The Relationship Between Periventricular Brain Injury and Deficits in Visual Processing Among Extremely-Low-Birthweight (<1000 g) Children

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Objective: To examine the relationship between neonatal, periventricular brain damage and visuomotor performance in extremely-low-birthweight (ELBW) children of normal intelligence whose birthweights were appropriate for gestational age (AGA).

Methods: Seventy-eight ELBW and 23 control children, all six years of age, completed two “motor-free” tests of visual spatial ability and three tests requiring visuomotor control.

Results: Full-term control children outperformed ELBW children with periventricular brain damage on all three tests requiring visuomotor guidance. No group differences were found on two “motor-free” tests of visual spatial ability. ELBW children without periventricular brain damage performed in a manner indistinguishable from controls on all tests included in this study.

Conclusions: The findings indicate that the presence and severity of periventricular brain injury are important factors to consider in predicting visuomotor development in ELBW children.

Key words: prematurity; extremely low birthweight; visuomotor; periventricular brain damage; intraventricular hemorrhage; visual; outcome.

Due to significant advances in medical technology, increasing numbers of infants born extremely prematurely are surviving each year. Although many of these infants go on to score within the normal range on tests of intelligence in later childhood (e.g., Downie, Frisk, & Jakobson, 2000; Forslund & Bjerre, 1990; Ornstein, Ohlsson, Edmonds, & Asztalos, 1991), a substantial proportion exhibits “minor” developmental disabilities (e.g., Vohr & Garcia-Coll, 1985). Evidence suggesting specific vulnerability in the visual systems of these tiny survivors is mounting, with problems in visuomotor control, in particular, frequently cited (e.g., Forslund & Bjerre, 1990; Frisk, Whyte, & Barnes, 1997; Ornstein et al., 1991; Ross, Lipper, & Auld, 1991). It is important to try to specify the precise nature and etiology of these visuomotor deficits, for they are thought to contribute to many of the problems the extremely premature experience in adjusting to school tasks (Ross et al., 1991; Saigal, Szatmari, Rosenbaum, Campbell, & King, 1991). A clear understanding of these factors will allow for more accurate, early detection of those children at greatest risk for experi-

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encouraging visuomotor delays and for the development and implementation of appropriate interventions.

By their nature, many of the tests used in clinical practice to assess visuomotor abilities are complex. Consider, for example, copying tasks like the Rey-Osterrieth Complex Figure (ROCF; Osterrieth, 1944; Rey, 1941). The complexity of the ROCF poses two kinds of difficulties. First, many young children find the test challenging, resulting in drawings that are difficult to score and interpret (Akshoomoff & Stiles, 1995); this limits the test’s utility as an early screening measure at or before school entry. Second, it is difficult to say whether poor performance on the ROCF or similar tasks results from inadequate visuospatial analysis, problems with fine motor control, or both. When tests of these latter abilities have been included in studies of very low birthweight children, difficulties with fine motor control are consistently described, whereas problems with visuospatial analysis have been reported in some studies (Luoma, Herrgård, & Martikainen, 1998) but not others (Goyen, Lui, & Woods, 1998; Thompson, Chapieski, & Miner, 1991).

Despite recent advances, little is known about the underlying neural causes of the visuomotor control problems that affect many ELBW children. Some investigators (Waber & McCormick, 1995) have suggested that extreme prematurity, in itself, has “a specific neurobehavioral impact on the development of the neurobehavioral mechanisms underlying the processing of (complex) visual information” (p. 732). It is possible, however, that difficulties in this area are related not to the degree of prematurity per se but to other problems that frequently affect this population. For example, within the ELBW population, a subgroup of children is born small for gestational age (SGA; i.e., birthweight more than two standard deviations below the mean for their gestational age). Some research indicates that the degree of growth restriction is negatively associated with overall performance on tests of motor development (Hutton, Pharoah, Cooke, & Stevenson, 1997; Martikainen, 1992) (but see Goyen et al., 1998, and Robertson, Etches, & Kyle, 1990, for contradictory findings).

Another factor to consider is that the smallest survivors of preterm birth are at high risk for two types of periventricular brain injury: germinal matrix/intraventricular hemorrhaging (IVH) and hypoxic/ischemic insults (H/I) (Volpe, 1995). Although both are detectable in the neonatal period with cranial ultrasonography, much past research has not allowed for a systematic investigation of the effects of such damage on visuomotor development. In some cases, either serial cranial ultrasounds were not performed (e.g., Waber & McCormick, 1995), or the scanning procedures used and the severity of detected periventricular injuries were not documented (Goyen et al., 1998). In other cases, the preterm sample included children with associated hydrocephalus (Thompson et al., 1991) or born SGA (Järvenpää, Virtanen, & Pohjavuori, 1991), making interpretation of the results difficult. Still other reports, utilizing either the results of cranial ultrasound scans (Bozynski et al., 1984; Jongmans et al., 1996) or magnetic resonance imaging (Olse´n et al., 1998), have demonstrated a clear relationship between the extent of periventricular brain damage and visuomotor performance, but the tests selected for use included both a fine motor and a visual spatial component, making separate evaluation of these constituent skills impossible.

In this study, a variety of tests requiring higher-order visual processing was administered to a group of 6-year-old ELBW children, including two “motor-free” tests of visual spatial ability and three tests requiring varying degrees of visual spatial analysis, manual dexterity, and visual guidance. In this latter group of tests, we included a modified, step-by-step (“piecemeal”) administration of the ROCF (Frisk, Fallon, & Whyte, 1993; Read, 1982). This administration format simplifies the task considerably. In our own normative studies, we have found that with this modified format, full-term, 6-year-old children are able to achieve scores comparable to those of 8-year-olds tested with the standard administration format (Knight, Frisk, & Jakobson, 2000). A second advantage of this modified format is that it minimizes the spatial and attentional demands of the task, allowing one to isolate deficits in the visual guidance of movement more than is possible with the standard format.

Based on past research, we hypothesized that performance on “motor-free” tests of visual spatial function and tests of fine motor control would be compromised in our preterm sample (cf. Luoma et al., 1998). Moreover, we expected to see a relationship between performance on these measures and the degree of periventricular brain damage sustained during the neonatal period, with those children who suffered the most extensive damage experiencing the greatest difficulty in comparison to full-term control children. To avoid interpretational problems relating to the effects of global
cognitive impairment, we limited our sample to children of normal intelligence. In addition, to isolate the effects of periventricular brain damage, we excluded children born SGA and those with a history of neurological impairments or conditions other than periventricular brain damage (e.g., hydrocephalus, epileptic seizures, severe sensory impairment).

Method

Participants

Of the 216 ELBW children born between 1984 and 1987 who were treated in the neonatal intensive care unit of Mt. Sinai Hospital or the Hospital for Sick Children (both in Toronto, Ontario), 178 underwent detailed neuropsychological assessment shortly after their sixth birthday. Those not tested included 33 children who were lost to follow-up or whose parents refused assessment; 4 who could not complete the standardized testing because of blindness, inability to talk, or severe motor handicap; and 1 who died prior to 6 years of age. Of those seen at 6 years, a subgroup of 78 children (35 boys; 43 girls) was selected for this study who met the following criteria: (1) all had undergone an appropriate series of head ultrasound scans from which the presence and the severity of periventricular brain injury could be determined (see Procedure section); (2) none had experienced neurologic disorders or damage other than periventricular brain injury during the neonatal period; (3) none of the participants was born SGA; (4) all had adequate vision and hearing at the time of testing; and (5) all were of normal intelligence, having achieved a Full Scale IQ rating of 80 or greater using the Wechsler Preschool and Primary Scales of Intelligence—Revised (WPPSI-R; Wechsler, 1989).

Data were also collected for comparison on 23 6-year-old, full-term (FT) children recruited through flyers, a newspaper advertisement, by follow-up program staff, and through the Frontenac County Board of Education. All FT control participants were born without complication and had no history of neurological disease or developmental problems. Children recruited through the Frontenac County Board of Education were tested at the school they attended. Children recruited through the flyer or newspaper advertisement were tested in the Department of Psychology at Queen’s University (Kings-
that the spontaneous use of this type of strategy provides a clear advantage when copying the ROCF or reproducing it from memory (Akshoomoff & Stiles, 1995; Waber & Holmes, 1985).

**Procedure**

*Documentation of Periventricular Brain Injury in the Preterm Sample.* A minimum of three cranial ultrasound scans was used to determine the presence and severity of periventricular brain injury in each of the preterm children. In all cases, the first scan was taken within the first 7 days of life and was used to determine the presence of IVH. Additional scans, taken at the end of the second week of life, and between the fourth and sixth weeks of life, were used to determine the severity of any noted IVH and to document the presence and severity of H/I damage (Partridge, Babcock, Steichen, & Han, 1983). For many participants, the results from other ultrasound scans were also available and were used when making judgments as to the severity of brain injury.

IVHs were graded in severity from mild to severe using a 4-point scale in which IVH confined to the germinal layer was classified as Grade 1; IVH with bleeding into the ventricles but without dilatation was classified as Grade 2; IVH with ventricular dilatation was classified as Grade 3; and IVH with associated hemorrhagic infarction in the parenchyma was classified as Grade 4 (based on Papile, Burstein, Burstein, & Koffler, 1978). Hypoxic-ischemic damage was also graded from least to most severe using a 4-point scale in which: the presence of a small, single anterior cyst less than 5 mm in size was classified as Grade 1; persistent periventricular echogenicity without subsequent cystic formation was classified as Grade 2; porencephaly less than 5 mm in size was classified as Grade 3; and widespread periventricular leukomalacia or porencephaly greater than 5 mm in size was classified as Grade 4. This latter coding system for H/I damage was developed by Frisk and Whyte (1994), based on the degree of handicap associated with these lesions as reported in the medical outcome literature in the late 1980s and early 1990s.

*Neuropsychological Testing.* All children were tested individually, starting with administration of the piecemeal ROCF. In this modified administration format, children were initially shown the first stimulus card, which depicts the central rectangle in bold. The stimulus card was placed flat on the table surface, approximately 30 cm directly in front of the child. The child was then instructed to draw the rectangle as accurately and as close in size to the presentation figure as possible, on a 21.5 cm by 28 cm piece of white paper placed horizontally in front of him or her. The children were not permitted to rotate either the stimulus card or the paper on which they were copying the figure. All children were instructed to inform the examiner when they were finished.

Once they had copied this element, the second element was displayed. Participants were shown that the element they had already drawn was now represented by dashed lines, and that the new piece they were to add to their drawing was represented by the solid lines. They were then instructed to add the new element to their drawing. Each new element was presented after the child indicated he or she was finished with the previous element. If the child did not begin drawing the new element at its presentation, instructions to “add the new piece” were repeated. If a child indicated that he or she could not find it, the next element was displayed. This format was followed until all 18 elements had been presented and copied.

Whenever possible, after copying the piecemeal ROCF, participants completed the remaining tests in the order specified: the PPVT-R, Gestalt Closure subtest, Grooved Pegboard, HVOT, and Block Design subtest. (Data were not collected for one or more of these additional tests in a small number of ELBW children due to scheduling constraints.) All of these tests were administered and scored according to standardized procedures. With the exception of the Grooved Pegboard, raw scores were converted to standard scores using appropriate age norms.

**Results**

*Group Characteristics*

Characteristics of the study groups are summarized in Table 1. On the basis of their ultrasound findings, the ELBW children were subdivided into three groups: (1) an ELBW no lesion group consisting of those ELBW participants having normal head ultrasound scans; (2) an ELBW mild lesion group consisting of those with Grades 1 or 2 IVH and/or H/I...
more formal education than the mothers of preterm children with severe lesions (see Table I).

<table>
<thead>
<tr>
<th>Group Differences on Experimental Measures</th>
</tr>
</thead>
</table>

A series of univariate analysis of variance (ANOVA) tests with group (no lesion, mild lesion, severe lesion) as the between-subjects factor was performed to determine the comparability of these three preterm groups in terms of birthweight and gestational age at birth. An alpha level of .05 was adopted for this and all subsequent analyses. Significant ANOVA results were followed with Tukey tests for honestly significant differences (Tukey HSD). These tests revealed that, although all of the preterm groups were matched for birthweight, the no lesion group was born slightly later in gestation than the mild lesion group (approximately 1.5 weeks later, on average, \( F[2, 75] = 8.344, p < .01 \)).

The comparability of the three groups of preterm children and the control children in terms of age at test and verbal intelligence (PPVT-R standard score) was assessed with two, univariate ANOVA tests with group (FT control, no lesion, mild lesion, severe lesion) as the between-subjects factor. These analyses revealed that the four groups were well matched in terms of each of these variables. The distributions of both mothers’ and fathers’ education across each subject group were analyzed with Kruskal-Wallis tests. These analyses revealed that the groups were well matched for fathers’ educational attainment, but differed in terms of mothers’ educational attainment (\( \chi^2[3] = 9.7, p < .05 \)), with the mothers of control children generally having more formal education than the mothers of preterm children with severe lesions (see Table I).

### Table I. Means, Standard Deviations (Parenttheses) and Ranges (Brackets) for the Demographic Measures

<table>
<thead>
<tr>
<th>FT controls</th>
<th>No lesion</th>
<th>Mild lesion</th>
<th>Severe lesion</th>
</tr>
</thead>
<tbody>
<tr>
<td>( n )</td>
<td>23</td>
<td>31</td>
<td>30</td>
</tr>
<tr>
<td>Gender</td>
<td>10 M; 13 F</td>
<td>14 M; 17 F</td>
<td>13 M; 17 F</td>
</tr>
<tr>
<td>Birthweight (gms)</td>
<td>3817 (533)</td>
<td>844 (101)</td>
<td>791 (117)</td>
</tr>
<tr>
<td>[2530–4600]</td>
<td>[660–1000]</td>
<td>[560–1000]</td>
<td>[650–1000]</td>
</tr>
<tr>
<td>Gestational age (wks)</td>
<td>40.3 (1.8)</td>
<td>26.9 (1.5)</td>
<td>25.5 (1.1)</td>
</tr>
<tr>
<td>[35–44]</td>
<td>[24–31]</td>
<td>[24–28]</td>
<td>[24–28]</td>
</tr>
<tr>
<td>Age at test (months)</td>
<td>77.7 (3.3)</td>
<td>76.7 (2.2)</td>
<td>76.6 (2.3)</td>
</tr>
<tr>
<td>[72–82]</td>
<td>[72–81]</td>
<td>[73–81]</td>
<td>[72–80]</td>
</tr>
<tr>
<td>PPVT-R score</td>
<td>105.4 (14.6)</td>
<td>106.5 (19.9)</td>
<td>104.9 (12.3)</td>
</tr>
<tr>
<td>[81–131]</td>
<td>[80–142]</td>
<td>[80–128]</td>
<td>[72–134]</td>
</tr>
<tr>
<td>Father’s education</td>
<td>4.9 (1.3)</td>
<td>5.3 (0.9)</td>
<td>5.0 (1.3)</td>
</tr>
<tr>
<td>Mother’s education</td>
<td>5.3 (1.1)</td>
<td>5.0 (1.1)</td>
<td>4.5 (1.2)</td>
</tr>
</tbody>
</table>

\( a \) Tukey HSD: significantly greater than mild lesion group.
\( b \) Kruskal-Wallis test for independent samples: significantly less than control group.
sions were most likely to be compromised on this task, although pairwise comparisons were not significant.

Group differences were clearly evident on all three of the tests with a fine motor component, and with each of these tests the presence and severity of periventricular brain damage appeared to be an important factor in determining performance. ELBW children with no evidence of periventricular brain damage performed each of the tests in a manner indistinguishable from controls.

The piecemeal ROCF was scored blind to group membership on two factors: organization and accuracy. The organization of participants’ drawings was assessed using the Developmental Scoring System developed for the standard ROCF (Bernstein & Waber, 1996). The organization score essentially dissociates a person’s ability to perceive the figure from the motor component involved in reproducing it and measures an individual’s appreciation of the basic structure of the design, irrespective of line quality and precision. As such, it provides an index of visual spatial ability. This score also takes the normal developmental course of children into account when assessing organizational quality. On this measure, there was a main effect of group, \( F(3, 97) = 5.138, p < .05 \), with ELBW children who had suffered mild or severe lesions performing significantly below the level of controls. Note that all of the children, including controls, performed below ceiling on this measure. The fact that the group differences reported above were evident even though the children had been provided with an organizational strategy for their drawings supports the conclusion that periventricular brain damage is associated with problems in visuospatial ability.

Piecemeal ROCF copies were also scored for accuracy using an established scoring system developed for the standard administration (Taylor, 1959). To establish interrater reliability for the accuracy scores, for approximately a third of the ROCF copies, a second rater who was also kept blind to group membership rescored copies produced by participants. Interrater reliability was determined using Spearman’s correlation. The correlation produced an alpha reliability of .96.

Copy accuracy scores were influenced by group membership, \( F(3, 97) = 5.578, p = .001 \). Post-hoc comparisons revealed that copies of the ROCF produced by FT control participants were significantly more accurate than those produced by ELBW children with either mild or severe periventricular brain injury. The accuracy scores of the ELBW children decreased with increasing severity of periventricu-

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### Table II. Means and Standard Deviations (in Parentheses) on Two “Motor-Free” Tests of Visual Spatial Ability

<table>
<thead>
<tr>
<th></th>
<th>FT controls</th>
<th>No lesion</th>
<th>Mild lesion</th>
<th>Severe lesion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hooper Visual Organization Test</td>
<td>19.3 (3.3)</td>
<td>20.6 (3.0)</td>
<td>19.2 (2.9)</td>
<td>18.1 (4.1)</td>
</tr>
<tr>
<td>Gestalt Closure</td>
<td>11.1 (2.6)</td>
<td>11.5 (2.7)</td>
<td>11.0 (2.8)</td>
<td>10.2 (3.5)</td>
</tr>
</tbody>
</table>

### Table III. Means and Standard Deviations (in Parentheses) on Three Tests Requiring Visuomotor Skill

<table>
<thead>
<tr>
<th></th>
<th>FT controls</th>
<th>No lesion</th>
<th>Mild lesion</th>
<th>Severe lesion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Piecemeal ROCF</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Organization</td>
<td>5.7 (1.9)</td>
<td>4.8 (1.7)</td>
<td>4.3*(1.2)</td>
<td>4.1+ (0.9)</td>
</tr>
<tr>
<td>Accuracy</td>
<td>22.5 (5.2)</td>
<td>20.9 (3.9)</td>
<td>19.1+ (4.8)</td>
<td>17.0+ (3.9)</td>
</tr>
<tr>
<td>Grooved Pegs: dominant hand</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time (s)</td>
<td>39.0 (7.2)</td>
<td>48.6 (15.0)</td>
<td>48.0 (10.6)</td>
<td>57.0+ (8.8)</td>
</tr>
<tr>
<td>Errors</td>
<td>0.4 (0.8)</td>
<td>0.5 (1.1)</td>
<td>0.4 (0.8)</td>
<td>0.3 (0.6)</td>
</tr>
<tr>
<td>Grooved Pegs: nondominant hand</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time (s)</td>
<td>45.7 (15.1)</td>
<td>61.9 (28.0)</td>
<td>53.6 (23.1)</td>
<td>65.1+ (19.6)</td>
</tr>
<tr>
<td>Errors</td>
<td>0.3 (0.5)</td>
<td>1.6 (2.8)</td>
<td>0.6 (0.9)</td>
<td>0.9+ (0.8)</td>
</tr>
<tr>
<td>Block Design</td>
<td>10.3 (2.6)</td>
<td>9.7 (1.8)</td>
<td>9.7 (2.6)</td>
<td>8.0+ (2.7)</td>
</tr>
</tbody>
</table>

*Tukey HSD: significantly different from FT controls.
* Tukey HSD: significantly different from no lesion group.
* Tukey HSD: significantly different from mild lesion group.
* Tukey HSD: trend toward being different from FT controls, \( p < .10 \).
lar brain injury, such that ELBW children with no evidence of periventricular brain injury produced significantly more accurate copies than did those ELBW children with severe lesions.

Performance on the Grooved Pegboard test was measured in terms of errors and total time taken to place all of the pegs. The results of the repeated measures ANOVA revealed a significant main effect of group, $F(1, 77) = 16.112, p < .001$, and committing fewer errors, $F(1, 77) = 5.557, p < .05$, when using their dominant hand. There were also significant group differences in completion time, $F(3, 77) = 4.226, p < .01$, with children with severe lesions taking longer to place all of the pegs than any of the other groups. A similar trend was observed in the analysis of error scores, $F(3, 77) = 2.266, p < .10$.

There was also a significant main effect of group on the Block Design test, $F(3, 82) = 3.085, p < .05$, with ELBW children who had suffered from severe periventricular brain damage performing significantly worse than FT controls.

**Discussion**

These findings offer support for the hypothesis that the presence and severity of periventricular brain damage are more important than ELBW status alone in predicting which preterm children will be at greatest risk for experiencing visuomotor problems at 6 years of age. Indeed, AGA ELBW children who were found to have no evidence of periventricular brain injury on cranial ultrasound performed at comparable levels to the full-term control children on all of the tests administered in this battery. Children with severe lesions, on the other hand, were impaired on many of these tests relative to controls, whereas those with mild lesions performed at an intermediate level, differing significantly from controls only on the piecemeal ROCF. However, due to the numerous exclusion criteria adopted, this study may underestimate the prevalence of visuomotor impairment in ELBW children.

These results add to previous findings pointing to the appropriateness of using neonatal cranial ultrasound findings to assist in the identification of those ELBW children at greatest risk for showing persistent problems with visuomotor control (see also Vohr et al., 1989). Early identification of such children is important because of the potential long-term, negative impact of visuomotor deficits on both academic achievement and on successful participation in a full range of activities of daily living (Ross et al., 1991; Saigal et al., 1991).

The results are also informative, as they suggest that deficits reflect underlying problems in fine motor control and, to a lesser extent, spatial analysis (cf. Luoma et al., 1998). Certainly, the spatial deficits of ELBW children with severe lesions (evident in their performance on the HVOT and in the organizational quality of their piecemeal ROCF copies) were not as striking as their fine motor problems. Nonetheless, these results suggest that both fine motor and visual spatial skills should be targeted during the development and implementation of intervention programs.

One can speculate as to why visuomotor problems should be particularly sensitive to severe periventricular brain injuries. Such injuries often compromise the optic radiations (e.g., Cioni et al., 1997; Olsén et al., 1998) and are associated with thinning of parietal or occipital white matter (Goto, Ota, Sugita, & Tanabe, 1994) and defects in the lower visual fields (Jacobson, Ek, Fernell, Flodmark, & Broberger, 1996). These findings, along with the results of psychophysical studies of preterm infants and children showing impairments in stereopsis (Jongmans et al., 1996), reduced contrast sensitivity in the low to medium spatial frequency range (Dowdeswell, Slater, Broomhall, & Tripp, 1995), impairments in the processing of visual motion (Downie, Jakobson, Frisk, & Ushycky, 2000; Jakobson, Downie, & Frisk, 1998), and disorders of oculomotor control (Cioni et al., 1997), all point specifically to an impairment in the dorsal cortical visual system. This system, which connects primary visual cortex to the posterior parietal lobe (Merigan & Maunsell, 1993), is a key element of a functional circuit also involving frontal cortex that is critically involved in visuomotor control (Goodale, Jakobson, & Servos, 1996) and in certain aspects of visual attention (e.g., Culham et al., 1998).

Studies currently under way in our laboratory are examining more directly the relationship between performance on tests of dorsal system functioning and tests of visuomotor control and visual attention in a group of kindergarten-age ELBW children. If, as we predict, a relationship appears between the functional integrity of this visual path-
way and performance on tests in these two visual domains, the results may have important implications for the appropriate selection of children to target for early intervention programs.

In this study, we adopted a nonstandard approach to the administration of the Rey-Osterrieth Complex Figure, originally developed for use with geriatric populations (Read, 1982). Certainly, the modifications introduced with this form of administration allowed the young children involved in this study to produce drawings that could be scored and that provided clinically useful information. We are currently establishing norms for this format, based on a large sample of children across a range of ages.

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