Clock Drawing in Developmental Dyslexia

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Abstract

Although developmental dyslexia is often defined as a language-based reading impairment not attributable to low intelligence or educational or socioeconomic limitations, the behavioral manifestations of dyslexia are not restricted to the realm of language. Functional brain imaging studies have shed light on physiological differences associated with poor reading both inside and outside the classical language areas of the brain. Concurrently, clinically useful tests that elicit these nonlinguistic deficits are few. Specifically, the integrity of the dorsal visual pathway, which predominantly projects to the parietal cortex, remains underinvestigated, lacking easily administered tests. Here we present the Clock Drawing Test (CDT), used to test the visuoconstructive ability of children with and without dyslexia and garden-variety poor readers. Compared to typically reading children, many children with dyslexia and some garden-variety poor readers showed significant left neglect, as measured by the distribution of figures drawn on the left clock face. In the poor readers with dyslexia, we observed spatial construction deficits like those of patients with acquired right-hemisphere lesions. The results suggest that in some children with dyslexia, right-hemisphere dysfunction may compound the phonological processing deficits attributed to the left hemisphere. The CDT provides an easy opportunity to assess skills known to be associated with right-hemisphere parietal function. This test can be easily administered to children for both clinical and research purposes.

Most researchers consider the core deficit in dyslexia to involve a dysfunction of phonological processing, letter naming, and verbal working memory (Torgesen & Davis, 1996; Wagner & Torgesen, 1987). In addition to these cognitive skills, some have studied the possible role of failure in the sensory processing mechanisms. Such nonlinguistic deficiencies have been documented in visual (Lovegrove, 1993; Lovegrove, Martin, et al., 1986) and auditory (Hari & Kiesila, 1996; Tallal, Miller, & Fitch, 1993) sensory processing, tests of balance and coordination, and an assortment of speeded, bimanual motor tasks (Nicolson, Fawcett, & Dean, 1995; Wolff, 1993). A shortfall in phonological awareness skills in dyslexia has been demonstrated consistently across different tests and cultures. The administration and interpretation of these language-based tests is relatively easy and time efficient. On the other hand, the complexities associated with administering tests designed to evaluate aspects of visual system integrity, such as magnocellular function, have led to a paucity of data from clinical evaluations and research studies. Computer-based stimulus presentation of motion displays or sinusoidal gratings used to evaluate magnocellular function often require a highly controlled laboratory environment, a good understanding of psychophysical experimentation, computational knowledge, and long testing sessions. As a result, only a limited number of studies in dyslexia have investigated the role of sensorimotor deficits (specifically of the visual system), sometimes giving rise to the unjustified opinion that research-based support for nonlinguistic deficits in dyslexia is contentious. This imbalance in the literature has made it difficult to reconcile two apparently disparate views concerning the etiology of this disorder and its neurobiological basis.

Developmental dyslexia, or reading disability (RD), is defined as "a disorder manifested by difficulty in learning to read despite conventional instruction, adequate intelligence, and sociocultural opportunity" (Critchley, 1970, p. 11). It is relatively common; 5% to 10% of 8- to 10-year-olds have exceptional difficulty in learning to read despite conventional instruction and average IQ. There is usually a strong family history. Developmental dyslexia has an organic neurological basis, demonstrated by physiological (Flowers, Wood, et al., 1991; Rumsey, Andreason, et al., 1992; Rumsey, Berman, et al., 1987; Rumsey & Eden, 1997; Rumsey, Zametkin, et al., 1994) and neuroanatomical (Galaburda & Kemper, 1978; Galaburda, Sherman, Rosen, Aboitiz, & Geschwind, 1985; Livingstone, Rosen et al. 1991) differences in the brains of individuals with dyslexia. Foremost, individuals with dyslexia have difficulties separating the sounds of words into their constituent phonemes to match their written alphabetic form (Bradley & Bryant, 1983; Liberman, Shankweiler, Liberman, Fowler, & Fischer, 1977). Numerous studies have demonstrated that the phonological abilities of individuals with dyslexia are deficient, and remediation strategies targeting phonological processing have been largely successful (Alexander, Anderson, et al., 1991; Torgesen & Davis, 1996). In addition to decoding problems, some individuals with dyslexia show impaired performance on a range of visual tasks (Lovegrove et al., 1986; Stein, 1993; Stein & Walsh, 1997) and complain of visual confusion (Eden, Stein, Wood, & Wood, 1995b). These visual manifestations have been studied in the framework of the magnocellular and parvocellular pathways, which are characterized by anatomical and physiological distinctions in the primate visual system (Ungerleider & Mishkin, 1982). In developmental dyslexia, demonstrations of reduced contrast sensitivity at low luminance levels, favorably processed by the magnocellular system, have led to the proposal of a magnocellular deficit in dyslexia (Lovegrove et al., 1986). A magnocellular deficit has been confirmed with other tasks involving luminance decision, visual motion, and flicker fusion frequency and further corroborated by anatomical (Livingstone, Rosen, Drislane, & Galaburda, 1991) and physiological (Eden, VanMeter, et al., 1996) techniques. Although the phonological deficits in dyslexia are inclement and result in poor application of the sound correspondence rules necessary for good decoding (Vellutino, 1977; Vellutino, Steger, & Kandel, 1972), it has been proposed that many children with dyslexia have problems with both phonological and visual processes (Cornelissen, Bradley, Fowler, & Stein, 1991; Cornelissen, Richardson, Mason, Fowler, & Stein, 1995; Eden, Stein, et al., 1995b; Talcott, Witton, et al., 2000).

In addition to their low scores on the psychophysical and physiological measures used to demonstrate magnocellular deficits, individuals with dyslexia have tended to perform more poorly on other visual tasks; differences in their temporal processing of visual information (Eden, Stein, et al., 1995a) and poor eye movement control (Eden, Stein, Wood, & Wood, 1994) are thought to be related to a magnocellular system deficit. A striking informal observation is that children with dyslexia appear to have a tendency to direct their attention away from their left side. When opening a book, individuals with dyslexia often look at the right page first, whereas individuals without dyslexia usually look at the left page. This correlates with findings that individuals with dyslexia perform worse on tasks where visual targets appear on their left-hand side (Hari, Renvall, & Tanskanen, 2000; Riddell, Fowler, & Stein, 1990; Stein, 1989).

A neglect of the left side of space is frequently observed in a more dramatic fashion in patients with right posterior parietal cortex lesions. Demonstrated in the 19th century by Hughlings Jackson and abundantly confirmed since then (Brain, 1941; Riddoch, 1935), visuoperceptive disorders have been associated with lesions of the right hemisphere. Lesions of the right parietal cortex often impair a person's ability to attend to or move into the left side of space. The coordinate system in which this kind of disorganization of space is most clearly seen varies from patient to patient. Usually, it is based on the ego center and also on the center of objects that are being inspected. Objects to the left of the patients are neglected or ignored, but also the left sides of objects tend to be neglected even if they are on the person's right side. Hence, the term *neglect* is used to describe a person's failure to respond to or report stimuli presented in a particular area of the visual field. If the deficiency in response can be attributed to a primary sensory or motor loss, then the patient is not considered to have neglect (e.g., as in hemianopia). Neglect is only half as common after left-hemisphere lesions, in which case right neglect manifests itself in rather different and milder forms. Neglect syndrome is most frequently observed in patients with damage to the occipital–temporal–parietal junction, but also in some cases of frontal and subcortical damage (K. M. Heilman & Valenstein, 1979; K. M. Heilman & Van den Abell, 1979).

The parietal cortex receives projections from the magnocellular system (Ungerleider & Mishkin, 1982). Hence, it displays properties such as sensitivity to the detection of movement, as is evident in single-unit recordings in monkeys (reviewed by Van Essen & Maunsell, 1983) and in task-related signal change in human functional brain imaging studies (Cheng, Fujita, et al., 1995). Impaired right posterior parietal cortex function has therefore long been suggested to be one of the cardinal characteristics of developmental dyslexia (Stein & Walsh, 1997). To validate the observation of left neglect in individuals with developmental dyslexia, a test is required that allows quantitative evaluation in children. One such test is the *Clock Drawing Test* (CDT). It is commonly used clinically to demonstrate neglect in individuals with brain damage (Friedman, 1991), but its use in developmental disorders has not yet been investigated.

Visuoperceptual disabilities are notoriously difficult to investigate because there is such a large variety of them; patients may be poor at one task but not at others. Clock drawing and copying have been used extensively and scaled to evaluate differential patterns of cognitive deficits among older people and patients with dementia and depression (Herrmann, Kidron, et al., 1998; Herrmann, Kidron, et al., 1999; Rouleau & Salmon, 1992; Rouleau, Salmon, et al., 1996; Shulman, 2000). The CDT is usually used only as a qualitative measure, but it can be quantified (Weinstein & Friedland, 1977). It is thought to be sensitive to visuospatial impairments, attention, and executive function. Whereas some clinicians have applied clock face drawing to assess frontal lobe integrity (due to its reliance on planning, organization, and self-monitoring), many have used it for its dependence on visuospatial and constructional abilities served by the right parietal cortex. The anatomical correlate of clock drawing has recently been elucidated by morphometric magnetic resonance imaging (MRI) studies, showing that clock drawing scores correlated significantly with right anterior and posterior superior temporal lobe volumes (Cahn-Weiner, Sullivan, et al., 1999). Corroborating this link between clock drawing and right posterior gray matter volume are studies of patients with right inferior parietal lobule lesions demonstrating that these patients are more likely to exhibit signs of neglect than those with lesions in other areas of the brain (Vallar, Lobel, et al., 1999). The CDT is particularly well suited to testing for hemispatial neglect because the individual draws from memory, so the test reveals the patient's internal spatial or motor representation rather than the state of his or her sensory pathways. Patients with right-sided strokes tend to neglect the left side of the clock, cramming all the numbers into the right side or omitting the numbers after 6. Generally, the more impaired their clock drawing, the more severe their stroke (Friedman, 1991).

Although the CDT has largely been used in older populations, it has been established that clock construction is fully developed in children by the age of 8 (Cohen, Ricci, Kibby, & Edmonds, 2000). Younger children (6- and 7-year-olds) may show neglect to the upper quadrant, but this is no longer evident by 8 years of age. The CDT can be administered quickly, and children enjoy doing it. A clock can be instantly examined for any peculiarities. A further advantage of the CDT is that it is not confounded by language ability, so verbal cues cannot facilitate performance.

To investigate if the CDT would be a suitable addition to test batteries primarily concerned with language and reading skills, we administered this test as an indicator of any atypical visuospatial ability in 93 children with an average age of 11 years. Our goal was to see if the comparison of the children with and without dyslexia would confirm the differences between the groups that we had observed informally in some children with dyslexia. We also compared the children with dyslexia with a group of children whose poor reading was explained by their low IQ. We expected to find better performance in this garden-variety poor reading (GVPR) group compared to the dyslexia group if a clock drawing deficit is specific to dyslexia. The comparison of a GVPR group eliminates the possibility that the deficit of interest is a consequence of poor reading ability rather than a characteristic or cause of dyslexia, and the inclusion of this sample makes our study design consistent with research practices investigating phonological deficits in dyslexia (Stanovich, 1988). A measure of phonological awareness was also scrutinized to establish whether a deficit in either of these tests happens to coexist in children with RD or whether poor clock drawing is a separate deficit that is not related to poor phonemic awareness.

TABLE 1
Profile of the 93 Participants Studied

Group	*n*	Chronological age (5th grade)	Reading standard score (5th grade)	IQ (WISC-R) standard score (3rd grade)
No dyslexia	39	range: 10.2–12.1 *M* = 10.9 *SD* = 1.0	range: 86–115 *M* = 98.03 *SD* = 8.1	range: 85–114 *M* = 102.2 *SD* = 7.3
Dyslexia	26	range: 10.9–12.2 *M* = 11.6 *SD* = 0.6	range: 65–84 *M* = 78.85 *SD* = 5.3	range: 85–115 *M* = 94.0 *SD* = 6.5
Garden-variety poor readers	12	range: 10.9–12.6 *M* = 11.7 *SD* = 0.8	range: 63–84 *M* = 74.3 *SD* = 11.9	range: 68–84 *M* = 76.4 *SD* = 4.78
Miscellaneous	16	range: 10.2–12.5 *M* = 11.2 *SD* = 0.8	range: 85–126 *M* = 109.7 *SD* = 14.7	range: 72–132 *M* = 101.7 *SD* = 17.5
Entire sample	93	range: 10.2–12.6	range: 63–126	range: 68–132

Method

Participants

We studied 93 children selected from a larger sample of typically reading (*n* = 485) and poor reading (*n* = 295) children enrolled in the Learning Disability Project at the Wake Forest University School of Medicine at Bowman Gray, in North Carolina (Felton & Wood, 1992). Children with dyslexia were compared with both typical readers and garden-variety poor readers (GVPR). The poor reading of the GVPR group, unlike that of the dyslexia group, was mainly the result of low IQ. We also included a miscellaneous sample of children to complete a wide range of reading and IQ levels. The characteristics of each group are detailed in Table 1.

The no dyslexia (ND) group was selected from the typically reading sample. Their reading ability at fifth grade on the *Woodcock-Johnson Psychoeducational Battery* reading standardized score (WJRSS; Woodcock & Johnson, 1977) was between 85 and 115. Their score on the *Wechsler Intelligence Scale for Children–Revised* (WISC-R; Wechsler, 1974) was also between 85 and 115. There were 39 children in the ND group: 21 boys, 18 girls (27 White and 12 non-White children). The dyslexia (D) group was selected from the poor readers. Their reading score at fifth grade on the WJRSS was below 85, but their IQ on the WISC-R was between 85 and 115. There were 26 children in the D group: 17 boys, 9 girls (11 White and 15 non-White children). The discrepancy between their IQ and standardized reading score was on average 15.2 points (1 *SD*) for the group, consistent with most research-based criteria for identifying dyslexia. The GVPR group was selected from the poor reading sample; their reading scores at fifth grade were below 85 on the WJRSS, but their IQ on the WISC-R was also below 85. There were 12 children in the GVPR group: 7 boys, 5 girls (4 White and 8 non-White children). The GVPR group's mean IQ was equivalent to their mean standardized reading score (see Table 1). Sixteen miscellaneous children were also included (6 boys, 10 girls, 13 White and 3 non-White children). They were all typical readers, but they had IQs below 85 or above 115. They were included in order to extend the range of reading and IQ levels to produce a more representative sample with which to compute correlations of clock drawing ability with other variables known to be associated with visuospatial performance or reading. For clock drawing specifically, there is little information for this age group about the effect of gender and handedness on task performance. For example, left-handers may perform differently from right-handers in the left visual field. It is known that girls perform somewhat lower than boys on visuospatial tasks (McGlone, 1980), and there has been some investigation into the preponderance of right-handedness in females (Hicks & Kinsbourne, 1976). Individuals with dyslexia have a higher incidence of left- or mixed-handedness compared to typical readers (Annett & Turner, 1974), and these factors need to be investigated in the context of clock drawing. Previous research has shown a greater propensity for left neglect in children with attention-deficit disorder (ADD; Voeller & Heilman, 1986), and as some of the children in our sample had a diagnosis of ADD, the diagnosis of ADD was included in the statistical analysis. Correlations were performed for measures of IQ, gender, handedness, visuospatial skills, and phonological ability.

Children with physical illness or neurological disorders were excluded from the study. A standard eye exam, including visual field examination to confrontation, was carried out by an independent orthoptist or ophthalmologist on all children. It has been demonstrated that sensory deficits are not responsible for the dramatic effect on performance seen in neglect patients (Rosenberger, 1974), but visual field deficits could possibly enhance the effect of hemispatial neglect. All children included in the study had typical or corrected-to-typical vision and typical visual fields.

Measures

Clock Drawing Test (CDT). The children were presented with a plain 8.5 × 11.0–in. blank sheet of paper and pen (not pencil, as we wanted their immediate response and did not allow them to make corrections). The instructions were, "I would like you to draw a clock, with all its numbers in it." No time limit was given.

Handedness and ADD. Handedness was determined using the *Edinburgh Test for Handedness* (Oldfield, 1971). The ADD portion of the *Diagnostic Interview for Children and Adolescents* (Herjanic, 1983) was completed by the parent or guardian of each child in order to see if ADD might affect the ability of children to perform the CDT. This is a structured interview, yielding a standardized measure of ADD based on the *Diagnostic and Statistical Manual of Mental Disorders,* third edition (DSM-III; American Psychiatric Association, 1980). Children were classified as ADD or no ADD.

Intelligence and Reading Ability. The *Wechsler Intelligence Scale for Children–Revised* had been administered when the children were in third grade to determine Verbal IQ (VIQ), Performance IQ (PIQ), and Full Scale IQ (FSIQ). Reading ability was assessed in fifth grade using the *Woodcock-Johnson Psycho-Educational Battery* (WJ; Woodcock & Johnson, 1977). Word Identification, Word Attack, and Passage Comprehension subscales were used to assess sight word vocabulary, mono- and polysyllabic nonword reading, and passage comprehension, respectively.

Visuospatial and Mathematical Skills. The scores from the Block Design subtest of the WISC-R were used to compute correlations with the CDT in order to assess the relationship between visuospatial skill and clock drawing. In this task, children were asked to make patterns with building blocks to match those shown in a booklet. As the CDT involves the use of numbers, the mathematical ability of the children was also measured, using the WJ Math standardized score, which measures ability of calculation and applied problems.

Phonological Awareness. The *Pig Latin Test* (PLT; Olson, Wise, Conners, Rack, & Fulker, 1989) was used to assess phonological ability in order to compare this with the result of the visuospatial tests. In this test, words are reassembled by deleting the initial phoneme from a word, placing it at the end of the word, and then adding *ay.* Thus *pig* is spoken as *igpay*. Correct answers, as well as the time to translate 27 words into Pig Latin, were scored at fifth grade.

Procedure

For the verbal, neuropsychological, and achievement tests aforementioned, a psychologist tested each child individually during two visits to the child's school. WISC-R and ADD data were collected at third grade only. A few months after the school testing had been completed, the visual tests were carried out individually on the fifth-graders at Wake Forest University School of Medicine at Bowman Gray as part of a longer testing battery.

Scoring

Many quantitative and qualitative analyses of the *Clock Drawing Test* have been reported (Goodglass & Kalpan, 1972; Henderson, Mack, et al., 1989; Rouleau & Salmon, 1992). In this study, we measured the following:

1. *Angle.* The angle between the top of the clock (where the number 12 is) and where the child had placed the numbers 2, 5, 8, and 11. These were chosen to measure the position of the numbers with respect to each other. Measuring every number would not add any more information because we were looking at the overall pattern. As the number 11 is often the most striking one in the case of left neglect, it was important to include this number. Numbers representing a quarter, half, and three-quarter hours were avoided, because their position might have been chosen using a different strategy. The measurements were made at the central points of each of these numbers, yielding the distance between them and the top of the clock. Lower values indicated squashing of the numbers in that particular quadrant of the clock.
2. *Clock size.* Clock size was measured by ruler from the center point to the top, bottom, and either side.
3. *Order and omission of figures.* Any deviation from the correct numeric order or omissions of the clock numbers were noted.

Statistical Analysis

The significance of the differences between the D, ND, and GVPR groups was determined by multiple analysis of variance (MANOVA). The dependent variables were the angles at which the numbers 2, 5, 8, and 11 were drawn in the CDT and were controlled for gender, handedness, and ADD. Where appropriate, the means of the groups were compared using post hoc two-tailed t tests to see whether the CDT could discriminate between them.

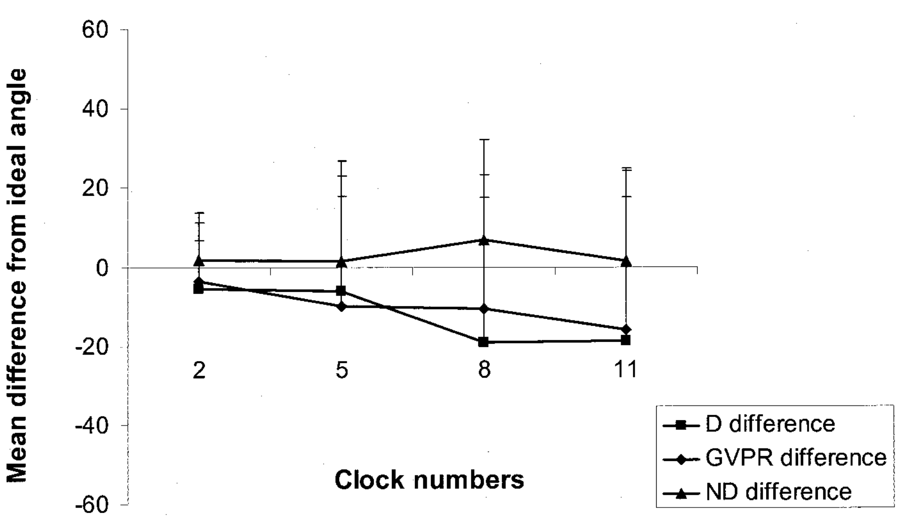

FIGURE 1. Distribution of clock angles for the numbers 2, 5, 8, and 11 drawn by children with and without dyslexia and garden-variety poor readers (GVPR). The dyslexia group showed significant differences compared to the control group for the

Results

Clock Drawing

1. *Angle.* A Number Position (4) × Group (2) × Gender (2) × Handedness (2) × ADD (2) MANOVA with repeated measures across the number position condition between the D and ND groups yielded a significant effect for group, $F(1, 59) = 6.23$, $p < .016$, with no further interactions. The same MANOVA comparing the D and GVPR groups produced only a trend but no significant differences. Post hoc comparison revealed a significant difference between participants with and without dyslexia for the angles of the numbers 2, 8, and 11, $t(61) = 2.29$, $p < .025$; $t(59) = 3.65$, $p < .0006$; and $t(58) = 2.40$, $p < .019$, respectively. These results are presented in Figure 1, which graphically represents the difference in angles subtended by the numbers 2, 5, 8, and 11 from their ideal location on the clock face. It shows how the values of the children with dyslexia are lower compared to those without dyslexia, particularly for the left side of the clock face (numbers 8 and 11). Although there was a similar trend for the GVPR group, it was not as strong as that for the dyslexia group.

2. *Clock size.* Similar MANOVAs were used to analyze the size of each quadrant of the clock drawn by the children, using all four measurements. However, this revealed no significant differences between the groups.

3. *Order of numbers.* All the children tended to first draw a circle and then put in the numbers from 1 to 12. None of the children in any of the groups reversed the order of these numbers. Some children left numbers out toward the end of the task; these children tended to finish quickly but often realized that their drawing did not look right and that they had omitted the last few numbers (e.g., the number 11 or the numbers 10 and 11). This suggests

that children with dyslexia do not produce defective clocks due to an inability to reproduce the correct sequence of numbers.

The children with dyslexia crowded the numbers into the right side of the clock compared to the children without dyslexia. In contrast, some of the children without dyslexia showed a tendency to fill in the numbers toward the left side of the clock, as shown by their larger angle for the number 8 (i.e., the angle is greater than 240 degrees, which is what would be predicted). The neglect seen in some of the clocks drawn by children with dyslexia is clearly demonstrated in Figure 2, which shows some unusual examples of clocks drawn by children with dyslexia matched with typical readers throughout a wide range of IQ levels (selected from the entire sample of $n = 93$). The mild left neglect exhibited by our children with dyslexia suggests that they may have right-hemisphere dysfunction in addition to their better documented left-hemisphere deficits. Like patients with posterior parietal lesions (for an example, see Figure 3), the children with dyslexia showed some distress after realizing that their clocks did not look right. However, unlike the patients with such lesions, they would often come to this realization immediately and be able to make an assessment of why their clocks looked odd.

The size of the angle provides a quantitative measure of clocks drawn by the three different groups of children. It is also of interest to establish how many children are responsible for these unusual clocks. To identify the number of children with dyslexia who drew defective clocks, we investigated how many children in each group performed 2 *SD* or more below the group mean (calculated from the ND sample). Using the value of the angle of the number 8, there were 3 (7.7%) children in the ND group, 12 (46.2%) in the D group, and 3 (25%) in the GVPR group who performed below this level. Although this is an arbitrary division of scores, it does give a sense of how many more children in the dyslexia group produced clocks that were different. This result is probably an underestimation, as 2 children with dyslexia did not complete their clock and did not include the number 8. In conclusion, about one in two children in the dyslexia group drew a clock with neglect in the lower left quadrant.

Phonological Awareness

The PLT accuracy scores were analyzed by a Group (2) × Gender (2) x Handedness (2) × ADD (2) MANOVA between D and ND groups. As expected, there was a significant effect for group, $F(1, 59) = 21.2$, $p < .0001$, but none of the other variables were significantly different. Likewise, the PLT time score yielded a significant difference for group, $F(1, 59) = 23.77$, $p < .0001$, with no other interactions. Protected t tests demonstrated significantly higher PLT accuracy scores for the ND group ($M = 16.26$, $SE = 0.58$) compared to the dyslexia group ($M = 11.25$, $SE = 0.88$), $t(61) = 4.94$, $p < .0001$, as well as faster PLT completion times for the ND group ($M = 193.46$ s, $SE = 8.65$) than for the dyslexia group ($M = 366.63$ s, $SE = 39.72$), $t(61) = 5.30$, $p < .0001$. There were no significant differences between the dyslexia group and the GVPR group for PLT accuracy scores or completion times.

Correlations

To explore the effect of clock drawing ability and the other tests we administered in these children, correlations were computed for the entire sample ($N = 93$). The clock variable used was that of the angles of the numbers 2, 5, 8, and 11 combined; lower values of this variable indicate neglect of the left side of space. Table 2 shows the correlations that were significant, confirming that reading in this sample was well correlated with the usual skills known to predict reading ability; positive correlations between reading ability and phonological awareness, IQ, mathematics, and visuospatial skill measured on the WISC-R Block Design subtest were found. Clock drawing significantly correlated with PLT as well as reading scores. There was very little association between WISC-R Block Design and clock drawing; this was also the case for mathematics and clock drawing. This implies that the CDT is different from other visuospatial tasks and that it is unlikely that a talent for mathematics helps a child to construct a clock. In accordance with the MANOVA results, clock drawing was not influenced by ADD, gender, or handedness. The strongest correlation for the *Clock Drawing Test* was with the *Pig Latin Test,* indicating that children in this sample with good phonemic awareness also had good visuospatial ability on the CDT.

Discussion

Developmental dyslexia is usually associated with left-hemisphere dysfunction because the skills that are impaired in dyslexia, such as verbal working memory and phonological processing, are known to primarily depend on this hemisphere. Indeed, anatomical (Galaburda & Kemper, 1978; Galaburda et al., 1985; Leonard, Voeller, et al., 1993) and physiological studies (Flowers et al., 1991; Rumsey et al., 1992; Rumsey et al., 1987; Rumsey & Eden, 1997; Rumsey et al., 1994) contrasting individuals with and without dyslexia have confirmed differences between the groups in numerous regions of the left hemisphere. However, discrepancies in brain physiology are also sometimes identified in right-hemisphere regions. The present study provides behavioral evidence that children with dyslexia neglect the left side of the image when they draw clock faces, suggesting a dysfunction of right-hemisphere mechanisms in addition to those frequently reported in the left hemisphere. Other than left neglect, there were no differences in clock size or in the ordering of numbers between children with and without dyslexia, suggesting that the test is indeed revealing left neglect rather than poor size constancy or num-

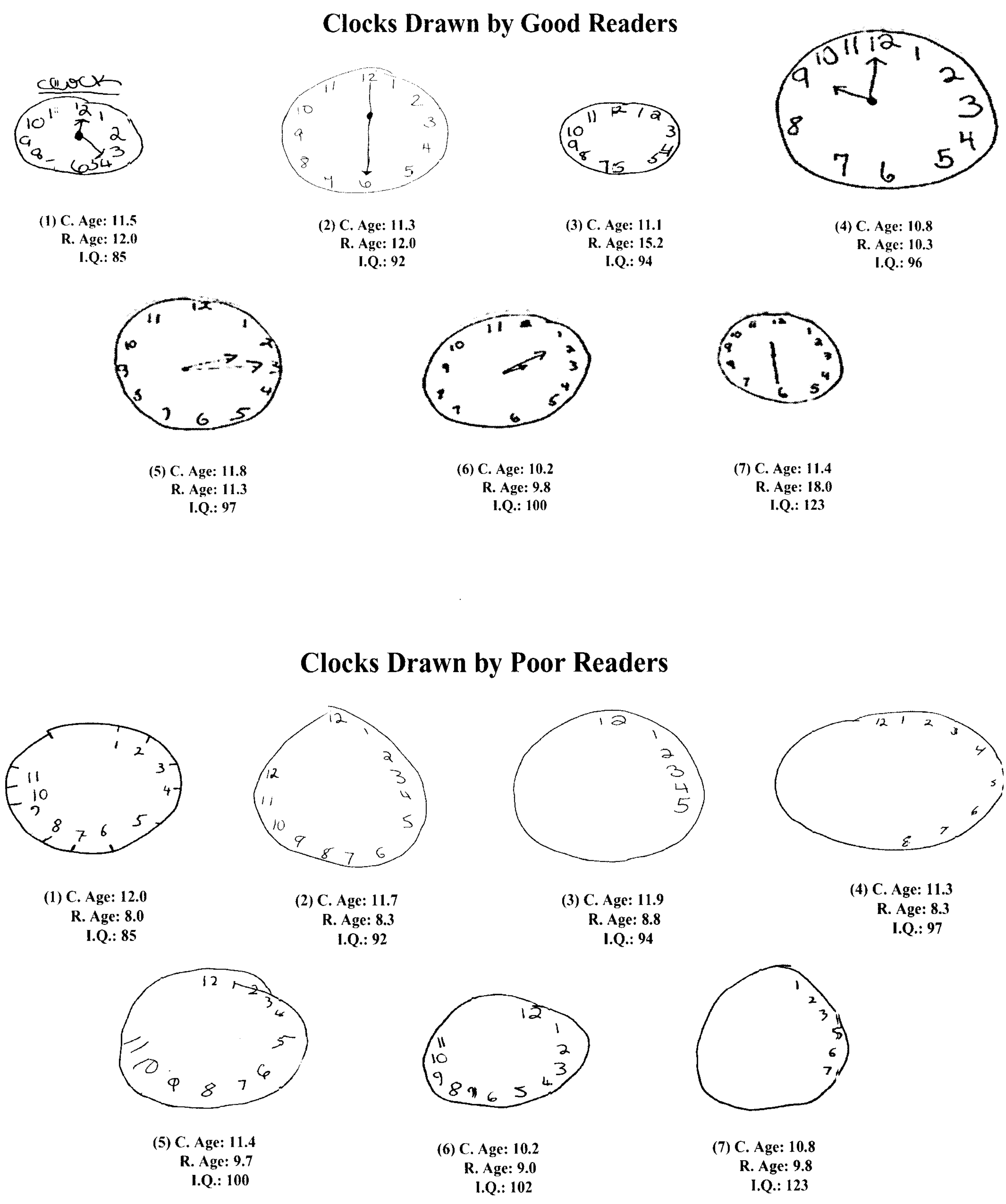

FIGURE 2. Examples of clocks drawn by children from the no dyslexia sample and from the dyslexia sample. Some of the more unusual demonstrations of clock drawing are presented.

ber skill. As clocks are usually drawn in a clockwise direction, it is possible that the CDT may have biased children toward bunching the figures on the right-hand side. However, typical readers showed the opposite pattern, namely, a slight tendency to compress the figures into the left field. The CDT did not correlate with either Performance or Verbal IQ, suggesting that these tests may not be sensitive to the same processes measured with the CDT. Gender, handedness, or ADD diagnosis did not influence CDT performance. Thus, our results provide more evidence for the view that many individuals with dyslexia suffer impaired visuospatial skills that cannot be explained by any other variables. However, it should be noted that the measure of ADD we used is not a continuous one, and a better way to investigate this defcit would be by studying a sample that also included individuals with ADD but no RD (Voeller & Heilman, 1986). The results from the correlation analysis suggest that neglect coexists with phonological deficits, so that those who do poorly on the CDT do not constitute a specific group of individuals with dyslexia. Almost half of the individuals with dyslexia performed 2 standard deviations below the typical readers. Garden-variety poor readers did not perform significantly better than individuals with dyslexia on clock drawing; therefore, the clock drawing deficit is not specific to dyslexia, but it is more frequent in the dyslexia group than in the garden-variety poor reading group. Phonemic awareness was also not significantly different between the GVPR and dyslexia groups, consistent with research that has questioned the validity of the distinction between dyslexia and garden-variety poor reading (Stanovich, 1994).

Why does the pathophysiology in the left hemisphere in developmental dyslexia not result in *right* neglect during clock drawing? There are two aspects that need to be considered to address this question: (a) the role of developmental versus acquired lesions and (b) the disproportionate right-sided vulnerability of the right hemisphere in attending to visuospatial materials. Acquired lesions will be considered first. Left-sided lesions can give rise to neglect on the right side, but right neglect is less common. Lesion patients may make reading errors that are confined to the right half of objects or words. An unusual patient with a left posterior lesion reported by Caramazza and Hillis (1990) neglected the right side regardless of length and irrespective of whether words were presented horizontally, vertically, or mirror reversed. This right neglect was therefore object centered, with the middle of the word acting as the reference point. In the present study, we found no examples of right neglect among our participants with dyslexia. Acquired cases of reading deficits therefore do not necessarily emulate developmental lesions in their behavioral manifestations. Similarly, phonological deficits are found in patients with acquired dyslexia, but they are not as commonly observed as in developmental dyslexia (Castles & Coltheart, 1993). The most likely reason for this discrepancy between developmental and acquired dyslexia resides in the recovery and reorganization that sets in during maturation in developmental disorders (Galaburda, 1992). The behavioral consequences are likely to differ compared to those cases in which a skill was once established and then lost as a result of instant brain damage. Likewise, lesions induced in the magnocellular system in monkeys (Area MT) initially result in the inability of the monkey to perform a visual motion discrimination task. However, several months after the lesion, the monkey recovers the majority of this skill and only exhibits a mild deficit. Developmental disorders and acquired lesions that share underlying cortical pathophysiology can therefore manifest in different behavioral consequences.

The second issue when considering why left-hemisphere pathophysiology in developmental dyslexia does not result in right neglect requires a discussion of the models underlying attention to visuospatial construction derived from human and animal data. It has been suggested that the right hemisphere is more vulnerable to damage and more significant resultant deficits than the left hemisphere. The theories explaining this observation are complex and will be only briefly addressed here (for a review, see Vallar, 1998). Kinsbourne (1970) has postulated that in healthy people, the right hemisphere has greater control of attention and the two hemispheres are in reciprocal balance. After a unilateral lesion, this mutually inhibitory interaction is disrupted, and so attention is biased to one side. As a result, stimuli contralateral to the lesion tend to be ignored. With the additional hypothesis that inhibition of the left hemisphere by the right hemisphere is twice as strong as vice versa, the observation that left neglect is twice as common as right neglect can be accommodated. Posner, Walker, et al. (1984) put forward a three-stage model of attention: disengagement, shifting, and engagement. Posner et al.'s finding that patients with right parietal lesions have particular problems with disengaging attention from the right rather than difficulty shifting it to the left is consistent with Kinsbourne's (1970) hypothesis, as are observations that posterior parietal cortex neurons are much more strongly modulated by shifting attention than they are by passive visual stimuli (Mountcastle, Anderson, et al. 1981).

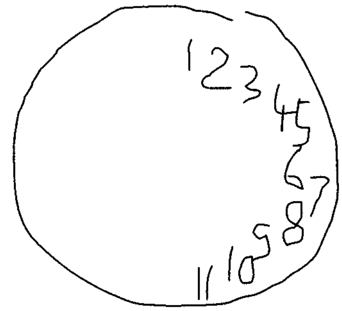

FIGURE 3. An example of a clock drawn by an adult patient with a right parietal lobe lesion resulting from a stroke.

TABLE 2

Correlation Matrix for 93 Children, Showing How the Clock Drawing Test Relates to Chronological Age, Reading Ability, Math, and Phonemic Awareness

	C. AGE (5th grade)	WJRSS Reading (5th grade)	WISC VIQ (3rd grade)	WISC PIQ (3rd grade)	WISC FIQ (3rd grade)	Sex**	Handedness**	ADD** (3rd grade)	Clock (5th grade)	Block design (3rd grade)	Math (5th grade)	Pig Latin score (5th grade)
C. AGE (5th grade)	1	–.59*	–.54*	–.44*	–.55*			.22	–.30*	–.37*	–.57*	–.32*
WJRSS (5th grade)		1	.65*	.55*	.68*	.24		–.39*	.29*	.50*	.79*	.68*
WISCVIQ (3rd grade)			1	.59*	.91*			–.33*		.46*	.71*	.38*
WISPIQ (3rd grade)				1	.87*					.80*	.63*	.37*
WISCFIQ (3rd grade)					1			–.30		.69*	.75*	.42*
SEX**						1					.22	.21
HANDEDNESS**							1					
ADD** (3rd grade)								1		–.25	–.31	–.29
CLOCK (5th grade)									1	.19	.23	.33*
BLOCK DESIGN (3rd grade)										1	.56*	.49*
MATH (5th grade)											1	.59
PIG LATIN SCORE (5th grade)												1

Pearson's and **Spearman Correlation Coefficients; $^{*}p < .01$.

Attentional bias to the right is much more likely to explain the mild left neglect shown by our participants with dyslexia. The clocks drawn by individuals with dyslexia resemble those of patients with what is called *spatial neglect* or other terms, such as *hemispatial neglect, visuospatial agnosia, visuospatial neglect,* and so forth (F. M. Heilman, Watson, et al., 1993). Although none of the children went to the extreme of writing all 12 numbers into the right side of the clock, as seen in some patients with right-hemisphere lesions, many of them wrote the majority of the numbers on the right side of the clock. Unlike lesion patients with severe neglect, children with dyslexia have enough awareness of the entire picture to orient themselves at the end of the task.

Attentional mechanisms defined by ADD status did not seem to correlate with the lack of spatial attention resulting in poor clock drawing. The reason for this can be considered in light of the distributed networks that underlie attention. Human and animal lesion studies have shown that damage to a number of cortical (temporo–parietal–occipital junction, cingulate gyrus) and subcortical regions (thalamus and mesencephalic reticular formation) will result in unilateral neglect (F. M. Heilman et al., 1993). Heilman and colleagues (F. M. Heilman et al., 1993; Mesulam, 1981; Watson, Heilman, Cauthen, & King, 1973) have proposed that the subcortical structures are involved in mediating arousal and attention, whereas the cortical areas are responsible for the analysis of the behavioral significance of stimuli. For example, the activity recorded from the neurons of the inferior parietal lobule (Area 7) of the monkey correlates with stimulus response or importance to the animal (Mountcastle, Anderson, & Motter, 1981; Mountcastle, Lynch, Georgopoulus, Sakata, & Acuna, 1975). As the inferior parietal lobule also has neurons that are active when the animal is fixating on an object of interest (visual fixation neurons), these may play a role in reading in the human homologue, the posterior parietal cortex. As neurons in the posterior parietal cortex of monkeys have bilateral receptive fields (Mountcastle et al., 1975), K. M. Heilman and Van Den Abell (1979) postulated that the right hemisphere contains more of these neurons, with the left hemisphere representing only the contralateral receptive fields. A lesion in the right hemisphere would therefore cause left neglect, because the left hemisphere would not be able to compensate, but damage in the left hemisphere would not result in right neglect, because the right hemisphere would be able to attend to ipsilateral stimuli. In summary, given some of the properties of the posterior parietal cortex that have been observed in human and animal lesion studies, this area appears to function as an interface between attention to, reception of, and response to significant events in space.

How do the parietal cortex and clock drawing relate to theories about a magnocellular deficit? Although the present study has not correlated clock drawing with tasks that are known to engage the magnocellular system (such as visual motion detection), functional brain imaging studies have shown that such tasks rely on extrastriate visual Area V5/MT and the parietal cortex (Cheng et al., 1995). Several investigators have demonstrated sensory deficits specific to the dorsally projecting parietal stream (dominated by the magnocellular system) in dyslexia (for a review, see Stein & Walsh, 1997). Tasks preferentially processed by the magnocellular system, such as visual motion perception, have been shown to elicit a strikingly different physiological response in the extrastriate cortex in individuals with dyslexia compared to controls (Demb, Boynton, et al., 1998; Eden, vanMeter, et al., 1996). Advances in functional neuroimaging techniques allow the question of shared systems to be investigated directly. For example, the regional specialization and spatial congruence of those cortical areas engaged in processes affected by developmental dyslexia can be identified with modern imaging technology. Functional brain imaging studies of reading, phonological awareness, and sensory processing have converged to yield agreement on atypical task-related signal change in the areas of the occipital, temporal, parietal, and frontal regions (Eden & Zeffiro, 1998). Despite these technical advances allowing noninvasive acquisition of physiological correlates of behavior, gaps remain in the array of behavioral measures used to elicit sensorimotor or visuospatial deficits. Functional brain imaging studies are time consuming and costly, and currently they do not provide an alternative for good neuropsychological evaluation. Filling this void of behavioral measures assessing visual system integrity would provide a link between behavioral aberrations measured with paper-and-pencil tests and the physiological basis of dyslexia revealed by fuctional brain imaging research. Further studies performed in children with dyslexia might help pinpoint the etiology of these deficits. That is, neurobiological anomalies might originate at several foci in the brain; alternatively, a single brain region that is constrained as a result of dyslexia might be responsible for processing both visual and phonological processes.

The link between the magnocellular system and the parietal cortex in the context of this study lies in the anatomical projections from the magnocellular layers of the lateral geniculate nucleus to the extrastriate visual cortex and the posterior parietal cortex. The posterior parietal cortex is active in visual motion perception and other magnocellular tasks. Unlike Area MT/V5, the parietal cortex is involved in many higher order perceptual and motivational influences. Although it is not yet known where the primary deficit of the magnocellular pathway occurs in dyslexia, anatomical or functional changes have been reported at multiple levels, including the lateral geniculate nucleus, extrastriate visual cortex Area MT/V5, and parietal regions. Irrespective of the known etiology, the existence of magnocellular projections to the parietal cortex provides good reason to believe that a deficit to this system could result in parietal cortex dysfunction, such as neglect. Human parietal cortex is more expansive in the right hemisphere, suggesting functional advantages of this hemisphere over the left hemisphere (Eidelberg & Galaburda, 1984). Furthermore, it has been suggested that the dorsal system is responsible for actions in near space (particularly in the lower visual field), such as object manipulation, and in human skills such as reading and writing (Previc, 1990). Evidence supporting this theory comes from human lesions in the parietal cortex resulting in neglect in near space but not in far space. Patients with right parietal damage have been shown to neglect objects not only in space but also in time. When identifying a visual object such as a letter, the identification of a second object close in time is impaired based on a phenomenon called *attentional blink.* This ability to allocate attention over time is impaired in a patient with right parietal lesions (Husain, Shapiro, et al., 1997) as well as in individuals with dyslexia. This temporal attention deficit provides a link to some of the difficulties observed when individuals with dyslexia process visual stimuli with short interstimulus intervals (Williams, Molinet, Lecluyse, 1989).

Conclusions

To date, there has been a disproportionately small number of investigations into the visual and visuoperceptual problems of individuals with dyslexia. These studies, often conducted in the framework of a magnocellular deficit hypothesis, have shown that children with dyslexia do indeed have aberrant perceptions of contrast and motion under certain stimulus conditions (Lovegrove et al., 1986; Stein, 1989; Williams & Lecluyse, 1990; Willows, 1991). In the present study, we present data illustrating that right-hemisphere function can be investigated in children with dyslexia using the *Clock Drawing Test.* From these results it seems that children with dyslexia suffer both visuospatial impairments characteristic of right posterior parietal cortex and phonological difficulties, pointing to left-hemisphere involvement. Thus, dyslexia probably results from a developmental process affecting both hemispheres. The extent to which this deficit affects cortical and subcortical structures and, therefore, can be interpreted in terms of the arousal and attention models that have been proposed is not yet clear, although there is evidence for atypical physiology and anatomy at both these levels. The *Clock Drawing Test* is extremely simple and requires only about 1 minute to perform. We therefore recommend its inclusion in testing batteries designed for research and clinical evaluations, in lieu of other, more extensive measures of visual system function. It is useful as a screening test for detecting visuospatial impairment in children with dyslexia. A deeper understanding of the processes involved when reading fails to develop typically may suggest new approaches to the diagnosis and treatment of developmental dyslexia.

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AUTHORS' NOTES

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