the controls. In addition, dyslexics exhibited a significantly greater number of right leads as compared to the controls (p<.01). The difference in the number of left leads between the two groups was not significant (See Table 23).

The between group difference in the number of right as compared to the number of left lead asymmetrical movements was also found at the individual level. Asymmetrical right lead scores exceeded or equalled asymmetrical left lead scores in 16 out of 18 dyslexics. This pattern was found for only nine out of 17 controls (x^2 =5.53,df=1,p<.03). These findings suggest that the quality of motor movements differs between the groups when performing the bimanual task.

Relation between symmetrical/asymmetrical movements and PPT performance

Pearson product-moment correlations were computed between PPT percentile scores from the three conditions obtained during the initial administration and the number of symmetrical movements, asymmetrical left leads and asymmetrical right leads, separately for each group. A diverse pattern of correlations emerged from this analysis. For the dyslexics, generally weak negative correlations emerged between the number of symmetrical and left asymmetrical movements versus percentile scores obtained from time 1 (values ranged from r=-.06 to r=-.41). The only exception to this was in the comparison between the number of left lead asymmetrical movements and performance in the nondominant hand condition. In this case, the correlation was in the positive direction (i.e., r=.30). On the other hand, the number of right asymmetrical movements and PPT percentile scores from time 1 were positively and more highly correlated (i.e., values ranged from r=.44 to r=.56). In other words, better PPT performance during time 1 tended to be associated with a greater number of right asymmetrical leads in time

2 for the dyslexic group. The same pattern of correlations emerged for the control group. The correlation coefficients for these comparisons are presented separately for each group in Table 24.[11]

Correlation coefficients were also computed between the PPT percentile scores obtained during the second administration and the three types of movements, for each group separately. Similar to the findings based on scores from the first administration, the results of this analysis demonstrated generally weak relations between symmetrical and left asymmetrical movements and PPT percentile scores for both groups. For dyslexics, the values ranged from r=-.14 to r=.22. For controls, the values ranged from r=-.14 to r=.28. However, as also demonstrated with PPT scores from the first administration, generally higher positive relations emerged between the number of right asymmetrical movements and PPT percentile scores. The one exception to this was exhibited by the controls in the nondominant hand condition. Basically no association emerged between this condition and the number of right asymmetrical movements in this group (r=.006). For dyslexics, the values ranged from r=.36 to r=.45. For controls, the values from the dominant and bimanual conditions are r=.48 and r=.42, respectively. The correlation coefficients for this analysis are displayed in Table 25.[12]

Relations between symmetrical/asymmetrical movements and language measures

In an effort to further examine the relation between reading and language skills and motor behavior, correlations between the three types of movements exhibited during the bimanual PPT condition (from administration 2) and selected psychometric variables (obtained during administration 1) were computed across subject groups. As demonstrated in Table 26, no association exists between the number of symmetrical movements made and performance on the various cognitive tests. However, several associations did emerge between the number of asymmetrical movements and performance on the reading and language tests. Specifically, faster naming speed (RAN subtests) tended to be associated with a greater number of left lead asymmetrical movements, whereas slower naming speed tended to be associated with more asymmetrical right hand movements. Similarly, better performance (i.e., higher percentile scores) on the reading and language measures tended to be correlated with a greater number of left lead asymmetrical movements, whereas the reverse was true for the number of right lead asymmetrical movements. When the relations between reading and language performance and types of movements were examined separately for each group, no clear pattern emerged. As can be seen in Table 27, the correlations were generally weak for both groups. One limitation of these data is the lack of information concerning language and reading ability at the time of the second administration. Psychometric data were collected only during the first administration, which was approximately one year prior to the second testing session. It is difficult to evaluate the relation between cognitive ability and the different types of motor behavior without this information.

Relations between symmetrical/asymmetrical movements and IHTT

The question of whether the various types of movements demonstrated during performance of the bimanual task is related to interhemispheric communication was addressed. Pearson product-moment correlations between the movement types and IHTT (based on median reaction time) from each of the four conditions were computed across the subject groups. As can be seen in Table 28, the resulting correlations were low, indicating little association between these two measures. Table 29 displays the relation between these variables separately for each subject group. The only pattern of findings of possible interest that emerged is for the dyslexic group with regard to left lead asymmetrical movements. Specifically, a higher number of left lead asymmetrical movements tended to be associated with longer IHTT values, but only in the left hand conditions (left hand straight r=.32; left hand crossed r=.51). When the right hand was responding, shorter IHTT values tended to be associated with a higher number of left asymmetrical movements (right hand straight r=-.37; right hand crossed r=-.40).

CHAPTER IV

Discussion

This study had four major findings: 1) reading disabled subjects performed more poorly than controls in the unimanual conditions of the PPT during an initial administration; 2) whereas PPT performance did not discriminate between the normal and disabled readers one year after the initial administration, more subtle indices of motor behavior did; 3) naming speed and PPT performance were strongly correlated in the normal readers but not in the poor readers; and 4) longer interhemispheric transfer times in the right hand condition was associated with better reading performance, especially for the dyslexic group.

Purdue Pegboard Test

The major purpose of this study was to investigate the presence of a left hemisphere dysfunction and a deficit in interhemispheric communication in a subgroup of disabled readers. To this end, PPT performance was examined, as it involves skills such as fine manual dexterity and planned sequential action, which are functions purportedly subserved by the left hemisphere (e.g., Geschwind, 1975; Heilman, 1979; Kimura, 1977; Kimura and Archibald, 1974). Moreover, performance in the nondominant left hand condition was hypothesized to be dependent upon the interhemispheric transfer of information. It had been predicted that a dysfunction in left hemisphere processing would disrupt PPT performance in both unimanual conditions. It was reasoned that right hand performance would be directly affected by a left hemisphere dysfunction since the distal musculature is controlled primarily by the contralateral hemisphere. Furthermore, left hand performance would also be affected by a left hemisphere dysfunction either more indirectly through commissural pathways or via direct ipsilateral connections. However, to the extent that the left hand condition receives input from the left hemisphere via commissural transmission, callosal inefficiency could also contribute to poor performance in this condition. It was therefore predicted that a deficit in interhemispheric transmission would interfere with left but not right hand performance. In other words, poor performance by the dyslexics as compared to the controls was expected only in the left hand condition if only a callosal deficit interfering with transmission was present. The results of this study demonstrated that dyslexics performed more poorly compared to the controls in each of the unimanual conditions during the initial administration. According to the hypotheses previously stated, this would suggest the presence of a left hemisphere dysfunction. However, one major limitation to the set of hypotheses proposed is that they do not account for the possibility that both a left hemisphere dysfunction as well as callosal inefficiency might have contributed to poor unimanual PPT performance. In other words, the mechanisms underlying poor performance in the right and left hand conditions may have differed. A left hemisphere dysfunction could have effected right hand performance, while this in addition to deficient interhemispheric transfer could have effected left hand performance. The likelihood that more than one process contributed to poor unimanual performance by the dyslexics is strengthened by the finding that, based on the raw scores, the dyslexics were significantly worse in the left versus right hand condition while controls showed no difference between these conditions. Of course this pattern by itself is not conclusive evidence of contributions from distinct processes to unimanual performance.

In addition to a left hemisphere dysfunction and callosal inefficiency, is the possibility that a right hemisphere dysfunction contributed to the poor left hand performance that was exhibited by the dyslexic group. This possibility is based on the fact that the distal musculature of the left hand is controlled primarily by the contralateral (i.e., right) hemisphere. An attempt had been made to control for this possibility, by including into the study only those subjects who scored 85 or above on performance IQ and achieved a scaled score of at least 7 on the Block Design subtest from the WISC-R. As previously mentioned, these criteria were adopted in order to exclude those children with perceptually based learning disabilities. Findings from patients with brain damage have demonstrated that deficits in visuoperceptual and visuoconstructive skills are more often associated with right hemisphere as compared to left hemisphere damage (Benton, 1985). These are skills that are believed to be involved in at least some of the WISC-R performance subtests, including, in particular, Block Design. It was therefore assumed that the possibility of having included children with right hemisphere dysfunction was minimized, whereby ruling out the possibility of a right hemisphere dysfunction as a contributing factor to poor left hand PPT performance. However, the ability to perform a particular skill is not necessarily an accurate indicator of the integrity of that entire hemisphere which predominantly subserves the specific skill. For example, it was previously seen that right hand tapping ability in commissurotomized patients does not necessarily reflect the extent of cortical damage in the left hemisphere. (See discussion of Kreuter, Kinsbourne and Trevarthen, 1972 in the section: Bimanual coordination tasks and the corpus callosum). Therefore, it may also be the case that intact visuoperceptual and constructional skills do not necessarily represent the functional integrity of the entire right hemisphere. Thus, it is necessary for future research to assess various (rather than one) functions of a particular hemisphere in addition to, if possible, measures of metabolic processes (e.g., such as those obtained by PET scans), in order to ascertain the full integrity of a cerebral hemisphere.

The possibility that more than one mechanism contributed to deficient performance in each of the unimanual PPT conditions might be evaluated by comparing the intercorrelation obtained between the unimanual PPT conditions from the first administration (see Table 4) with the test-retest reliabilities (see Table 17). The logic behind this comparison is based on the notion that the highest possible correlation obtainable is when a score derived from a reliable measure is compared to itself. If the degree of association between the dominant and nondominant conditions is similar to the correlations between each of these conditions with themselves, then this would suggest that only one underlying system was contributing to unimanual PPT performance. Test re-test reliability coefficients based on the dyslexic's unimanual raw scores (see Table 17) were similar to the value of the correlation between the dominant and nondominant conditions. However, it is possible that the test-retest reliabilities decreased over the one year lapse between testing sessions, making the issue of underlying systems difficult to address using this approach. If a second PPT administration had occurred after a shorter time period, then, perhaps, this approach would have yielded more useful information. Future research should include multiple administrations of the PPT while systematically varying the length of the intersession interval to explore this issue further.

In contrast to the unimanual conditions, the bimanual PPT condition did not discriminate between the two groups. However, as previously mentioned, Gardner and Broman (1979) did find differences between their control and MBD samples in the bimanual condition. At least two factors may have contributed to this discrepancy. First of all, as previously described, Gardner and Broman examined a heterogeneous group of learning disabled children with respect to symptomatolgy and perhaps underlying etiology. If their MBD sample had been divided into subtypes, then it would have been possible to examine the extent to which the bimanual condition discriminated between the controls and each learning disabled group. It is unclear whether all the learning disabled groups would have performed worse than the controls in this condition. With regard to the present study, it is important to note that both the control and dyslexic groups performed around the 35th percentile in the bimanual condition. It could be argued that the controls as a group performed less well than expected and consequently eliminated any between group difference that otherwise might have emerged.[13] Thus, interpreting the finding of no performance difference between the groups in the bimanual condition as reflecting unexpectedly good performance by the dyslexics is not necessarily warranted. It is unclear why the controls may have performed less well than expected, and unfortunately, these data are difficult to interpret without this information.

PPT re-administration

A surprising finding emerged from this study with regard to PPT performance during the second administration. Initially, as described above, the subject groups differed in their performance of the unimanual PPT conditions. However, when the PPT was readministered approximately one year later, the between group differences in the unimanual conditions disappeared (see Tables 18, 19 and 20). The major factor which contributed to the elimination of the initial between group differences was an increase in the dyslexic group's scores, without a comparable increase in the control group's scores. These patterns are difficult to evaluate because, according to Gardner and Broman's (1979) normative data, a ceiling effect likely accounted for the lack of change in the control group's scores from time 1 to time 2 (see Appendix D). The mean ages of the control group at the time of the first and second PPT administrations were 11.18 years and 12.31 years, respectively. As can be seen from Table 20, in contrast to the dyslexics, the controls were performing around the 50th percentile in the unimanual conditions at time 1. Based on the normative data, mean raw scores would not be expected to change significantly between ages 11 and 12. In fact, in a much smaller sample (N=160 total across 10 age levels), Costa, Scarola and Rapin (1964) have also demonstrated little change in PPT performance above age 10. It is thus possible that fine manual differences between the disabled and normal readers in unimanual skills were still present at the time of the second testing session, but were not reflected in the standard PPT scores due to the older ages of the subjects.

Yet, the factors that contributed to improved unimanual performance in the dyslexic group remain to be uncovered. One factor that may have contributed to improved performance is a practice effect. Although difficult to evaluate in this data set, it is possible that performance during the first administration served to establish a motor template which was easily accessible, albeit one year later. Factors related to neurological maturation are also potential candidates for having played a role in improved unimanual performance during the second testing session. For example, it is possible that the dyslexics have, for a period of time, lagged behind the controls with regard to the maturation of intra- and interhemispheric connections. If developmental processes played a role, then between group differences would be expected in unimanual performance during time 1 among the younger subjects only. Performance differences would not be expected between the older dyslexics and controls. In addition, PPT performance differences within the dyslexic sample between the younger and older subjects would also be expected if performance was related to a developmental process. However, as previously reported, unlike the controls, very little association was found between age and PPT performance in the dyslexic group. As can be seen in Appendix D, in contrast to the prediction based on a developmental hypothesis, group differences appear more pronounced in the older rather than the younger subjects. Also, as expected from the pattern of low correlations, no differences appear to have emerged between the younger and older dyslexics. However, the number of subjects in each age group is relatively small, and these numbers differ between the dyslexics and controls. Unfortunately this data set does not permit a more detailed evaluation of possible developmental effects, but future research should address this question. Perhaps using age groups that are younger than the ones used in the present study would be helpful in avoiding any confounds from a ceiling effect.

Additional indices of motor functioning

Another interesting finding that emerged from this study was the suggestion of group differences in particular aspects of motor behavior during PPT bimanual performance, which may not be reflected in the overall score. Specifically, in the absence of symmetrical hand movements, the groups were found to differ in their distribution of right and left hand lead movements. The dyslexics exhibited more right than left hand leads, whereas the controls exhibited about an equal number of right and left hand leads (see Table 23). Furthermore, a greater number of right leads was associated with generally better PPT performance during the first and second administrations (see Tables 24 and 25). Unfortunately, data on asymmetric movements during the first administration of the bimanual condition were not obtained. It would have been interesting to compare the number of right leads exhibited during time one with the number exhibited during time two. If an increase in the number of right leads had been found, this would perhaps have been reflective of changes of those processes which also resulted in better PPT performance by the dyslexics. Alternatively, if no change in the number of right leads had been found, this would have reflected a more general dysfunction in the system, which over the one year period was no longer manifested by PPT performance. One possible interpretation of the present findings is that the more consistent pattern of asymmetric hand movements in the dyslexic group reflects a heavier reliance or perhaps an over activation of particular left hemisphere processes, with less reliance on other intra- as well as inter-hemispheric processes. However, it is unclear to what extent these hand asymmetries are indicative of hemispheric functioning. Unfortunately, no clear pattern emerged between performance on various cognitive measures and asymmetrical movements (see Tables 26 and 27). In general, faster naming speed and better performance on the language and reading tests tended to be associated with a greater number of left leads. Conversely, slower naming speed and poorer reading performance tended to be associated with an increased number of right leads. However, the relations between right and left hand leads and cognitive performance were very weak and inconsistent when each group was examined separately. These data are difficult to interpret, especially in the absence of measures of cognitive performance during the second administration.

The pattern of relations between the number of asymmetrical movements and IHTT is also difficult to interpret. Most interesting is that the relation between these variables differed between the groups. Generally there was little association between IHTT and asymmetrical movements in the control group, whereas these variables were more strongly related in the dyslexic group. One potentially important outcome was that unlike unimanual PPT performance, the number of pegs placed in the bimanual condition did not correlate with either naming speed or reading performance (see Table 13). In contrast, the asymmetrical movements that occurred during PPT bimanual performance, were found to correlate with various other cognitive measures. Although the interpretation of the present data set is ambiguous, they do highlight the potential importance of systematically examining those qualitative aspects of behaviors which are not reflected in standardized scores.

Motor and naming speed skills

Given the possibility of different mechanisms operating in unimanual PPT performance, results from the PPT in the present study can only be adequately interpreted in conjunction with additional measures of callosal transfer and other indicators of left hemisphere functioning. The Rapid Automatized Naming Test (RAN) is a measure of naming speed. Performance on this task involved naming series of repetitive familiar stimuli as quickly as possible. Criteria for subject inclusion required controls to perform within the normal range on all four parts of this task and for dyslexics to perform within the deficit range on at least one part of the RAN or on another naming test. Correlations between the RAN subtests and unimanual PPT conditions on the combined subject groups were generally strong (see Table 13). The direction of the correlations indicated that faster naming speed was associated with better performance in each of the unimanual conditions. One possible interpretation of these findings is that the language and motor systems involved in each of these tasks are intimately linked. The variance shared by these measures may involve a general speed factor which contributes to performance in various cognitive domains. When the relation between the RAN and PPT conditions were examined separately for each group, strikingly different patterns of correlations emerged (see Tables 14 and 14.1). For the controls, faster naming speed was strongly associated with better PPT performance, especially in the PPT dominant hand condition. However, for the reading disabled group, performance on the PPT and RAN subtests were only weakly correlated. The largest between group difference in the magnitude of the correlations occurred in the dominant hand condition. Although weaker for the dyslexics, the relation between RAN performance and nondominant PPT performance did not significantly differ between the groups. Grounded in both theoretical reasoning and empirical support, which were previously described, motor systems are believed to be intimately related to language systems. Findings from the present study provide some support for this view since Purdue pegboard deficits were demonstrated in children with language disabilities. Of course evidence demonstrating intact fine motor functioning in other subtypes of learning disabled children need to be obtained before conclusions regarding the specificity of deficient motor systems can be reached. Nevertheless, the overall group differences in the pattern of correlations based on PPT and RAN performance suggest that the motor and language systems in the dyslexic group may be more weakly linked as compared to the controls. A weak linkage between these systems may be a consequence of a deficit in a central timing mechanism which serves to attenuate the relation between timed tasks. Future research may explore this possibility by examining other measures which involve timing, but do not involve either motor or language functions.

Alternatively, the pattern of low correlations between PPT and RAN performance in the dyslexic group suggests that different processes as opposed to one dysfunctional system may have contributed to poor performance on each of these tasks. Wolff and colleagues (1984) have proposed that speed-timing thresholds are impaired in certain reading disabled groups. They suggest that this specific dysfunction manifests itself in sequencing skills and coordinated action. If at least one of the links which normally interrelates and therefore contributes to the organization of the motor and language systems is a speed/timing mechanism, then it is proposed that this mechanism is deficient in the dyslexic sample. Consequently, the motor and language systems of the dyslexic group may be at one level relatively dissociated, and therefore perform their respective functions with less contribution from the other. As to why a greater dissociation compared to the controls tended to occur between these functional systems when the right hand was performing is unclear. Perhaps this reflects the prominent role of the left hemisphere in these specific language and motor functions, suggesting one possible hemispheric site of disorganization.

IHTT estimated from reaction time

It had been predicted that a left hemisphere deficit would contribute to differences in reaction time between the dyslexics and controls, especially when responses were made with the right hand. Between group differences in IHTT were also expected if a deficit in interhemispheric transmission was present. Neither one of these hypotheses were supported based on the reaction time and, therefore, on the IHTT data. The implications of these findings, in effect, appear to be discordant with those suggested by the PPT data. However, there are interpretive problems with regard to the IHTT values which need to be taken into account before any conclusions are reached. For example, the average estimated time based on reaction time for simple visual information to cross the cerebral commissures in manual reaction time studies using adult subjects is approximately 2.5 msec (e.g., Bashore, 1981). As demonstrated in Table 9, IHTT values within the range of those reported in the literature were in fact achieved by the dyslexics when they responded with their left hand, and by the controls in the straight left hand and crossed right hand conditions. Problematic, though, is that group means below 2.0 msec, including in one case a negative value (-2.16), were also obtained by the groups in some of the conditions. It is unclear how to interpret these values since they might be too low to reflect the time it takes for information to cross the cerebral commissures. As reported by Bashore (1981), IHTT values between 1.0 and 8.0 msec reflect transmission by large diameter, myelinated axons, which constitute only 10% of human callosal fibers. It is unclear to what extent these values can be extended to the age group in the present study.

It could be argued that the number of trials used in the present study was insufficient to produce valid estimates of IHTT in each of the conditions. A total of 100 trials of simple checkerboards were presented to each hand-visual field combination. Other studies have obtained the anatomically predicted effects using as many as 300 (e.g., Jeeves, 1969) and 360 (e.g., Anzola et al., 1977) per hand-visual field combination. However, Berlucchi and coworkers have obtained the desired results using as few as 40 (Berlucchi et al., 1977) and 90 (Berlucchi et al., 1971) trials per hand-visual field combination. Yet, there are important differences between these latter studies and the present study, which may account for the different outcomes. Most importantly, all of the above mentioned studies investigating IHTT based upon reaction time used adult subjects. The protocol employed in the present study had been piloted on adult subjects, and the predicted effects in fact, were obtained. Unfortunately, it had not been piloted on children, which if it had, would have likely pinpointed those variables which needed age-related adjustments. For instance, it is possible that more trials are needed with children than adults due to increased variability in attention and/or motor behavior.

Interestingly, examination of the individual subject's data in each of the conditions revealed that a value of 2.5 msec or greater was in fact obtained by the majority of those who demonstrated positive IHTTs. Only one or two subjects in each of the conditions obtained an IHTT between 0 and <2.5 msec. In other words, when a positive IHTT was achieved by any given subject, it was usually larger than 2.5 msec. The low group mean IHTT values calculated in the four conditions (i.e., for dyslexics: right hand straight and crossed; for controls: right hand straight and left hand crossed) were therefore, generally due to relatively large negative values. Negative values indicate that reaction time in the contralateral hand-visual field condition was faster than in its ipsilateral counterpart. The question arises as to why these negative values occur in particular conditions and if they are achieved consistently by the same subjects.

At the individual level, it had been reported that 32% of the dyslexics and 40% of the controls obtained positive IHTTs in at least three out of the four hand-position conditions. If these statistics are broken down by the responding hand, it is seen that 48% (i.e., 12 out of 25) of the dyslexics and 44% (i.e., 11 out of 25) of the controls obtained positive IHTTs in both left hand conditions (i.e., straight and crossed). However, only 20% (i.e., 5 out of 25) of the dyslexics and 32% (i.e., 8 out of 25) of the controls demonstrated positive IHTT values in both right hand conditions. Thus, performance in the right hand conditions tended to be more variable at the individual level as compared to performance in the left hand conditions, especially for the dyslexics. Factors such as attention and motivation have been known to effect reaction time performance. However, why these factors, to the extent that they are operating, should selectively effect performance in one hand versus the other is unclear. Bashore (1981) has raised the possibility that different cortical mechanisms may be involved in different reaction time tasks, depending upon the task requirements. Similarly, it might be the case that performance by the left and right hands may utilize different cortical processes when engaging in reaction time tasks. The fact that low correlations had been found between IHTTs obtained in the right versus left hand conditions adds support to this possibility. IHTT calculated from right hand responses reflects the transfer of information from the right to left hemisphere, whereas IHTT based on left hand responses reflects transmission in the reverse direction (i.e., from the left to the right hemisphere). Data have previously been described which suggested differences between the hemispheres in terms of their respective patterns of neuronal connectivity (e.g., Gur, Packer, Hungerbueler, Reivich, Obrist, Amarnek and Sackeim, 1980). It would follow that differing neuronal patterns (even if only slightly modified) might affect related behavioral processes. For example, there may be certain components of the information transfer process (e.g., speed, route and influences from other systems), which are governed by the specific patterns of neuronal connections. Thus, it is possible that those processes which produced negative IHTT estimates in the right hand conditions were different from those operating in the left hand conditions.

Although there were no overall differences in reaction time between the hands, hemispheric specialization for differences in perceiving the simple visual stimuli may have also contributed to the variability between the hands in yielding reliable IHTT estimates. In other words, more negative values may have been obtained in the right than in the left hand conditions for some individuals due to a right hemispheric superiority in stimulus detection. According to the anatomical predictions, LVF information arrives to the left hemisphere by a more indirect route (i.e., callosal) as compared to RVF information. However, just because information is received at a sooner point in time by a particular hemisphere does not necessarily mean that this information will also be processed and responded to more quickly. In the present study, signals received by the left hemisphere from each visual field are assumed to arrive within milliseconds of each other. Given the brief time interval during which this process occurs, it is possible that the nature of the signal itself contributes to the sequence of it's processing within the temporal framework. The nature of the information received by the left hemisphere via the callosum from the right hemisphere is likely to be different from information that is directly received from the RVF. This is plausible in light of the fact that the right hemisphere is specialized in the processing of visual pattern information. It is unlikely that the right hemisphere becomes "blind" to the signals that are passing through it, functioning only in terms of a passageway. Even if only slight differences exist between the hemispheres in their ability to perform a task, information arriving to the relatively less efficient hemisphere from the more efficient hemisphere, albeit at a later point in time, might be responded to more quickly than information arriving directly (and therefore faster) to that hemisphere. There are theorists (e.g., Moscovitch, 1979) who might argue that the checkerboard task used in this study involved precategorical, low-level perceptual requirements, which would not be differentially processed by the hemispheres. However, individual differences may exist in the extent to which the two hemispheres are equally capable of performing this type of task. Given the variability in the magnitude and direction of the IHTT estimates, this possibility cannot be ruled out.

Interestingly, differences in the hands were also demonstrated when the relation between IHTT and reaction time was evaluated (see Tables 10 and 11). Faster reaction times tended to be associated with longer IHTTs in the left hand conditions, whereas slower reaction times tended to be associated with longer IHTTs in the right hand conditions. Perhaps these differences reflect additional factors which might be involved in the differential ability of the hands to yield reliable IHTT estimates. One factor which might differentially affect the relation between response time and transfer time for the left and right hands may have to do with the particular hemisphere that has initiated the signal transfer. It is possible that the nature of the information that is transferred from one hemisphere to the other depends upon the direction of the process. For example, when the left hand was responding, information was transferred from the left to the right hemisphere. In this case, presumably a motor command to initiate a response was the signal being transferred. If the right hemisphere tended to have an advantage on this particular task, then the response time may have occurred relatively more quickly. When the right hand was responding, information was transferred from the right to the left hemisphere. However, rather than a motor signal, the information being transferred to the left hemisphere could well have been sensory or perceptual in nature. This possibility is based on the notion that the executive controls for certain motor skills are subserved primarily by the left hemisphere. Although the right hemisphere may be capable of generating motor responses such as those required in this task, when a choice is possible, perhaps the hemisphere most adept at this skill assumes control. In this case, the left hemisphere would be the likely candidate for generating the motor command. Perhaps slower reaction times were associated with longer IHTT estimates in the right to left direction of transfer due to the necessity by the left hemisphere to, only upon receiving the signal, begin to initiate the command to execute a motor response. Milner and Lines (1982), as previously mentioned, postulated that different pathways of transfer between the hemispheres may be engaged depending upon the nature of the response. To briefly review, they suggested that transfer of information in tasks that require a manual response cross the more anterior, motor regions of the corpus callosum. Alternatively, when a vocal response is required, signals are transferred along "sensory" routes. This hypothesis was put forth in an attempt to explain their findings that changes in stimulus intensity affected information transfer only in those conditions where a vocal rather than a manual response was required. One way to possibly demonstrate that the left and right hand conditions involve transfer across different regions of the callosum would be if changes in stimulus intensity affects transmission when the right but not the left hand was responding.

Other factors which might also affect the relation between IHTT and reaction time, and, therefore, contribute to differences in IHTT estimates that were obtained by the left and right hands, are activation and arousal asymmetries. The reaction time conditions in the present study were blocked by hand. In effect, priming of a particular hemisphere likely occurred since the subject knew which hand he was going to respond with. As previously described, Heilman and Van Den Abell (1979) investigated the differential effects of a lateralized warning stimulus on reaction times in normal adults. To briefly review, their results demonstrated that ipsilateral hand reaction times were reduced more when warning stimuli were presented to the right versus the left hemisphere. In addition, these investigators demonstrated shorter right hand reaction times when warning stimuli were presented to the right hemisphere rather than directly to the left hemisphere. If the left and right hemispheres are differentially involved in activation and arousal systems, as was previously suggested (Tucker and Williamson, 1984), then perhaps the phenomenon of priming differentially effects these systems, and subsequently effects the process of information transfer. Given the present data set, the question of differential activation and arousal effects is difficult to evaluate, especially since no overall hand differences in reaction time were found. However, the potentially differential effects of activation and arousal asymmetries on IHTT estimates obtained from the left and right hands need to be considered in future research, in order to understand the role played by these systems in the transfer of information.

It has been suggested that the specific transcallosal route utilized to transfer information between the hemispheres is determined by several factors relating to the task requirements and nature of the signal. In addition, a cluster of factors including interactions with more general systems of activation and arousal, may, in turn, influence the timing and perhaps quality of the actual transmission. Of course individual differences in the callosum, as perhaps regulated by selective cell death during neurogenesis, may also be region specific and must therefore also be considered when evaluating different mechanisms of transfer. In sum, the IHTT data from the present study suggest that different factors may be involved when interhemispheric communication is required to occur for task performance, and these need to be disentangled empirically. For example, perhaps the type of information required to be transferred should be varied in addition to investigating possibly differential priming effects. Behavioral IHTTs obtained in these various ways should then be compared to IHTTs that are derived from other procedures, such as electrophysiological methods[14] and perhaps electrical stimulation mapping techniques.

In an attempt to establish convergent validity, the relation between IHTTs obtained in the four hand-orientation of hand conditions and the PPT nondominant hand score was evaluated. These measures were initially hypothesized to reflect similar underlying processes and were therefore expected to be strongly correlated. The relation between these measures was especially important to evaluate in light of the previously described discrepancy in the findings obtained from each measure independently. Specifically, between group differences were demonstrated in PPT nondominant hand performance, raising the possibility of inefficient interhemispheric communication. However, no between group differences were found in IHTT in any of the hand conditions. Examination of the relation between IHTT and the PPT nondominant hand score uncovered several interesting findings (see Table 12). Specifically, when the linear effect of the PPT dominant hand score was removed, the correlations between IHTT and the nondominant hand score tended to become stronger. Although the differences in the magnitude of the correlations with and without the effects of the dominant hand raw score were not significant, the slight magnitude increase in the correlations again raises the possibility of at least two underlying systems contributing to unimanual PPT performance. The resulting partial correlations between the nondominant hand score and the IHTT measures are relatively strong, particularly for the dyslexics. Interestingly, the one IHTT condition for the dyslexics that showed little association with the PPT nondominant score (i.e., right straight r=-.04) is the only condition which also generated a negative IHTT for the group average (see Table 9). The magnitude of the remaining correlations for this group suggest that at least some variance between IHTT and the PPT nondominant hand score is shared, implying that similar underlying mechanisms may have contributed to these scores. Why the relations between IHTT and the PPT nondominant hand score were weaker for the control group is unclear.

Further examination of the partial correlations between IHTT and the nondominant PPT score revealed differences in the direction of the correlations, depending upon the hand that was used in the reaction time conditions. Again, differences were seen between the left and right hands. Better PPT nondominant hand performance was associated with longer IHTTs derived from left hand responses. Conversely, better PPT nondominant hand performance was associated with faster IHTTs when calculated from right hand responses. In other words, when information was transferred from the left to the right hemisphere, longer transfer time was associated with better

PPT nondominant hand performance. However, when information was transferred from the right to the left hemisphere, faster transmission times were associated with better PPT nondominant hand performance. Interpretation of these patterns is difficult since it is unclear what factors were contributing to the IHTT values generated from the right hand reaction time conditions. Nevertheless, these data raise the possibility that the speed with which information is transferred is associated with the level of performance on a particular task. For example, slower (or faster) transfer time may be found to either impede or facilitate performance depending upon the particular route and direction of the transfer.

Interestingly, correlations between cognitive measures and IHTT values revealed an association between longer transfer times and better reading scores, but only for the dyslexics. This relation was found only in the right hand condition, which is the case when information is tranferred from the right to left hemisphere. This relation appears counterintuitive as one would expect more efficient performance when information is received as quickly as possible by the hemisphere that is dominant for the particular task. However, only the dyslexic group is showing this pattern which suggests that longer transfer time might reflect a compensatory mechanism that improves the efficiency of task performance.

General Conclusions

In sum, the data from this study do not clearly indicate whether there is a deficit in left hemisphere functioning and/or callosal inefficiency, although some of the findings have suggested that both of these deficiencies may be present in the reading disabled sample. However, it may be the case that these particular questions are not the most useful ones and that future research should focus more precisely on the status of the interrelations of various inter- and intrahemispheric processes. Reading disabled children are not acallosal or commissurotomized patients where left hemisphere processes may be more easily separated from callosal functions. In addition, it may be more difficult to assess the functional integrity of the left hemisphere than previously thought. As an interdependent network of subsystems, in contrast to a global functional system, hypotheses concerning the specific intrahemispheric processes involved need to be formulated, and a multimethod approach to examining these subprocesses should be employed.

The findings from this study have raised interesting questions concerning the validity of reaction time estimates of IHTT. In particular, it has been suggested that IHTTs derived from the left and right hands might reflect different underlying mechanisms. Factors such as hemispheric specialization and the effects of differential priming are suspected to have played a role in the speed and efficiency with which information was transmitted. In addition, the nature of the signals being transmitted likely had a primary role in determining the specific transcallosal route utilized. One important finding from this study was that the speed with which information is transferred was associated with either an improved or decreased level of performance. The specific factors determining the speed of a signal and the conditions under which a particular speed enhances performance should be more clearly identified in future research. This line of inquiry has widespread ramifications for remediation of particular learning deficiencies.

Notes

1. In the present report, the term "dominant hand" always refers to the right hand and the term "nondominant hand" always refers to the left hand.

2. The time interval between testing sessions ranged between two to twenty-six months. However, there was no systematic difference between the subject groups in the inter-session interval (ISI). The dyslexics' ISI=1.01 years, SD=.49 and the controls' ISI=1.17 years, SD=.53 (t<1).

3. In an attempt to examine the possible existence of a speed/accuracy tradeoff in performance, correlations between the number of pegs placed and the number of fine manual errors made in each condition were analyzed. Pearson product-moment correlations were computed separately for each group and resulted in values ranging from r=-.25 to .38 for the dyslexics and from r=.04 to .36 for the controls. These low correlations indicate that the number of errors made was not related to the number of pegs placed.

4. The lowest inter-rater reliability was obtained in the dominant hand condition (r=.69). Values ranging from r=.81 to r=.85 were obtained for the remaining conditions (i.e., non-dominant, bimanual left hand, bimanual right hand).

5. All post hoc paired comparisons were evaluated by the Neuman-Keuls procedure.

6. The same analysis was computed using mean RT as the dependent variable. The results were similar to those based upon median RT.

7. The identical analysis was computed using IHTT based upon mean RT as the dependent variable. The results were similar to those based upon median IHTT.

8. Correlations and partial correlations (i.e., with the linear effects of the dominant hand score removed) between IHTT and PPT nondominant score were also performed using the percentile value. Results from these analyses revealed patterns similar to those as described based upon the raw score.

9. Initial PPT scores from the subgroup of 38 Ss who returned to the laboratory for the second administration were re-evaluated to insure that this subgroup accurately represented performance by the entire sample. A 2 x 3 ANOVA was performed on the initial set of raw scores with Group (dyslexic versus control) and Condition (right hand versus left hand versus bimanual) as between and within group

factors, respectively. A pattern identical to that which was demonstrated based upon the entire sample was obtained. A significant main effect for Condition [F(2,72)=91.72,p=.0001] emerged, and again demonstrated best performance in the right hand condition as compared to the left hand and bimanual conditions (p<.01 for both). Similarly, the Group x Condition interaction [F(2,72)=4.10,p=.02] was significant and again revealed the largest between group difference in the left hand condition. This analysis was also repeated on the percentile scores, and revealed a pattern of findings that was identical to that pattern which was initially reported. Specifically, no main effect for either Condition [F(2,72)=1.63,p<.2] or Group [F(1,36)=3.37,p<.07] was obtained, while the Group x Condition interaction was marginally significant [F(2,72)=2.97,p=.06].

10. Since the mean number of pegs placed in the bimanual condition during time 2 was almost identical for the groups (dyslexic M=11.37; controls M=11.53), the number of each movement made (i.e., number of left leads and number of right leads) was used as the dependent variable as opposed to a percentage score (i.e., number of each movements/total number of movements).

11. Correlations were also computed between PPT raw scores from time 1 and movements from time 2, separately for each group. For the dyslexics, a pattern similar to that found based upon the percentile scores was obtained. For the controls, with only one exception, all the correlations were positive and very low (values ranged from r=.005 to r=.21).

12. Correlations were computed between PPT raw scores from time 2 and movement types from time 2. The results of these correlations were similar to those results based on the percentiles for each group.

13. The fact that the control group performed well on other cognitive measures that were not part of the inclusion criteria (see Table 1) suggests that their unexpectedly low performance on the bimanual condition was an anomalous occurrence and is not likely indicative of a generally dysfunctional group.

14. In a preliminary study on a subgroup of the present sample (N=10 dyslexics and 10 controls), visual evoked potential measures of IHTT revealed different patterns in the length of transfer in response to left versus right visual field presentations between the subject groups (Davidson, Saron, Leslie and Reiner, 1985). These initial findings suggest that different processes associated with information transfer might be assessed when using different techniques. Unfortunately the VEP measures of IHTT were collected almost two years after the manual reaction time study was run, preventing direct comparison between measures.

Figure 1: Illustrations of the three types of fine manual errors.

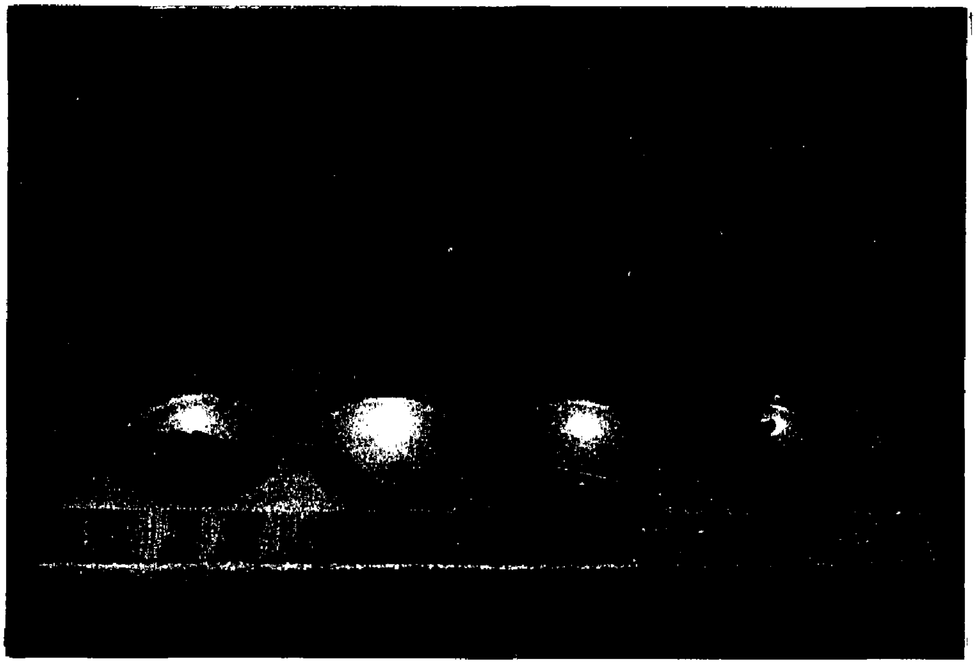
a) A peg spilled out of the left hand cup.

b) Two pegs, rather than one, were picked up by the left hand.

c) The peg was unintentionally dropped by the right hand in the process of placing it.

Figure 1

a) spill



b) pick up

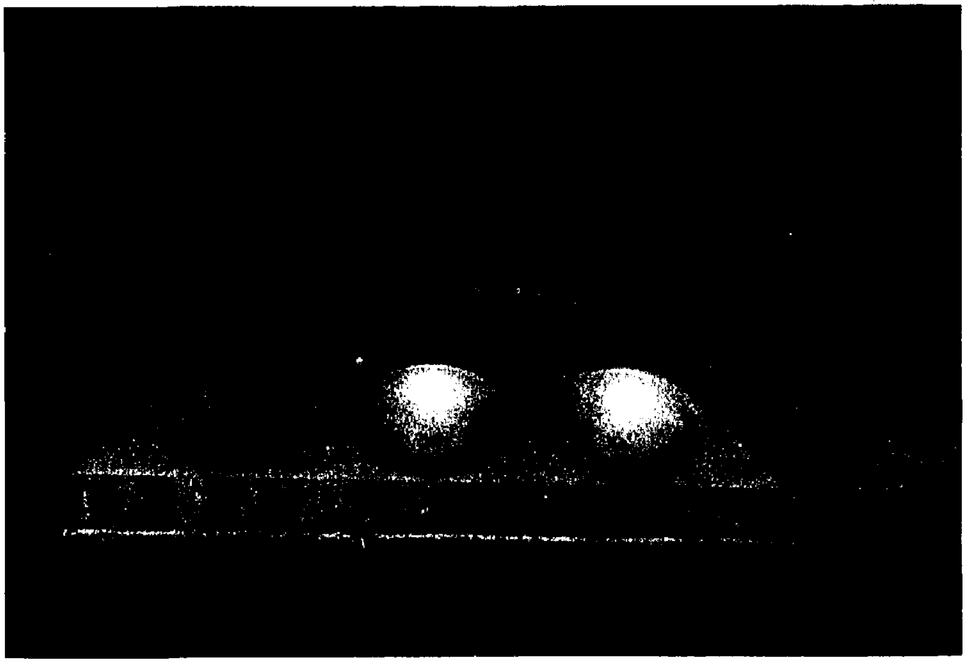


Figure 1

c) drop

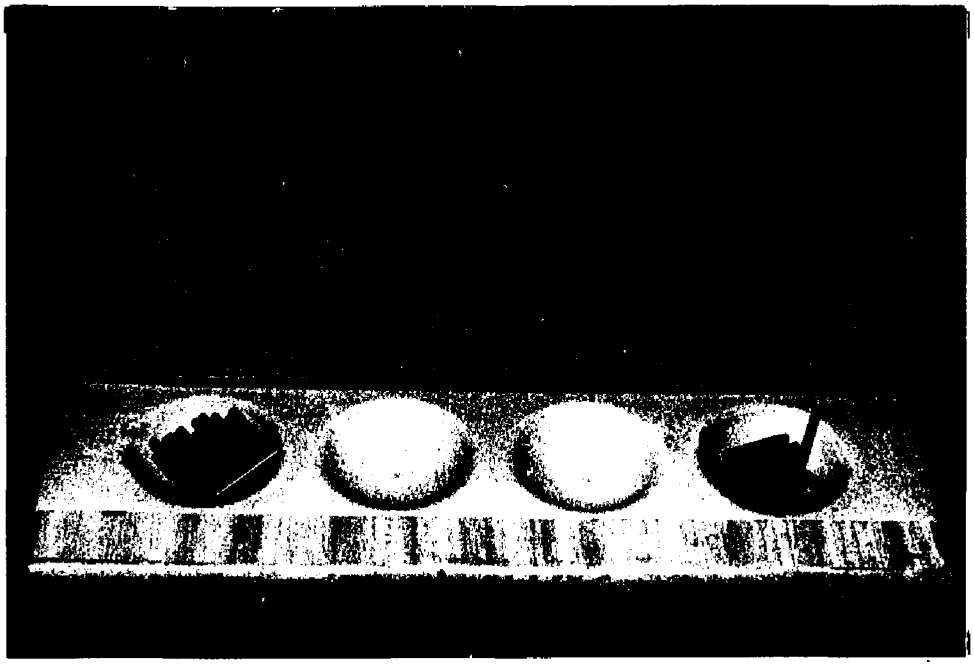


Figure 2: Examples of bimanual movements at each target point.

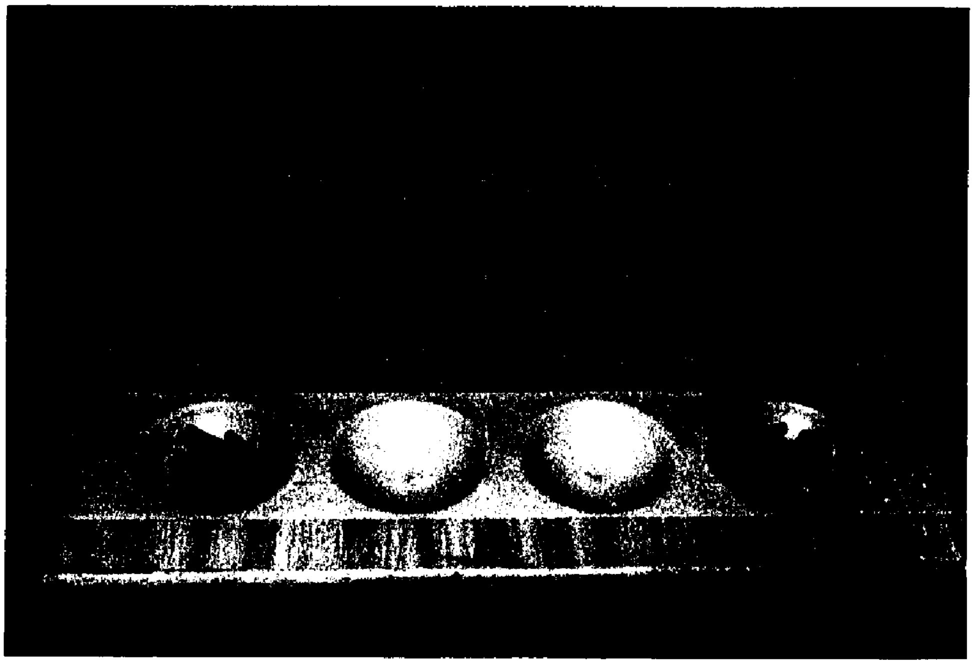
1) Symmetrical movement:
  a) leaving the cups; and
  b) leaving the placed pegs.

2) Right hand leading the left:
  a) when leaving the cups; and
  b) when leaving the pegs.

3) Left hand leading the right:
  a) when leaving the cups; and
  b) when leaving the pegs.

Figure 2

1a) Symmetrical



1b) Symmetrical

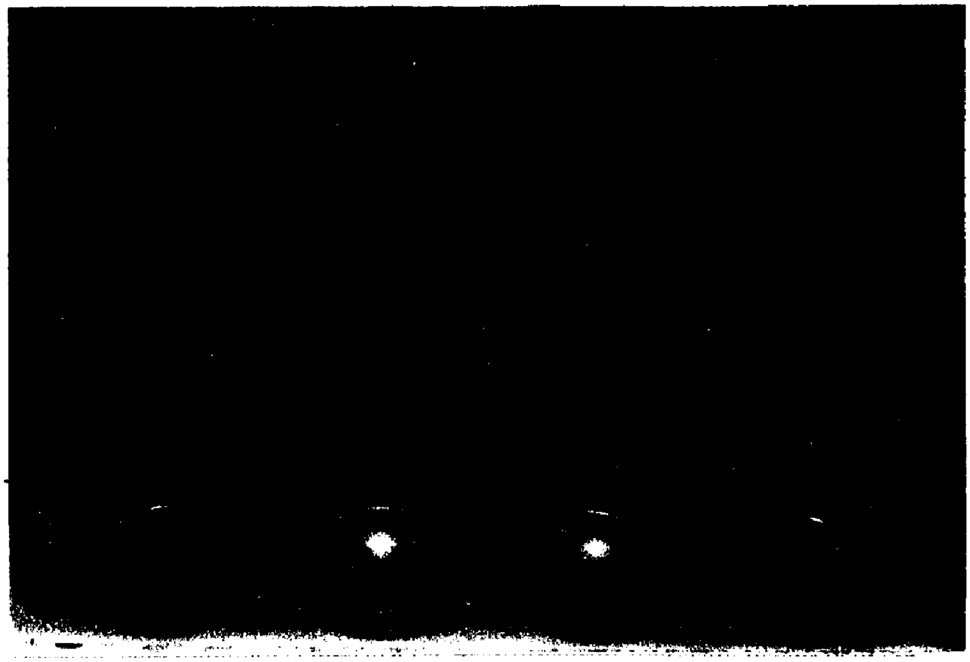
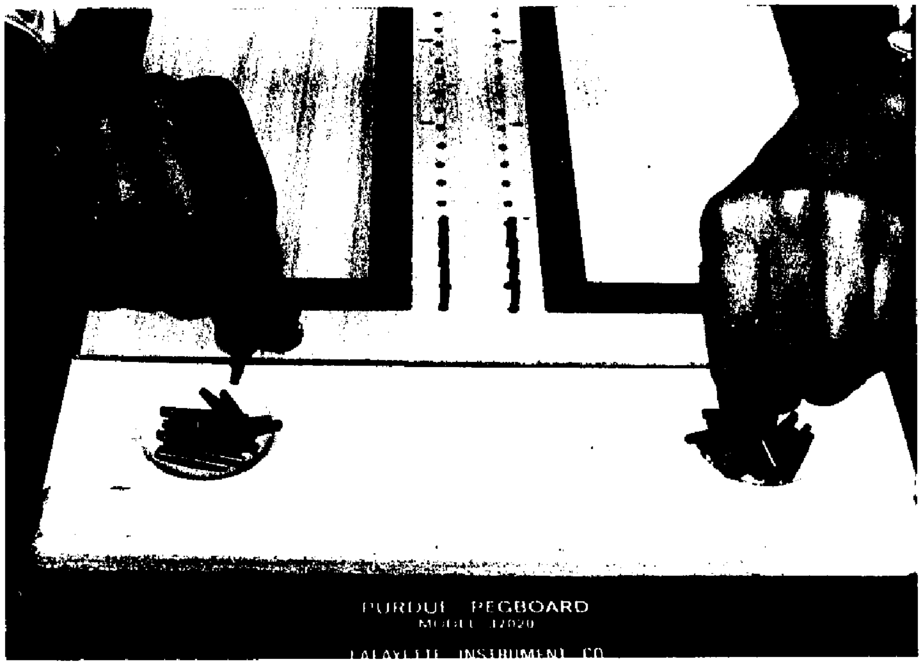


Figure 2

2a) Right lead



2b) Right lead

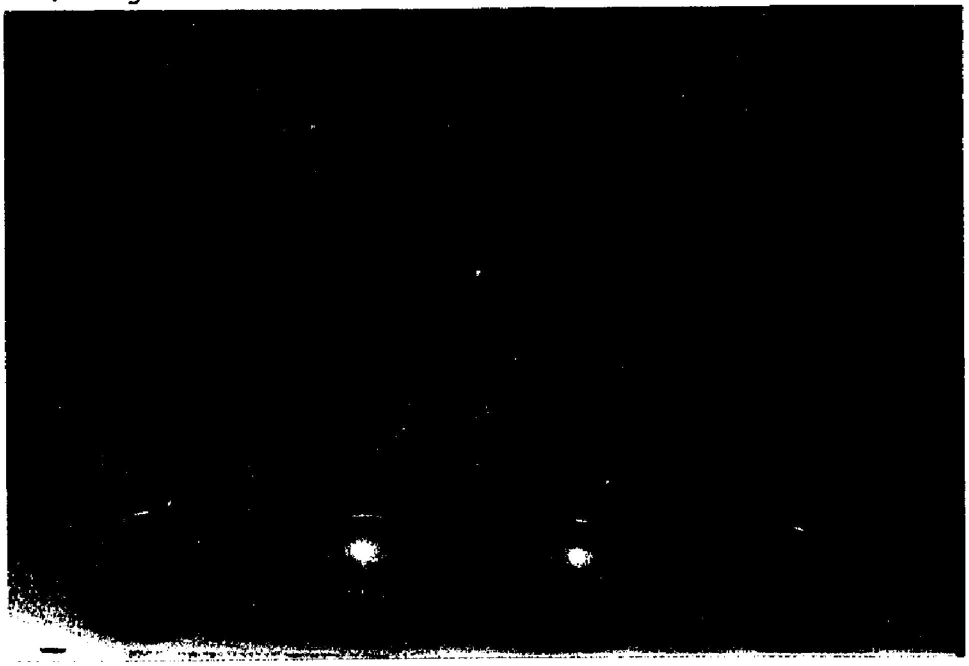
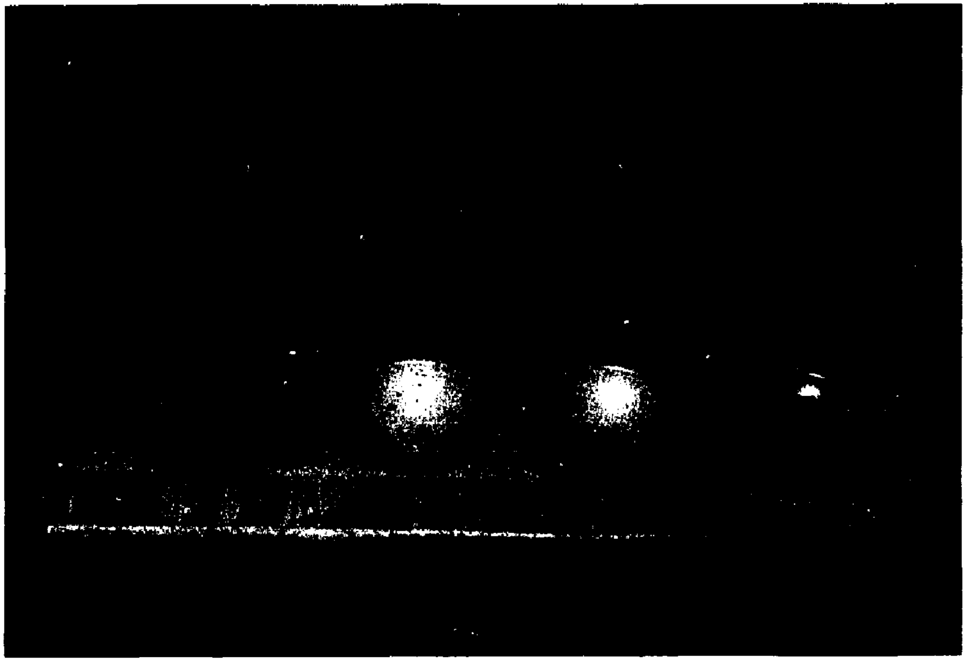


Figure 2

3a) Left lead



3b) Left lead

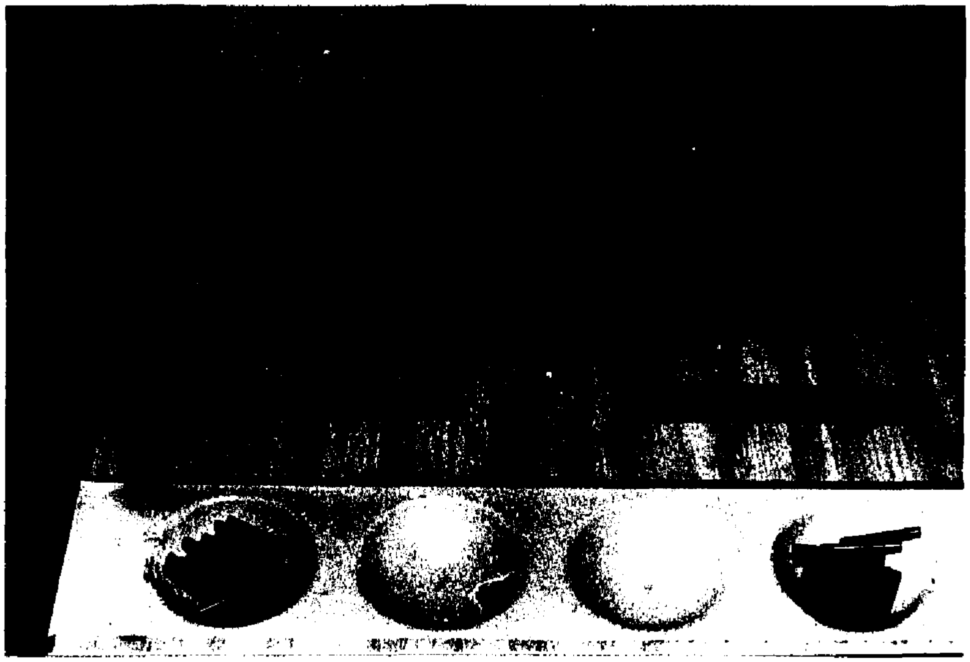


Figure 3: Mean raw score performance (i.e., number of pegs placed) for dyslexics and controls (N=25 for both) separately for each of the three PPT conditions.

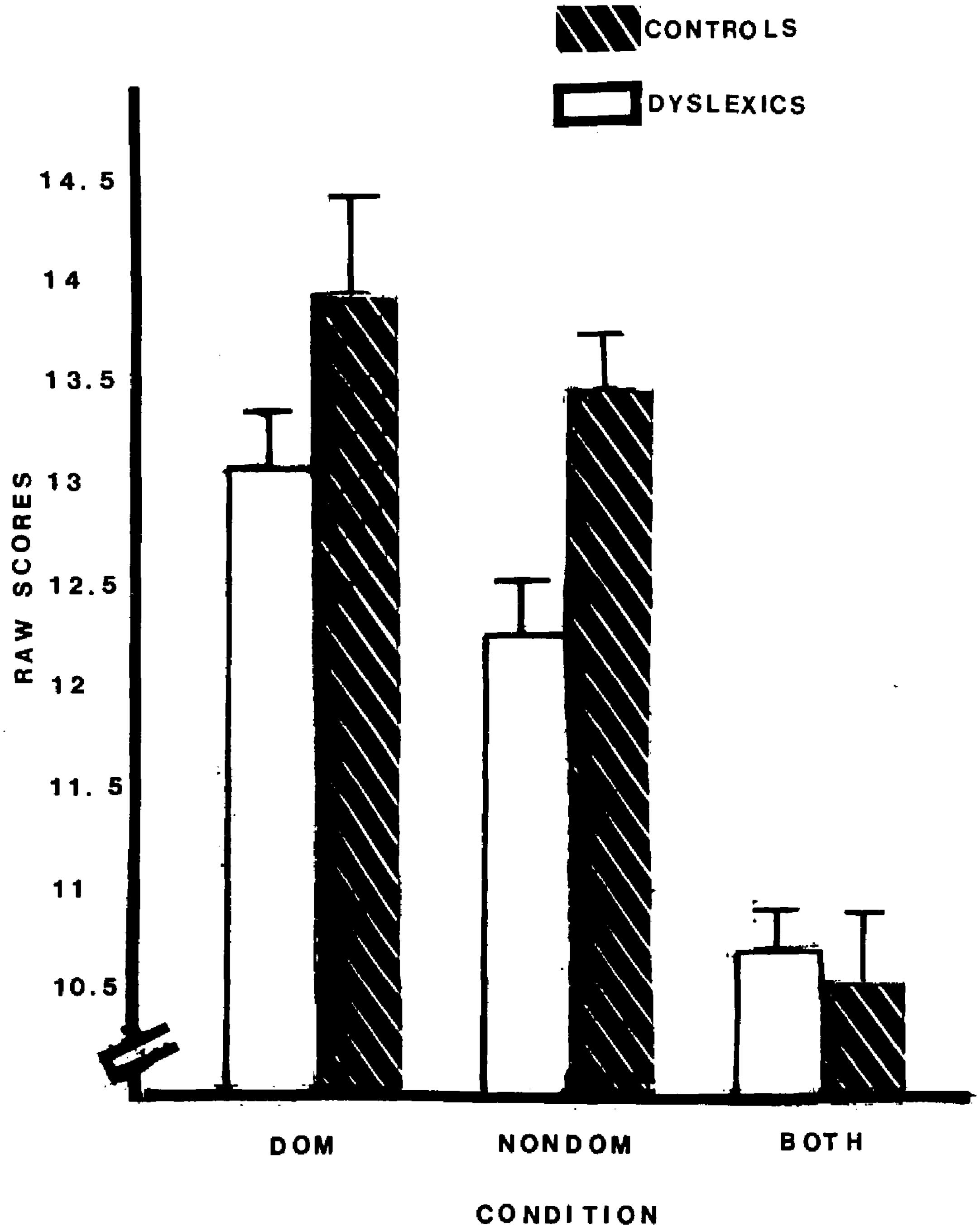
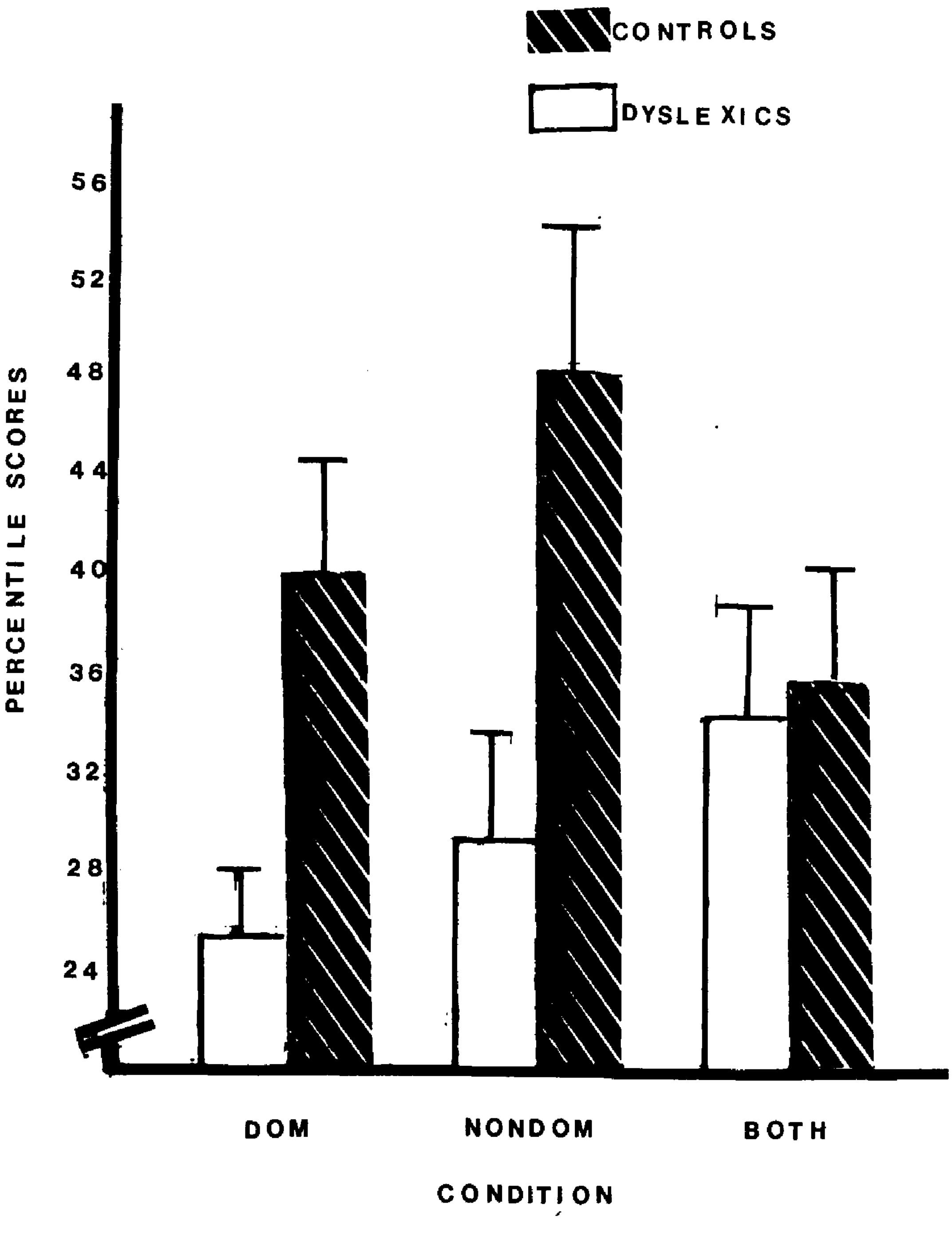

CONTROLS
DYSLEXICS
RAW SCORES
14.5
14
13.5
13
12.5
12
11.5
11
10.5
DOM
NONDOM
BOTH
CONDITION

Figure 4: Mean percentile scores for dyslexics and controls separately for each of the three PPT conditions. Percentiles are based upon Gardner and Broman (1979). N=25 per group.


CONTROLS
DYSLEXICS
PERCENTILE SCORES
56
52
48
44
40
36
32
28
24
DOM
NONDOM
BOTH
CONDITION

Appendix A

Psychometric measures included in the battery:

1. Bender Visual Motor Gestalt Test (Bender, 1966). Subjects are required to reproduce line drawings of a figure presented one at a time on cards in front of them. This test can be used to assess grapho-motor and visual-spatial skills.

2. Benton-Spreen Right-Left Orientation Test (Benton and Spreen, 1969). This test consists of 32 commands which assess the subject's knowledge of right and left on his own body and on the body of someone facing him.

3. Eye Dominance Measure. A subject is required to binocularly focus on the experimenters nose through a small opening. Sighting eye dominance is then measured by having the subject alternately close his left and right eye and report whether or not he sees the original object of focus.

4. Gates-MacGinite Reading Comprehension Subtest (Gates and MacGinite, 1972). This is a scholastic achievement test which measures children's reading comprehension skills. Subjects are asked to read numerous short stories silently and then answer a series of questions about them.

5. GFW Test of Auditory Discrimination - Quiet Subtest (Goldman, Fristoe, Woodcock, 1970). This test requires subjects to discriminate between phonetically confusable words by pointing to pictures representing the words they heard.

6. GFW Test of Auditory Discrimination - Noise Subtest (Goldman, Fristoe, Woodcock, 1970). This test requires subjects to discriminate between phonetically confusable words in the presence of background noise.

7. Gray Oral Reading Test (Gray, 1967). This test provides an additional measure of oral-decoding skills by requiring subjects to read paragraphs aloud.

8. Harris Test of Lateral Dominance (Harris, 1958). The child is asked to pantomine 10 common actions. If 7 or more actions are performed exclusively with the right hand, then the child was considered right-handed.

9. Hiskey-Nebraska Test of Learning Aptitude - Visual Attention Span Subtest (Hiskey, 1955). This test measures short-term visual memory by presenting subjects with pictures of objects which can be easily labelled. Visual linguistic memory and sequencing skills may be assessed.

10. ITPA Sound Blending Subtest (Kirk, et al., 1968). Words and nonsense words are auditorially presented to subjects in a manner which divides them into separate successive sounds. Subjects are then instructed to blend the sounds into a complete word or nonsense word.

11. ITPA Visual Sequential Memory Subtest (Kirk, et al., 1968). This test requires subjects to remember and duplicate series of visually presented nonsensical shapes. It assesses short-term visual sequential non-verbal memory skills.

12. NCCEA Sentence Construction Subtest (Spreen and Benton, 1977). Subjects are provided with two or three specific words and are asked to generate sentences using those words. This test provides a measure of children's expressive syntactical abilities.

13. NCCEA Sentence Repetition Subtest (Spreen and Benton, 1977). This test assesses auditory-linguistic memory by having subjects repeat sentences of progressively increasing length.

14. NCCEA Visual Naming Subtest (Spreen and Benton, 1977). Subjects are presented with ten common objects, and without touching them, are required to name them in a specified order.

15. NCCEA Word Fluency Subtest (Spreen and Benton, 1977). This test assesses word-retrieval skills by requiring subjects to spontaneously generate as many words as possible beginning with certain letters within a specified period of time.

16. Purdue Pegboard Test (Tiffin, 1968). This test measures the manual dexterity (fine and gross hand movements) of each hand separately and of both hands simultaneously.

17. Rapid Automatized Naming Test (RAN) (Denckla and Rudel, 1976b). This test requires the subject to name common stimuli as quickly as possible. The four sets of stimuli are: colors, numbers, objects and letters.

18. The Token Test for Children (DiSimoni, 1978). This test is a measure of auditory receptive language skills. Subjects are asked to manipulate objects of different colors and shapes in response to verbal commands which increase in length and syntactic complexity.

19. <u>Woodcock Reading Mastery Tests - Word Attack Subtest</u> (Woodcock, 1973). This test measures children's ability to identify nonsense words through the application of phonic and structural analysis.

20. <u>Woodcock Reading Mastery Tests - Word Identification Subtest</u> (Woodcock, 1973). This test measures children's ability to identify words through the application of whole word and phonetic analysis.

Appendix B

List of Tables:

Table 1: Psychometric characteristics of the groups.[a,b,c]

Measures used for subject inclusion:

Measure	Dyslexics		Controls	
	M	SD	M	SD
Harris Handedness	96.80	7.48	97.20	4.58
FSIQ	115.08	11.90	121.88	12.54
PIQ	117.60	12.11	114.28	14.27
Block Design Subtest	13.12	2.26	12.84	3.54
GFW Quiet	92.16	18.91	73.64	24.46
Visual Naming Subtest	55.50	33.21	77.32	10.04
RAN: Colors	43.96	34.76	78.00	16.87
Objects	37.76	27.04	73.40	14.49
Numbers	21.16	27.64	75.96	20.66
Letters	11.84	25.72	81.44	18.24
Myklebust Quotient	0.73	0.08	1.18	0.17

Table 1: continued

Additional psychometric data:

Reading Measures	Dyslexics		Controls	
	M	SD	M	SD
Word Attack	32.48	24.30	81.88	14.20
Word Identification	17.60	15.97	77.32	13.55
Gray Oral	19.92	13.15	81.60	12.75
Gates-MacGinite	36.23	27.10	82.44	14.55

Language, Motor and Memory Measures

	Dyslexics		Controls	
	M	SD	M	SD
VIQ	110.16	11.88	124.20	11.50
Sentence Construction	50.04	33.98	64.04	20.76
Word Fluency	43.52	22.71	66.00	29.59
Sentence Repetition	47.64	33.28	71.04	28.69
Sound Blending	83.00	13.93	94.30	4.79
Token Test: I	55.75	2.44	57.10	2.20
II	59.24	16.04	60.04	18.31
III	56.08	24.54	60.52	20.05
IV	59.04	23.96	68.48	19.58
V	50.48	26.32	62.80	24.13
Total	55.60	22.24	68.24	16.77

Table 1: continued

Right-Left Orientation	72.64	19.03	62.76	29.54
GFW Noisy	45.00	31.08	44.96	27.18
Visual Attention Span	49.80	38.99	57.24	43.26
Sequential Memory	73.72	27.04	69.60	27.05
Bender Gestalt	37.78	31.53	48.33	26.90
Purdue Pegboard[d] :Dom	25.88	18.98	40.36	26.68
Non-dom	29.72	24.65	48.76	27.86
Bimanual	34.64	21.59	35.84	25.05

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[a] N=25 per group except for Visual Naming (N=24 for dyslexics), Gates-MacGinite (N=22 for dyslexics), Sentence Repetition (N=24 for controls), Sound Blending (N=22 for dyslexics, N=23 for controls), Bender Gestalt (N=9 for dyslexics, N=15 for controls), Token Test I (N=16 for dyslexics, N=20 for controls).

[b] The means for the psychometric measures are based on percentile scores except for the WISC-R (FIQ, PIQ, VIQ), Block Design (scaled score), and Myklebust Quotient.

[c] Each measure is described in Appendix A.

[d] The PPT raw scores based on N=25 for each group are presented in Appendix B.

Table 2: Psychometric characteristics of the returning subjects. N's=19 per group.a,b,c

	Dyslexics		Controls	
	M	SD	M	SD
Age	12.08	1.30	12.31	1.40
VIQ	111.68	12.86	126.84	11.69
PIQ	119.74	11.95	116.79	13.87
FSIQ	117.21	12.50	124.84	12.28
MQ	0.72	0.09	1.21	0.17
Word Attack	31.26	25.37	83.74	14.34
Word Identification	17.89	16.94	81.79	10.09
Gray Oral	20.47	14.87	84.11	12.37
Gates-MacGinite	39.63	29.84	82.89	13.14

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[a] The means for the reading measures are based on percentile scores.

[b] The Myklebust Quotient (MQ) was calculated using the percentile score from Word Identification.

[c] The ages reported in this table represent the ages of the Ss when they returned for the additional testing session. However, the WISC-R and reading tests were not re-administered so that the scores reported in this table represent performance during the initial testing sessions.

Table 3: Pearson product-moment correlations between PPT conditions, separately by group, based upon percentile scores. N=25 per group.

Dyslexics

	Nondominant	Bimanual
Dominant	.554**	.409*
Nondominant		.500**

Controls

	Nondominant	Bimanual
Dominant	.561**	.671***
Nondominant		.738****

---

*   p<.05
**   p<.01
*** p<.001
****p<.0001

Table 4: Pearson product-moment correlations between PPT conditions, separately by group, based upon raw scores. N=25 per group.

Dyslexics

	Nondominant	Bimanual
Dominant	.517**	.349
Nondominant		.513**

Controls

	Nondominant	Bimanual
Dominant	.595**	.696****
Nondominant		.784****

---

* p<.05
** p<.01
*** p<.001
****p<.0001

Table 5: Means and standard deviations for median reaction times (in milliseconds) averaged across orientation of hand and group, split by hand and visual field. N=50.

	Left Hand		Right Hand	
	LVF	RVF	LVF	RVF
M	321.53	324.41	321.42	319.82
SD	45.40	41.37	44.05	39.31

Table 6: Means and standard deviations for median reaction times (in milliseconds) across orientation by hand, split by hand, visual field, and group. N=25 per group.

		Left Hand		Right Hand	
		LVF	RVF	LVF	RVF
Dys	M	321.35	324.98	318.68	318.96
	SD	40.26	35.09	34.35	34.39
Cont	M	321.72	323.85	324.16	320.67
	SD	50.43	47.18	52.19	44.03

Table 7: Means and standard deviations for median reaction times (in milliseconds) split by hand, orientation of hand, visual field and group. N=25 per group.

		Left Hand				Right Hand			
		Straight		Crossed		Straight		Crossed	
		LVF	RVF	LVF	RVF	LVF	RVF	LVF	RVF
Dys	M	319.71	323.32	322.98	326.64	317.40	319.57	319.97	318.35
	SD	38.99	32.33	42.23	38.26	35.51	36.46	33.84	32.93
Con	M	320.12	323.08	323.32	324.62	319.50	317.75	328.81	323.59
	SD	50.23	48.19	51.62	47.13	49.43	45.26	55.44	43.49

Table 8: Percentage of Ss in each group who showed the predicted effects:
LVF(RT) < RVF(RT) when left hand is responding.
RVF(RT) < LVF(RT) when right hand is responding.
N=25 per group.

	Straight Hand		Crossed Hands	
	Left Hand	Right Hand	Left Hand	Right Hand
Dys	64%	36%	64%	48%
Cont	64%	52%	56%	56%

Table 9: Interhemispheric transfer time (IHTT) computed by subtracting the ipsilateral hand-visual field reaction time from the contralateral hand-visual field reaction time. The reaction times are based upon the medians for each condition combination. A positive IHTT reflects an effect in the anatomically predicted direction; a negative IHTT reflects an effect in the direction opposite to the anatomical prediction. N=25 per group.

		Straight hand		Crossed hand	
		Left hand	Right hand	Left hand	Right hand
Dys	M	3.60	-2.16	3.65	1.62
	SD	13.04	11.82	13.59	10.76
Cont	M	2.97	1.77	1.31	5.22
	SD	12.98	12.27	12.66	16.46

Table 10: Pearson product-moment correlations between interhemispheric transfer time (IHTT) and overall reaction time (RT). Overall reaction time was computed by summing the LVF and RVF reaction time (based on the median), separately for each group and hand condition. Positive values indicate an association between longer IHTT and slower reaction time. Negative values indicate an association between longer IHTT and shorter reaction time. N=25 per group .

	Dyslexics	Controls
IHTT	LVF + RVF RT	LVF + RVF RT
Straight Right Hand	-.08	.34*
Crossed Right Hand	.09	.73****
Straight Left Hand	-.52***	-.16
Crossed Left Hand	-.30	-.36*

---

* p<.10
** p<.05
*** p<.01
****p<.001

Table 11: Pearson product-moment correlations between IHTT and reaction time (based on the median) separately for each visual field. Positive values reflect an association between longer IHTT and slower reaction time. Negative values are indicative of an association between longer IHTT and faster reaction time. N=25 per group.

	Dyslexics		Controls	
	RVF	LVF	RVF	LVF
IHTT				
Straight Right Hand	-.24	.09	.22	.45**
Crossed Right Hand	-.08	.24	.64***	.80****
Straight Left Hand	-.36*	-.63***	-.03	-.28
Crossed Left Hand	-.13	-.44**	-.24	-.46**

---

* $p<.10$
** $p<.05$
*** $p<.001$
**** $p<.0001$

Table 12: Pearson product-moment correlations between IHTT (based upon median reaction times) and PPT nondominant hand raw score, separately by hand, orientation and group. Also, correlations between these variables are presented with the linear effects of the dominant condition PPT score removed. A positive correlation indicates an association between better PPT nondominant performance and longer IHTT values. A negative correlation indicates an association between better PPT performance and shorter IHTT values. N=25 per group.

Dyslexics

	Correlations	Partial Correlations
	Nondom raw score	Nondom raw score
IHTT		
Right Straight	-.02	-.04
Right Crossed	-.31	-.35
Left Straight	.29	.47
Left Crossed	.43	.51

Controls

	Correlations	Partial Correlations
	Nondom raw score	Nondom raw score
IHTT		
Right Straight	-.16	.07
Right Crossed	.12	.28
Left Straight	.14	.15
Left Crossed	-.16	-.31

Table 13: Correlations between PPT raw scores and language measures across subject groups. Positive values reflect an association between better PPT performance and slower naming (RAN) speed. Negative values indicate an association between better PPT performance and faster naming (RAN) speed. N=50.a,b,c

	Dom	Nondom	Bimanual
RAN-Colors	-.35**	-.29*	-.14
Objects	-.22	-.38**	-.16
Numbers	-.40**	-.43**	-.14
Letters	-.35**	-.42**	-.13
Sentence Repetition	.19	.17	-.02
Word Fluency	.23	.18	-.10
Word Attack	.31*	.39**	-.06
Word Identification	.38**	.44***	.03
Gray Oral	.39**	.45***	.04
Gates-MacGinite	.19	.37**	.02
MQ	.30*	.39**	.03

---

* p<.05

** p<.01

*** p<.001

a Appendix A provides a description of each language measure.

b Except for the RAN subtests raw scores, which are based on time in seconds, the means for the reading and language tests are based on percentile scores. PPT scores are based on raw scores.

c N=50 except for Gates-MacGinite (N=47) and Sentence Repetition (N=49).

Table 14: Correlations between PPT raw scores and language measures, separately for each group. Positive values reflect an association between better PPT performance and slower naming (RAN) speed. Negative values indicate an association between better PPT performance and faster naming (RAN) speed.a,b,c,d

	Dyslexics			Controls		
	Dom	Non-dom	Bimanual	Dom	Non-dom	Bimanual
RAN-Colors	.05	-.03	.05	-.61***	-.30	-.51**
Objects	.20	-.18	-.20	-.46*	-.36	-.37
Numbers	-.07	-.18	-.02	-.69***	-.51**	-.66***
Letters	.05	-.18	-.06	-.52**	-.36	-.57**
Sentence Repetition	.32	.34	.19	-.17	-.33	-.18
Word Fluency	.12	-.02	-.22	.14	.11	-.01
Word Attack	.31	.38	.12	-.03	-.14	-.24
Word Identification	.29	.31	.05	.26	.28	.26
Gray Oral	.26	.49**	.18	.39	.20	.27
Gates-MacGinite	-.08	.30	.09	.05	.05	.12
MQ	.10	.13	.13	.11	.21	.16

---

* p<.05

** p<.01

*** p<.001

a Appendix A provides a description of each language measure.

b Except for the RAN subtests raw scores, which are based on time in seconds, the means for the reading and language tests are based on percentile scores. PPT scores are based on raw scores.

c N=25 per group except for Gates-MacGinite (N=22 for dyslexics) and Sentence Repetition (N=24 for controls).

d Scatterplots based on the significant PPT versus RAN correlations obtained for the controls are displayed in Appendix E.

Table 14.1: Correlation coefficients based on PPT and RAN raw scores obtained by dyslexics and controls were compared using Fisher's Zr transformation. This table displays the probabilities of these comparisons. (The correlations themselves are displayed in Table 14).

r_{controls} versus $r_{\text{dyslexics}}$

	Dom	Nondom	Bimanual
RAN-Colors	$p<.05$	N.S.	$p<.05$
Objects	$p<.05$	N.S.	N.S.
Numbers	$p<.01$	N.S.	$p<.05$
Letters	$p<.05$	N.S.	$p<.05$

Table 15: Pearson product-moment correlations between IHTT (based upon median reaction times from the straight hand conditions) and language measures. Positive values for the RAN subtests indicate an association between longer IHTTs and slower naming speed. Negative values for the RAN subtests indicate a relation between longer IHTTs and faster naming speed.a,b,c,d

	Dyslexics		Controls	
	IHTT Right Hand	IHTT Left Hand	IHTT Right Hand	IHTT Left Hand
RAN:Colors	.19	-.12	.12	-.10
Objects	-.03	-.30	.03	-.30
Numbers	.10	-.12	.28	-.16
Letters	.13	-.24	.19	-.18
Word Attack	.40**	-.01	.17	-.36*
Word Identification	.47**	-.14	.02	-.01
Gray Oral	.45**	.23	-.14	.25
Gates-MacGinite	-.18	.11	.17	.04
Sentence Repetition	-.04	-.19	.31	-.04
Word Fluency	-.12	.45**	-.27	.34
MQ	.48**	.04	.10	-.09

---

* p<.10

** p<.05

a Appendix A provides a description of each language measure.

b Except for the RAN subtests raw scores, which are based on the time in seconds, the means for the reading tests are based on percentile scores.

c N=25 per group except for Gates-MacGinite (N=22 for dyslexics; N=25 for controls) and Sentence Repetition (N=25 for dyslexics; N=24 for controls).

d Scatterplots for selected correlations are displayed in Appendix F.

Table 16: Pearson product-moment correlations between IHTT (based upon median reaction times from the straight hand conditions) and language measures, across subject groups. Positive values for the RAN subtests indicate an association between longer IHTTs and slower naming speed. Negative values for the RAN subtests indicate a relation between longer IHTTs and faster naming speed.a,b,c

	IHTT Right Hand	IHTT Left Hand
RAN:Colors	.05	-.08
Objects	-.11	-.21
Numbers	-.01	-.07
Letters	-.04	-.11
Word Attack	.31**	-.10
Word Identification	.26*	-.06
Gray Oral	.21	.07
Gates-MacGinite	.06	.03
Sentence Repetition	.17	-.12
Word Fluency	-.12	.34**
MQ	.25*	-.04

---

* p<.10

** p<.05

a Appendix A provides a description of each language measure.

b Except for the RAN subtests raw scores, which are based on the time in seconds, the means for the reading tests are based on percentile scores.

c N=50 except for Gates-MacGinite (N=47) and Sentence Repetition (N=49).

Table 17: PPT test-retest reliabilities based on raw and percentile scores. The second administration occurred approximately one year after the first. N=19 per group.

Dyslexics

	Raw	Percentile
Dominant	.54**	.56***
Nondom	.57***	.48**
Bimanual	.42*	.37

Controls

	Raw	Percentile
Dominant	.66***	.72****
Nondom	.55***	.41*
Bimanual	.56***	.60***

---

*   p<.10
**   p<.05
*** p<.01
****p<.001

<u>Table</u> <u>18</u>: Means and standard deviations for PPT raw and percentile scores split by Group and Time across the unimanual (i.e. dominant and nondominant) conditions. N=19 per group.

<u>Raw</u> <u>Scores</u>

		<u>Time</u> <u>1</u>	<u>Time</u> <u>2</u>
Dyslexic	M	12.82	13.84
	SD	1.57	1.85
Control	M	13.95	14.13
	SD	1.66	2.09

<u>Percentile</u> <u>Scores</u>

		<u>Time</u> <u>1</u>	<u>Time</u> <u>2</u>
Dyslexic	M	30.11	41.50
	SD	23.52	29.33
Control	M	47.89	46.50
	SD	26.93	30.28

Table 19: PPT means and standard deviations based on raw scores from the first (T1) and second (T2) administrations. N's=19 per group.

Raw Scores

		Dominant		Non-dominant		Bimanual	
		T1	T2	T1	T2	T1	T2
Dys	M	13.16	14.26	12.47	13.42	10.74	11.37
	SD	1.26	1.97	1.81	1.68	1.19	1.21
Cont	M	14.21	14.58	13.68	13.68	10.74	11.53
	SD	1.72	2.06	1.60	2.08	1.45	1.61

Table 20: PPT means and standard deviations based on percentile scores from the first (T1) and second (T2) administrations. N's=19 per group.

Percentile Scores

		Dominant		Non-dominant		Bimanual	
		T1	T2	T1	T2	T1	T2
Dys	M	27.74	40.58	32.47	42.42	35.47	41.89
	SD	20.08	31.42	26.86	27.90	22.85	25.48
Cont	M	44.16	44.79	51.63	48.21	37.79	47.00
	SD	26.54	30.61	27.52	30.68	25.14	30.09

Table 21: Pearson product-moment correlations between PPT conditions, separately by group, based upon percentile scores from the second administration. N=19 per group.

Dyslexics

	Nondominant	Bimanual
Dominant	.525*	.737***
Nondominant		.779****

Controls

	Nondominant	Bimanual
Dominant	.466*	.756***
Nondominant		.598**

---

* p<.05
** p<.01
*** p<.001
****p<.0001

Table 22: Pearson product-moment correlations between PPT conditions, separately by group, based upon raw scores from the second administration. N=19 per group.

Dyslexics

	Nondominant	Bimanual
Dominant	.453*	.610**
Nondominant		.685***

Controls

	Nondominant	Bimanual
Dominant	.452*	.713***
Nondominant		.499*

---

* p<.05
** p<.01
***p<.001

Table 23: Means and standard deviations of the number of left and right hand leads displayed by each group during bimanual PPT performance. N=18 dyslexics and 17 controls.

Asymmetrical Movements

		Left Leads	Right Leads
Dys	M	3.94	9.44
	SD	2.46	5.32
Cont	M	5.29	6.18
	SD	3.26	4.89

Table 24: Pearson product-moment correlations between PPT percentile scores for each condition obtained during the first administration and the number of symmetrical, asymmetrical left and right movements during the second administration. Positive values reflect a relation between better PPT performance and a higher incidence of a particular movement. N's=18 for the dyslexics and 17 for the controls.

Dyslexics

	Movements		
	Symmetrical	Left Asym	Right Asym
PPT1			
Dominant	-.20	-.31	.44*
Nondom	-.21	.30	.29
Bimanual	-.41*	-.06	.56**

Controls

	Movements		
	Symmetrical	Left Asym	Right Asym
PPT1			
Dominant	-.01	-.03	.42*
Nondom	-.30	.11	.51**
Bimanual	.01	-.01	.39

---

* p<.10
** p<.05

Table 25: Pearson product-moment correlations between PPT percentile scores and movement types obtained during the second administration. Positive values reflect an association between better performance and a higher occurrence of a particular movement. N's=18 for the dyslexics and 17 for the controls.

Dyslexics

	Movements		
	Symmetrical	Left Asym	Right Asym
PPT2			
Dominant	-.02	-.10	.36
Nondom	-.14	.07	.42*
Bimanual	-.12	.22	.45*

Controls

	Movements		
	Symmetrical	Left Asym	Right Asym
PPT2			
Dominant	.08	-.14	.48**
Nondom	.28	.07	.01
Bimanual	.23	-.01	.42*

---

* p<.10
** p<.05

Table 26: Pearson product-moment correlations between symmetrical, asymmetrical left and right movements and selected language and reading measures. Positive values involving the RAN subtests indicate an association between slower naming speed and an increased number of the particular movement. Negative values between these variables indicate an association between faster naming speed and a fewer number of movements.a,b

		Asymmetrical	
	Symmetrical	Left	Right
RAN-Colors	-.13	-.22	.23
Objects	-.15	-.30*	.31*
Numbers	-.17	-.37**	.35**
Letters	-.06	-.39**	.24
Sentence Repetition	-.06	.05	.04
Word Fluency	.04	.39**	-.22
Word Attack	.19	.16	-.30*
Word Identification	.15	.25	-.28
Gray Oral	.18	.25	-.32*
Gates-MacGinite	.11	.18	-.18
MQ	.16	.25	-.31*

---

* p<.10

** p<.05

a Except for the RAN subtests raw scores, which are based on time in seconds, the means for the reading and language tests are based on percentile scores.

b N=35 except for Sentence Repetition (N=34) and the Gates-MacGinite (N=32).

Table 27: Pearson product-moment correlations between symmetrical, asymmetrical left and right movements and selected language and reading measures. Positive values involving the RAN subtests indicate an association between slower naming speed and an increased incidence of a particular movement. Negative values between these variables indicate an association between faster naming speed and a fewer number of the movements.a,b

	Dyslexics			Controls		
		Asymmetrical			Asymmetrical	
	Sym	Left	Right	Sym	Left	Right
RAN:Colors	.05	-.07	.03	-.19	-.20	.18
Objects	-.10	-.28	.17	.13	-.09	.07
Numbers	-.12	-.18	.23	.08	-.50**	.13
Letters	.11	-.38	.03	.25	-.35	-.08
Sentence Repetition	.02	.33	.02	-.27	-.41	.30
Word Fluency	.13	.42*	-.23	-.21	.26	.04
Word Attack	.05	.12	-.13	.07	-.45*	.05
Word Identification	-.14	.11	.09	.08	.09	-.11
Gray Oral	-.05	.08	-.01	.09	.10	-.20
Gates Mac-Ginite	-.06	.36	.04	-.05	-.43*	.12
MQ	-.01	-.06	-.03	-.03	.17	-.12

* p<.10

** p<.05

a Except for the RAN subtests raw scores, which are based on the time in seconds, the means for the reading and language tests are based on percentile scores.

b N=18 for dyslexics and 17 for controls except for Sentence Repetition (N=16 for the control group) and the Gates-MacGinite (N=15 for the dyslexic group).

Table 28: Pearson product-moment correlations between movement types and IHTT (based on median reaction time) for each condition. Positive values indicate an association between a higher number of movements and longer transfer time. Negative values indicate an association between an increase in the number of movements and shorter transfer time. N=35.

	IHTT			
	Straight hand		Crossed hand	
	Left hand	Right hand	Left hand	Right hand
Symmetrical	.15	.03	-.12	-.14
Left Asymmetrical	.10	-.01	.14	-.28
Right Asymmetrical	-.11	-.23	.29*	.08

*p<.10

Table 29: Pearson product-moment correlations between movement types and IHTT (based on median reaction time) for each condition, separately for each group. Positive values indicate an association between a higher number of movements and longer transfer time. Negative values indicate an association between an increase in the number of movements and shorter transfer time. N=18 for dyslexics and 17 for controls.

Dyslexics

	IHTT			
	Straight hand		Crossed hand	
	Left hand	Right hand	Left hand	Right hand
Symmetrical	.35	.03	-.12	.02
Left Asymmetrical	.32	-.37	.51**	-.40*
Right Asymmetrical	-.31	-.04	.16	-.14

Controls

	IHTT			
	Straight hand		Crossed hand	
	Left hand	Right hand	Left hand	Right hand
Symmetrical	-.06	-.06	-.06	-.27
Left Asymmetrical	-.08	.17	-.13	-.24
Right Asymmetrical	.11	-.34	.41*	.28

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* p<.10

** p<.05

Appendix C

A preliminary analysis of the PPT data from the first administration, on a subgroup (N for dyslexics=23; N for controls=23) of the present sample, revealed a pattern of between group differences which was suggestive of both a left hemisphere dysfunction and an interhemispheric transfer deficit (Leslie, Davidson and Batey, 1985). The major finding based upon PPT raw scores from this preliminary analysis was the presence of a significant Group x Condition interaction [F(2,88)=5.65,p=.005], which revealed a larger between group difference in the nondominant hand (p<.01) than in the dominant hand (p<.05) condition. This identical pattern was also obtained using the percentile scores [F(2,88)=3.34,p=.04]. It had been hypothesized that a left hemisphere dysfunction alone would not account for this discrepancy between the unimanual conditions. "If unimanual performance with either hand was simply a function of left hemisphere processing, comparable dyslexic deficits should be observed in both" (p. 367). Raw score data demonstrated worse performance by dyslexics in the left versus right hand conditions (p<.01), whereas controls showed no difference between these conditions. To the extent that the executive controls for left hand fine manual action are initiated by the left hemisphere, it was suggested that a deficit in interhemispheric transfer could account for poorer left versus right hand performance in the dyslexics compared to the controls. As previously reported, the final analysis based on the completed sample (i.e., N=50) also demonstrated between group differences in the unimanual conditions of the PPT. However, a discrepancy in the ability for each condition to discriminate between the groups was not present. That is, the dyslexic group exhibited performance deficits as compared to the controls, which were comparble in the dominant and nondominant conditions. In essence, what had been suggested by a preliminary investigation of the data was not supported upon subsequent analysis of the completed data set. For reasons that will be discussed below, several changes and additions to the subject sample were made after the preliminary analysis was performed during the remaining stages of data collection. Data from three subjects (2 controls and 1 dyslexic) that were included in the preliminary analysis were later eliminated from the study. Unfortunately background history data for these subjects had been received only after they had participated in the first PPT session. The background information revealed a history of menigitis for one of the three subjects, and a history of emotional problems for the other two. The completed sample of 50, therefore, included seven additional subjects (3 dyslexics and 4 controls) who were not included in the preliminary analysis. Presented below are the mean unimanual PPT scores for the : A) initial subsample of 46 upon whose data the preliminary analysis was based; B) the three subjects who were later excluded from the study due to their background history; C) the remaining subsample of 43 who were included in the present study; D) the 7 subjects who were added to the present study; and E) the entire sample of 50 that comprise the present study.

Tables: Means and standard deviations of PPT raw and percentile scores based on the:

A) Subsample of 46. The preliminary analysis was based on this subsample's data (Leslie, Davidson and Batey, 1985). N=23 dyslexics and 23 controls.

		Raw			Percentiles		
		Dom	Nondom	Both	Dom	Nondom	Both
Dys	M	13.00	12.13	10.52	23.70	26.91	29.83
	SD	1.28	1.55	0.85	18.24	21.58	17.22
Cont	M	13.70	13.39	10.43	36.30	46.52	33.39
	SD	1.79	1.80	1.41	27.07	30.84	24.39

B) Three subjects who were excluded from the subsample of 46 (i.e., Table A) due to a history of medical and emotional problems. N=1 dyslexic and 2 controls.

		Raw			Percentiles		
		Dom	Nondom	Both	Dom	Nondom	Both
Dys	M	14.00	12.00	10.00	31.00	15.00	14.00
	SD	-	-	-	-	-	-
Cont	M	11.50	11.50	10.00	4.00	11.00	22.00
	SD	0.71	0.71	0.00	2.83	7.07	0.00

C) The remaining sample of 43 who were included in the present study. N=22 dyslexics and 21 controls.

		Raw			Percentiles		
		Dom	Nondom	Both	Dom	Nondom	Both
Dys	M	12.95	12.14	10.55	23.36	27.45	30.64
	SD	1.29	1.58	0.86	18.53	21.92	17.18
Cont	M	13.90	13.57	10.48	39.33	49.95	34.38
	SD	1.73	1.78	1.47	26.27	30.03	25.22

D) The 7 subjects who were added to the study. N=3 dyslexics and 4 controls.

		Raw			Percentiles		
		Dom	Nondom	Both	Dom	Nondom	Both
Dys	M	14.00	13.33	12.00	44.33	46.33	64.00
	SD	0	2.52	2.00	11.72	42.15	32.05
Cont	M	14.50	13.25	11.25	45.75	42.50	43.50
	SD	2.08	0.50	1.71	32.41	11.62	26.16

E) The entire sample in the present study. N's=25 per group.

		Raw			Percentiles		
		Dom	Nondom	Both	Dom	Nondom	Both
Dys	M	13.08	12.28	10.72	25.88	29.72	34.64
	SD	1.26	1.70	1.10	18.98	24.65	21.59
Cont	M	14.00	13.52	10.60	40.36	48.76	35.84
	SD	1.76	1.64	1.50	26.68	27.86	25.05

As can be seen from the above tables, the two control subjects who were removed from the study (Table B) had particularly low unimanual scores. Removal of these scores, therefore, increased the control groups means (Table C compared to Table A). This is particularly true in the dominant hand condition. In effect, this increase in the mean PPT score (for both raw and percentile scores) in the dominant hand condition served to augment the between group difference in that condition. With the exception of the control group's nondominant percentile score, the addition of the seven subjects raised both groups scores. This is particularly true for the dyslexic group. However, the dyslexic's scores increased by approximately the same amount in the dominant and nondominant hand conditions, so that the between group difference in each condition is roughly the same as that found in the sample of 43 subjects (Tables C and E).

Thus, the inconsistent finding of comparable between group differences based upon the entire subject sample (i.e., N=50) in the unimanual conditions is largely due to the elimination of two control subjects. The elimination of these subjects served to increase the control groups dominant hand PPT score.

Appendix D

A. Reproduction of Gardner and Broman's (1979) norms based on their male samples ages 8-0 to 15-11.

B. PPT raw scores from the first administration, separated by age and group.

C. PPT percentile scores from the first administration, separated by age and group.

A) Purdue Pegboard - Normative data: Below is an abridged copy of the normative data that were presented by Gardner and Broman (1979). Although they collected data on males and females separately down to age 5, only those norms based on their male samples ages 8-16 years are presented below. N=30 per 6 month age group, with the following exceptions: 13-0 to 13-5 N=40; 15-6 to 15-11 N=23.

Unimanual Conditions

Age	Dominant hand		Nondominant hand	
	Mean	SD	Mean	SD
8-0 to 8-5	12.70	1.60	12.17	1.51
8-6 to 8-11	13.90	2.19	12.57	1.85
9-0 to 9-5	13.33	1.60	12.43	1.59
9-6 to 9-11	13.87	1.91	12.87	2.05
10-0 to 10-5	14.03	1.88	12.87	1.72
10-6 to 10-11	14.73	1.51	13.90	1.84
11-0 to 11-5	14.93	1.86	14.00	1.98
11-6 to 11-11	14.83	1.60	13.93	1.60
12-0 to 12-5	14.83	1.78	13.67	2.02
12-6 to 12-11	15.37	2.81	14.00	2.38
13-0 to 13-5	15.15	1.92	13.90	2.00
13-6 to 13-11	14.87	1.72	14.10	1.47
14-0 to 14-5	15.67	1.47	14.40	1.57
14-6 to 14-11	14.70	1.49	14.33	1.65
15-0 to 15-5	15.57	1.59	14.87	1.50
15-6 to 15-11	15.09	1.50	14.30	1.61

B) Raw PPT scores from the first administration, separated by age and group.

Raw Scores

Dyslexics

Age		Dom	Nondom	Both
9	M	13.50	13.25	12.00
(n=4)	SD	1.73	2.63	1.63
10	M	12.80	11.60	10.40
(n=10)	SD	0.92	1.07	0.84
11	M	12.00	13.00	10.50
(n=2)	SD	2.83	0	2.12
12	M	13.44	12.44	10.56
(n=9)	SD	1.01	1.88	0.53

Controls

Age		Dom	Nondom	Both
9	M	13.20	12.40	9.40
(n=5)	SD	1.10	1.34	1.14
10	M	13.75	13.75	10.50
(n=4)	SD	0.96	1.89	1.91
11	M	13.91	13.45	10.64
(n=11)	SD	2.21	1.44	1.43
12	M	15.20	14.60	11.80
(n=5)	SD	1.30	1.82	0.84

C) Percentile PPT scores from the first administration, separated by age and group.

Percentile Scores

Dyslexics

Age		Dom	Nondom	Both
9	M	49.50	53.75	66.00
(n=4)	SD	29.41	41.44	23.68
10	M	19.40	18.10	30.80
(n=10)	SD	13.05	13.80	14.54
11	M	16.00	29.50	33.50
(n=2)	SD	21.21	2.12	45.96
12	M	24.78	32.00	25.22
(n=9)	SD	12.31	22.39	8.76

Controls

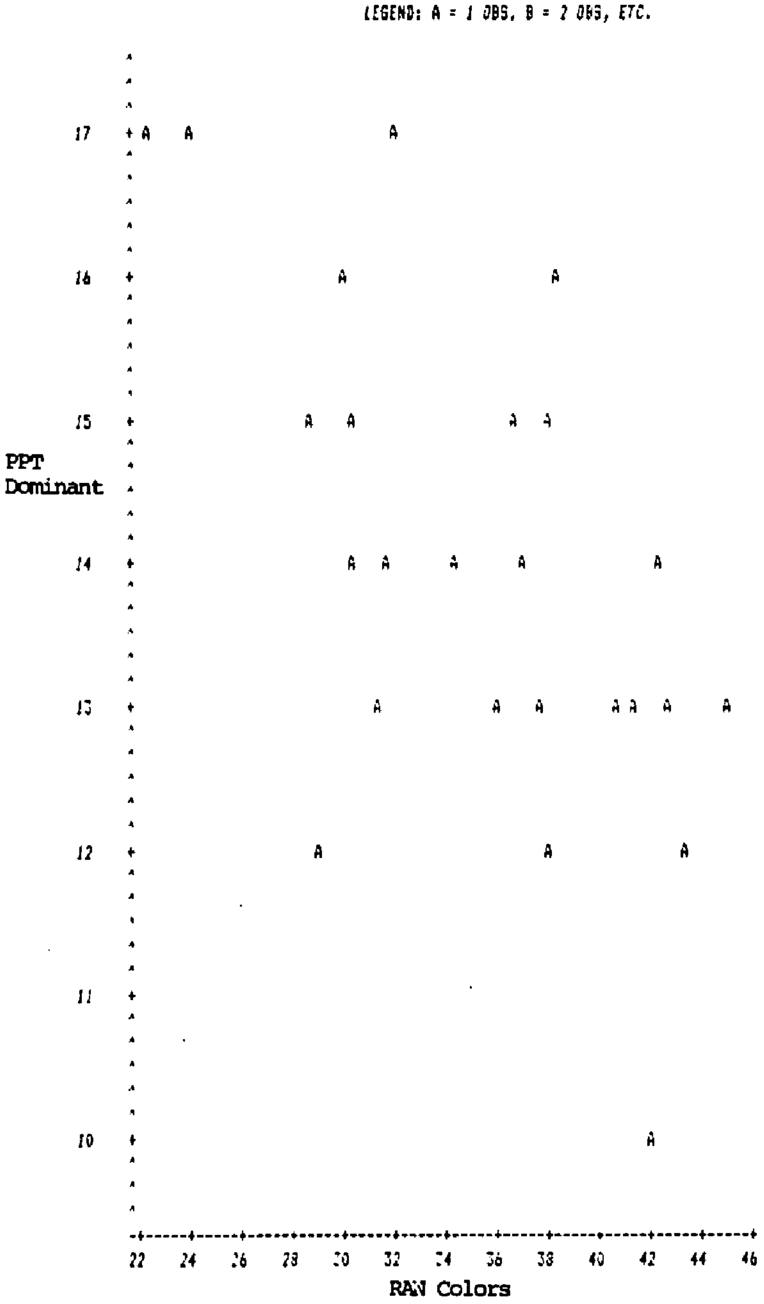
Age		Dom	Nondom	Both
9	M	43.40	47.40	24.20
(n=5)	SD	25.57	29.05	25.31
10	M	35.75	59.50	42.50
(n=4)	SD	18.28	36.67	33.05
11	M	37.36	41.45	32.91
(n=11)	SD	34.20	26.55	25.04
12	M	47.60	57.60	48.60
(n=5)	SD	17.91	26.09	17.21

Appendix E

Displayed below are scatterplots that correspond to the significant correlations between PPT and RAN raw scores. These plots are based on the control sample only. N=25. (The corresponding correlations are presented in Table 14).

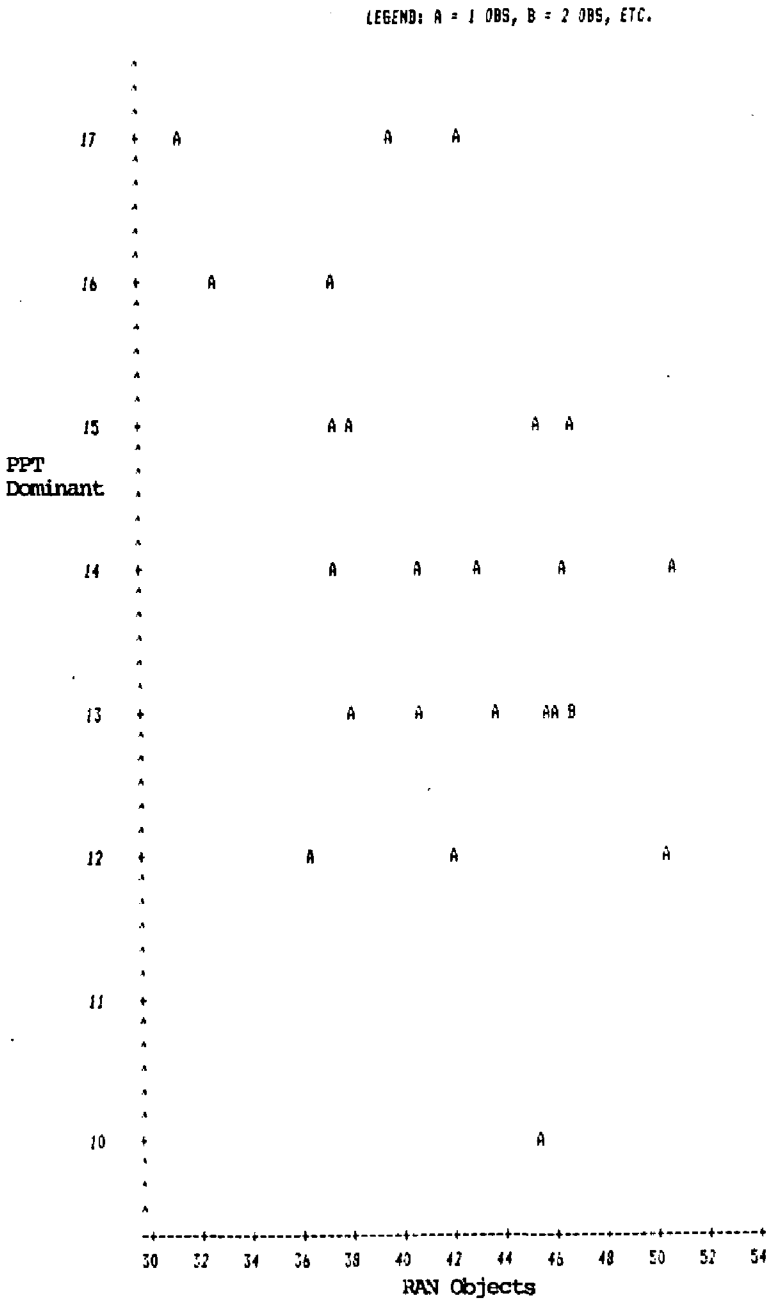
A) PPT Dominant Versus RAN Colors (raw scores)

r=-.61



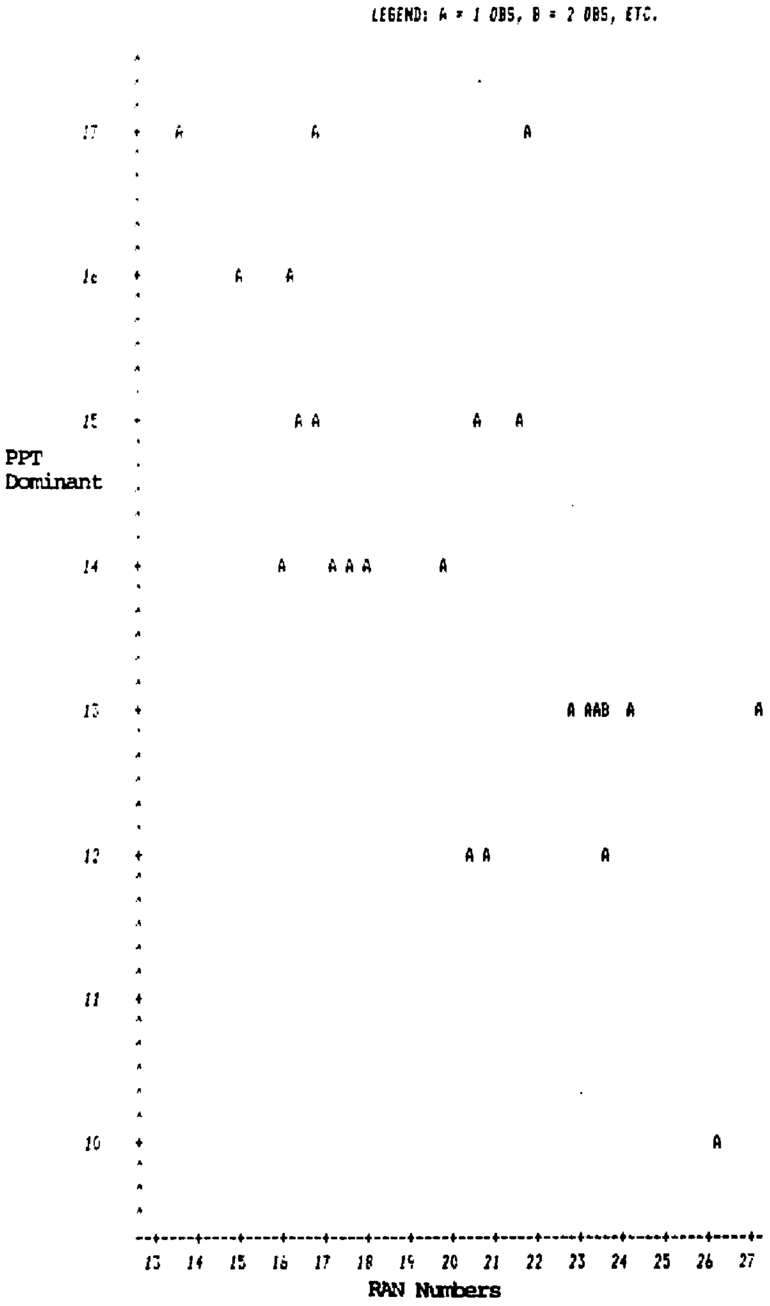
B) PPT Dominant Versus RAN Objects (raw scores)

r=-.46



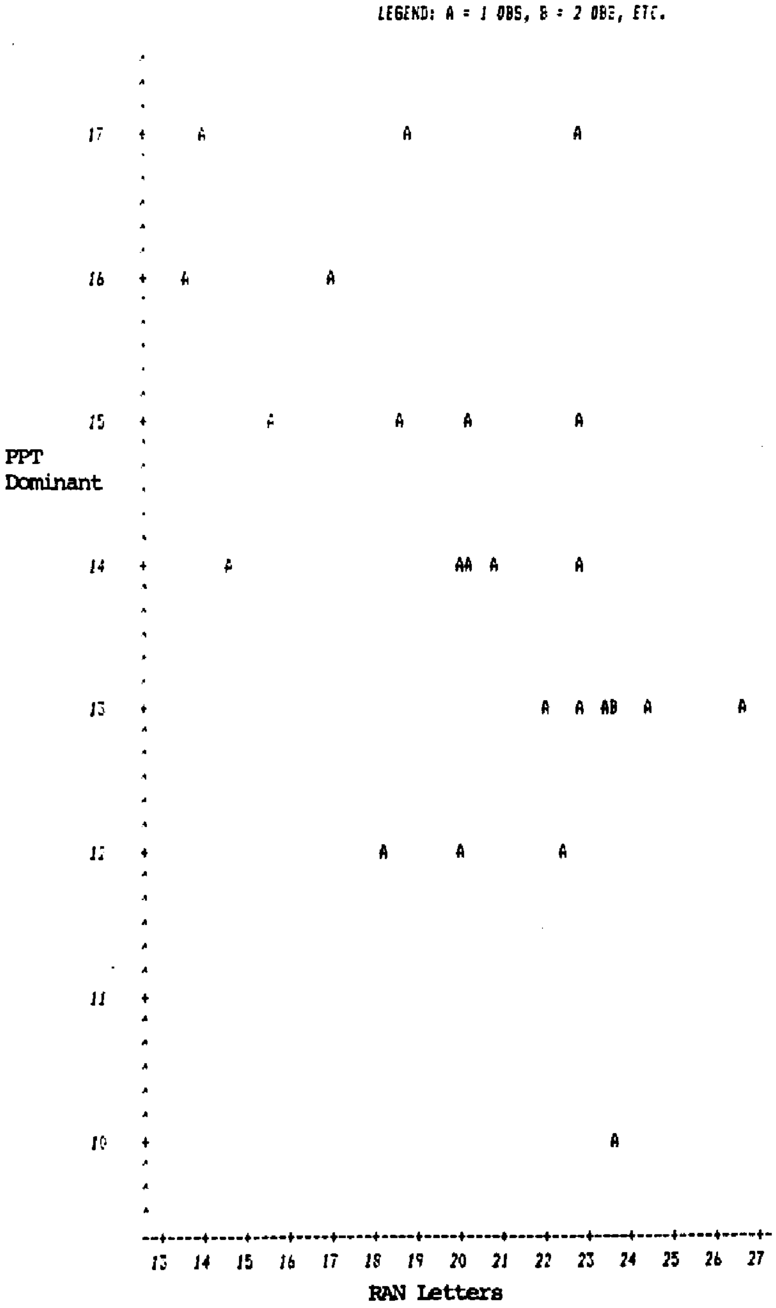
C) PPT Dominant Versus RAN Numbers (raw scores)

r=-.69



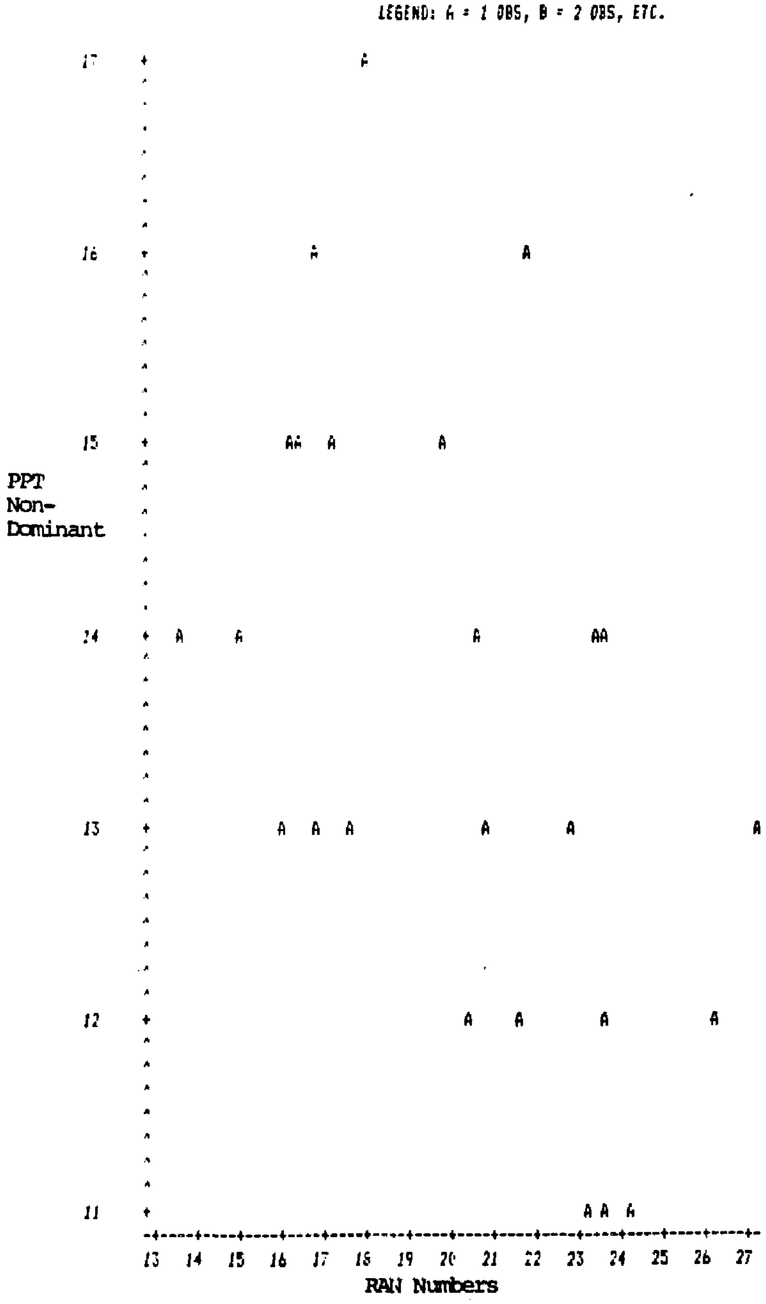
D) PPT Dominant Versus RAN Letters (raw scores)

r=-.52



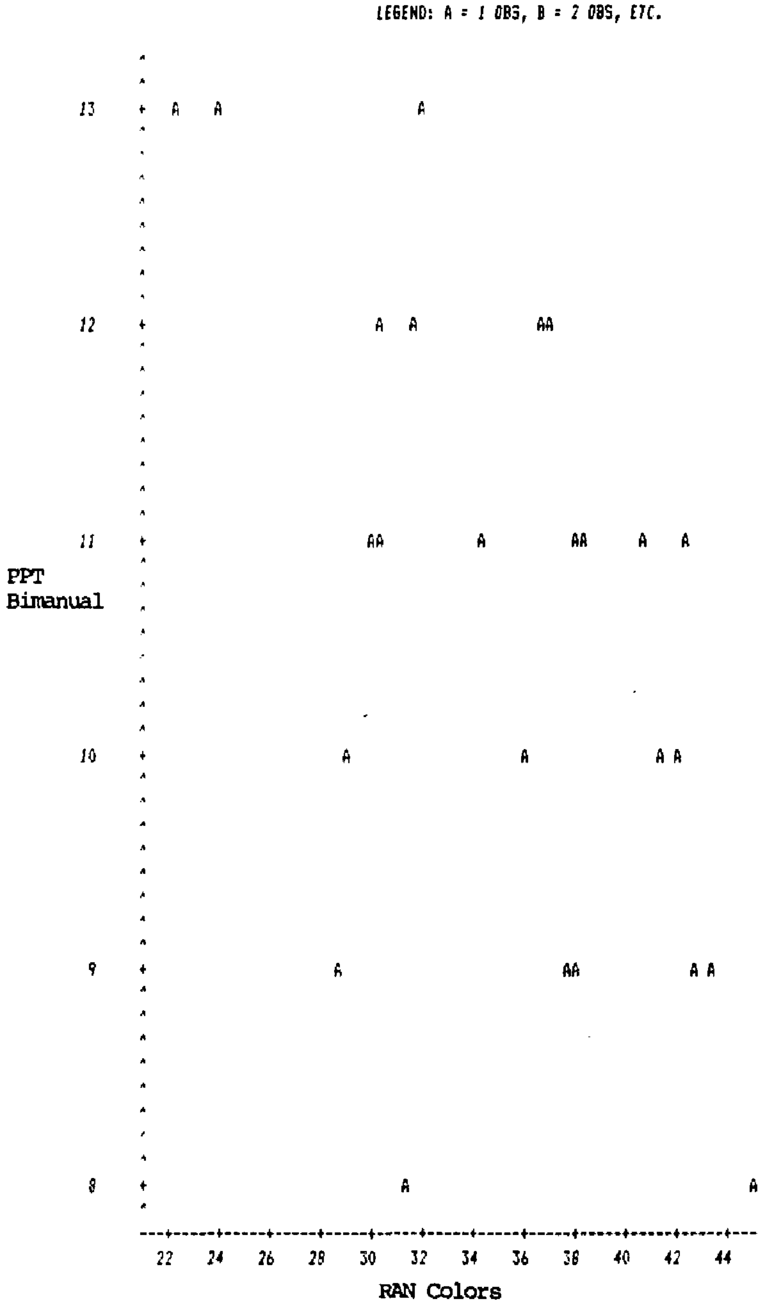
E) PPT Non-dominant Versus RAN Numbers (raw scores)

r=-.51



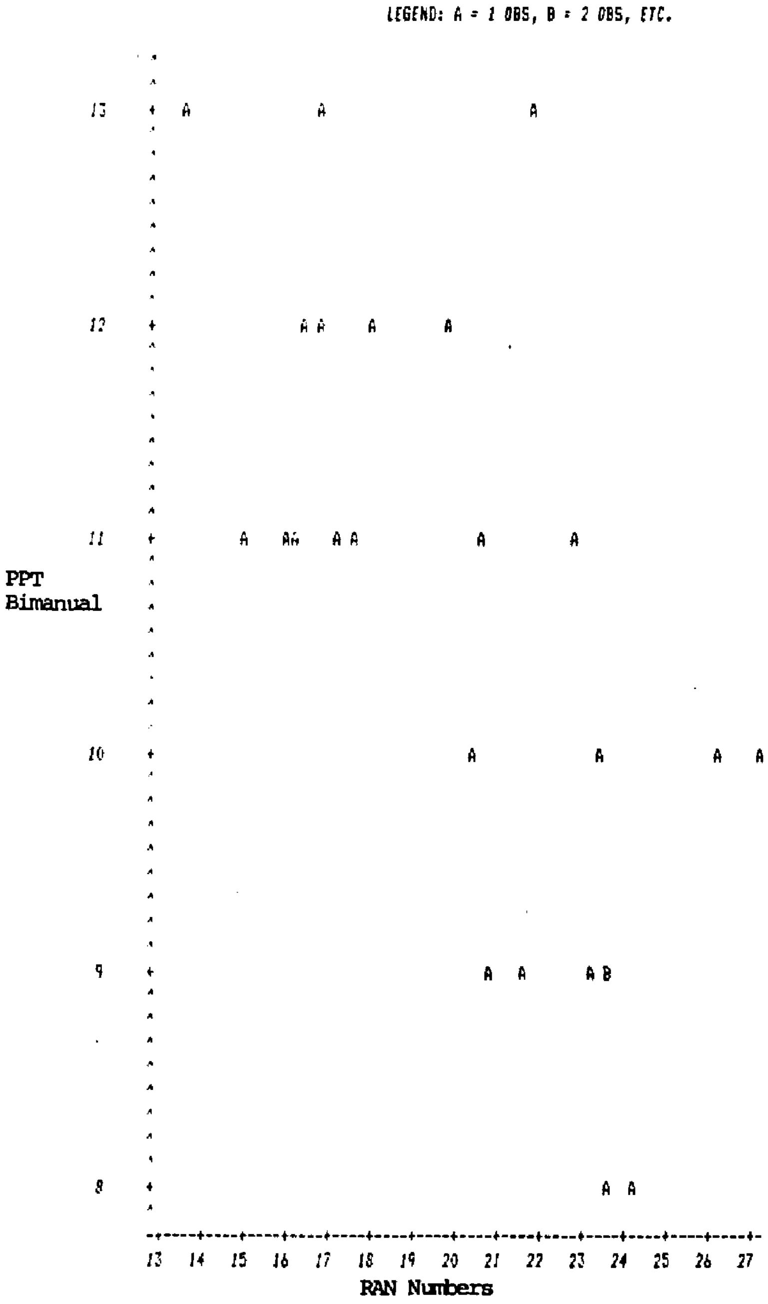
F) PPT Bimanual Versus RAN Colors (raw scores)

r=-.51



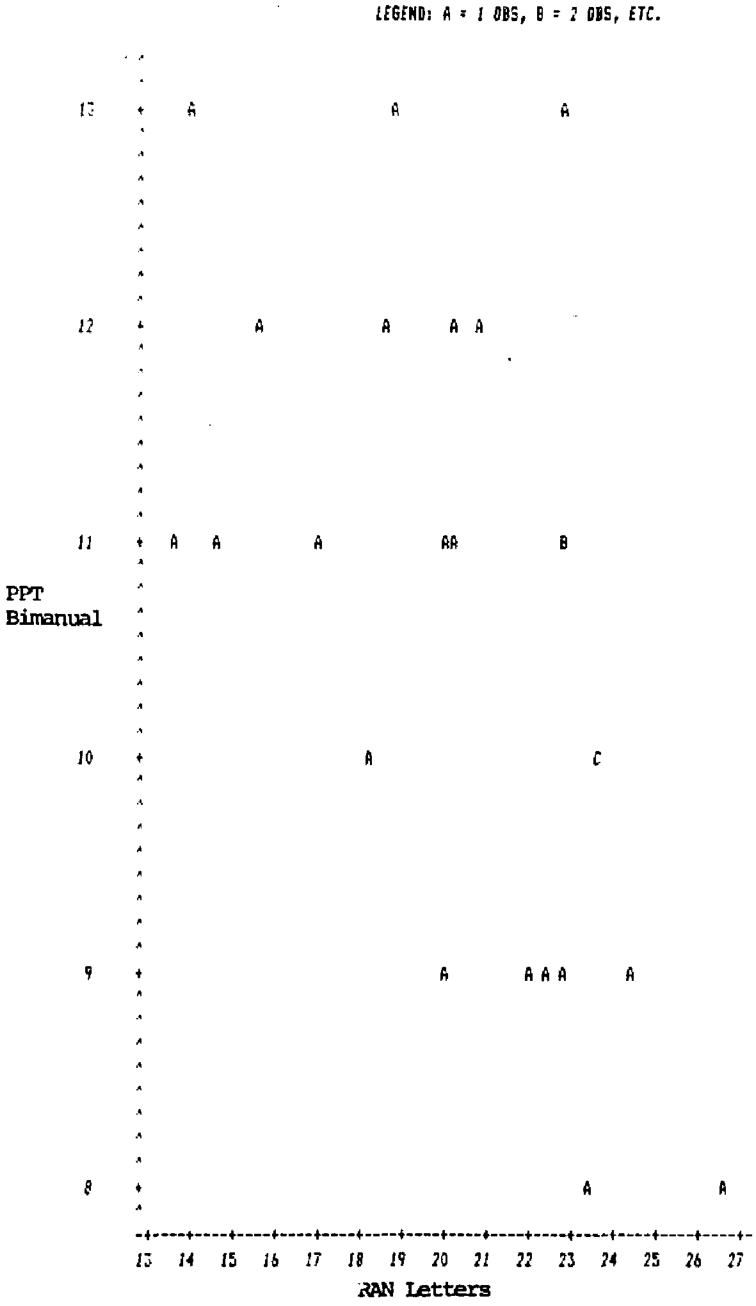
G) PPT Bimanual Versus RAN Numbers (raw scores)

r=-.66



H) PPT Bimanual Versus RAN Letters (raw scores)

r=-.57

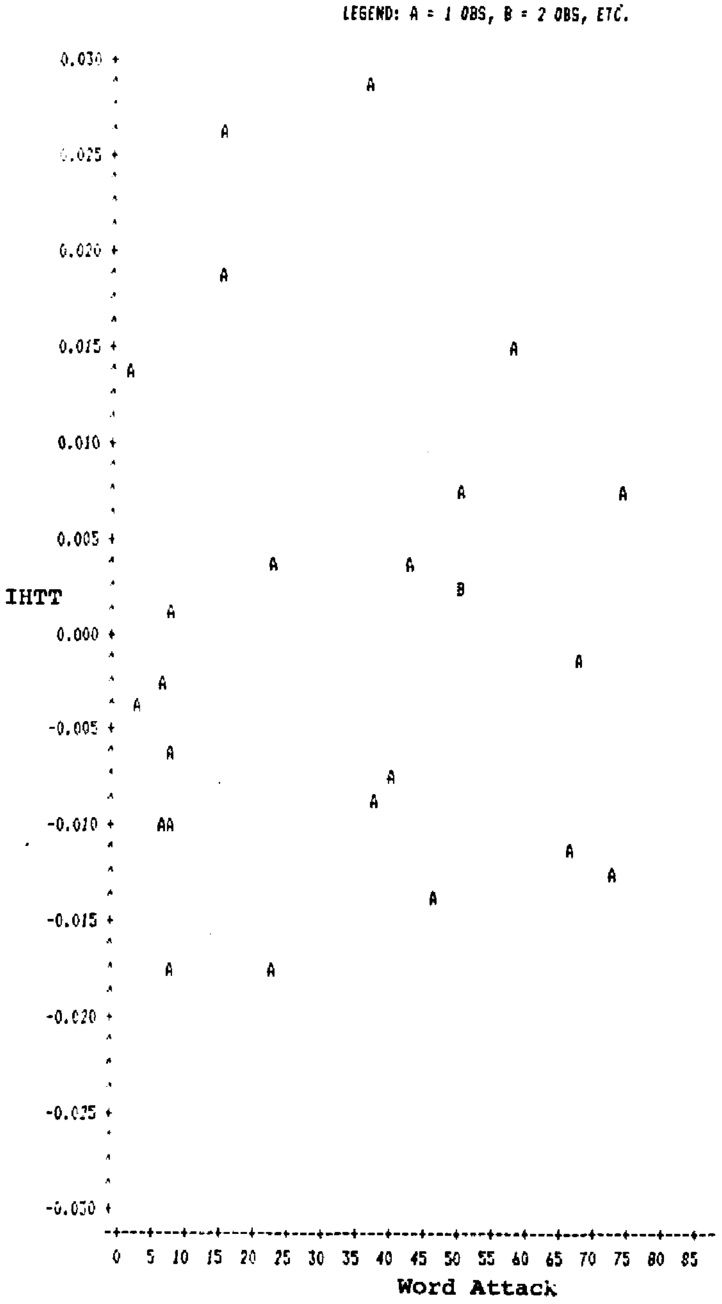


Appendix F

Displayed below are the scatterplots that correspond to the significant correlations between IHTT obtained in the right hand condition and specific reading measures. These plots are based on the dyslexic sample only. N=25. (The corresponding correlations are presented in Table 15).

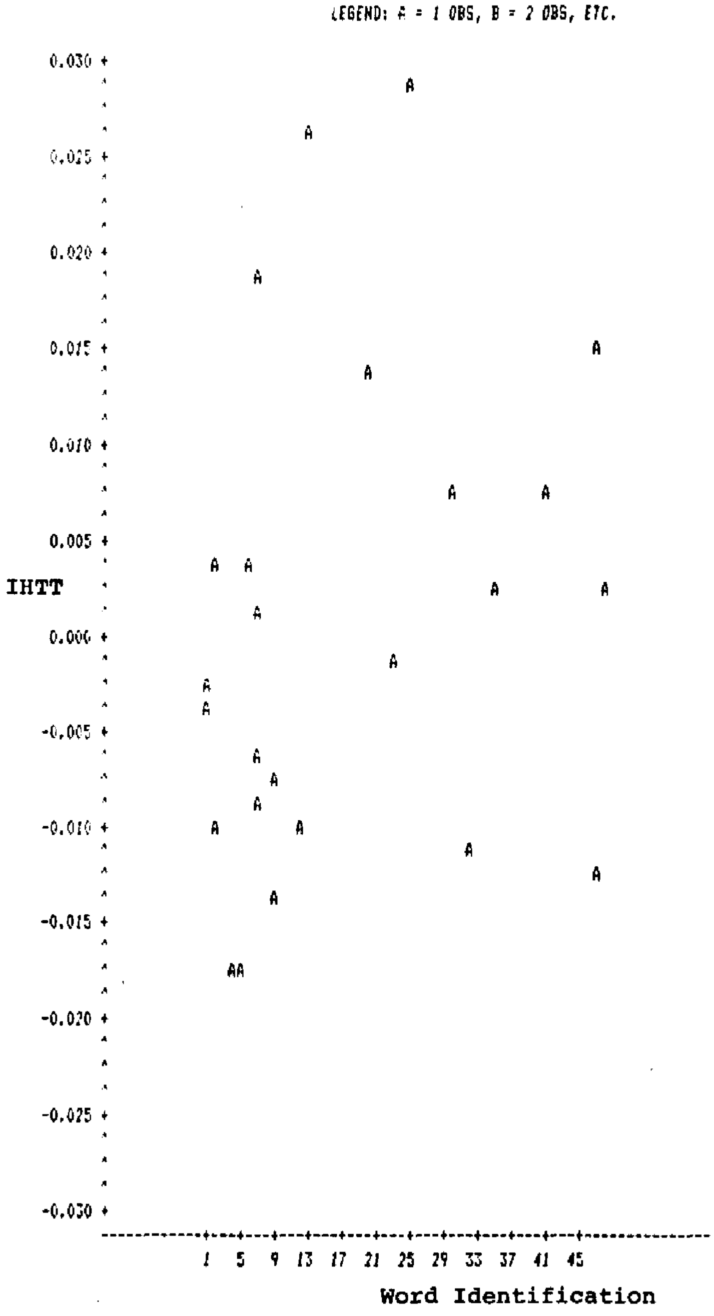
A) Word Attack versus Right Hand IHTT

r=.40



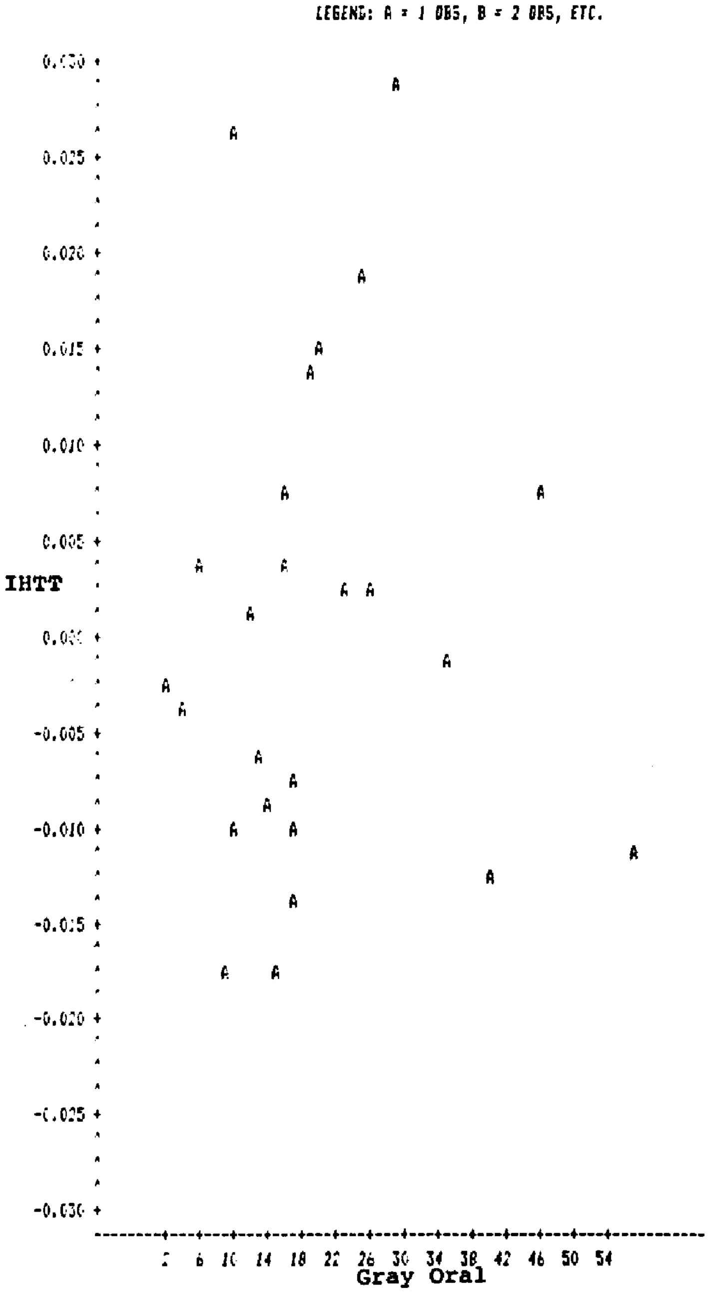
B) Word Identification versus Right Hand IHTT

r=.47



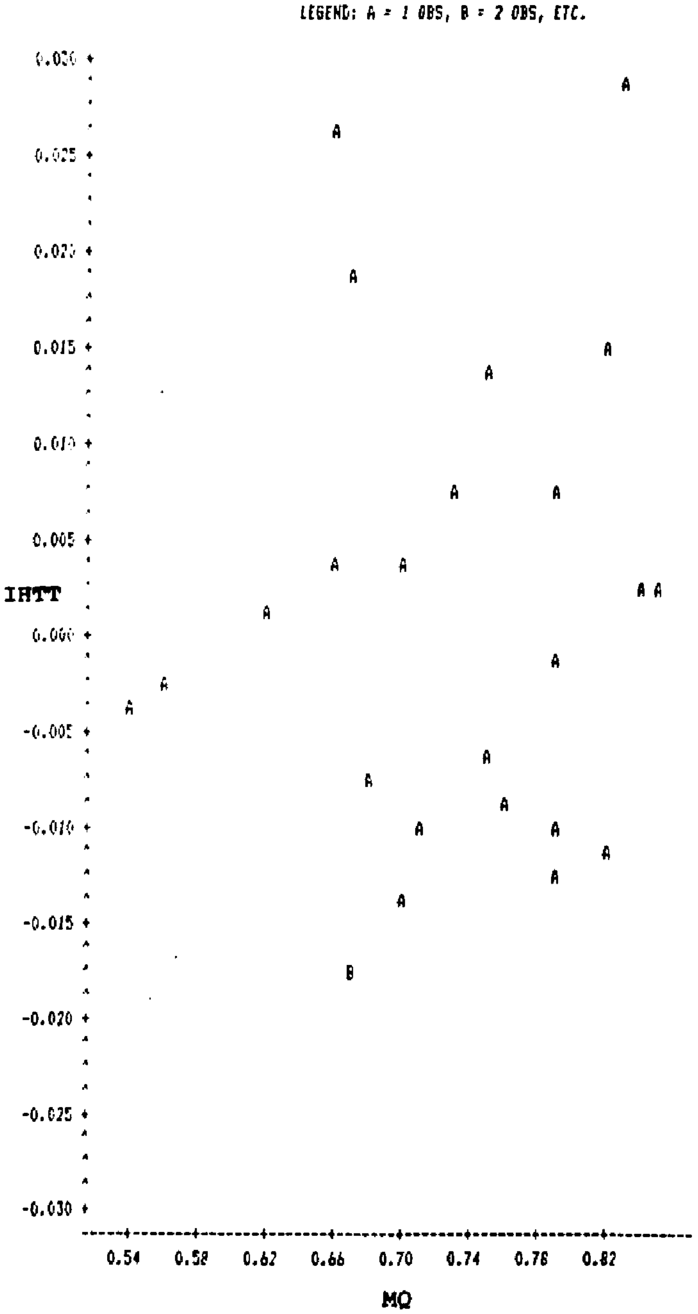
C) Gray Oral versus Right Hand IHTT

r=.45



D) MQ versus Right Hand IHTT

r=.48



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