The Early Motor Repertoire of Children Born Preterm Is Associated With Intelligence at School Age
Janneke L. M. Bruggink, Koenraad N. Van Braeckel and Arend F. Bos
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The Early Motor Repertoire of Children Born Preterm Is Associated With Intelligence at School Age

WHAT’S KNOWN ON THIS SUBJECT: The motor repertoire at 3 to 4 months after term is associated with motor outcomes at school age for infants at high risk.

WHAT THIS STUDY ADDS: The motor repertoire to 8 weeks after term is associated with intelligence at school age for preterm children.

abstract

OBJECTIVE: The goal was to determine whether the quality of general movements (GMs) for preterm children had predictive value for cognitive development at school age.

METHODS: In this prospective cohort study, 60 preterm infants (gestational age, median: 30.0 weeks [range: 25–33 weeks]; birth weight, median: 1130 g [range: 595–1800 g]) without cerebral palsy were studied. The quality of GMs was assessed prospectively as normal or abnormal, from video recordings that were made at regular intervals until 17 weeks after term. At 7 to 11 years, intelligence was tested by using the Wechsler Intelligence Scale for Children III, Dutch version. Total IQ (TIQ), verbal IQ (VIQ), and performance IQ (PIQ) scores were calculated.

RESULTS: The median TIQ was 93 (range: 67–113), VIQ 96 (range: 68–117), and PIQ 92 (range: 65–119). Fifteen children (25%) had low TIQ scores (<85). When the quality of GMs normalized before 8 weeks after term, TIQ, VIQ, and PIQ scores were in the normal range. Consistently abnormal GMs to 8 weeks after term were associated with lower TIQ, VIQ, and PIQ scores. With correction for male gender and the educational levels of the parents, the likelihood ratio of consistently abnormal GMs for a low TIQ was 4.9 (95% confidence interval: 1.3–17.6). The model explained 22.4% of the variance.

CONCLUSIONS: The quality of GMs during the early postterm period is a marker for intelligence at school age. Abnormal GMs during the early postterm period may reflect injury or developmental disruptions of brain areas involved in cognitive development. Pediatrics 2010;125: e1356–e1363

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KEY WORDS
preterm infants, cognition, follow-up study, school age, general movements

ABBREVIATIONS
CI—confidence interval
FM—fidgety movement
GM—general movement
PIQ—performance IQ
TIQ—total IQ
VIQ—verbal IQ

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Children born preterm have lower IQ scores than their term peers, even in the absence of brain lesions and/or severe disability. It is estimated that cognitive deficits occur in 25% to 50% of children born preterm with very low birth weight (<1500 g). Cognitive problems without major motor deficits are the predominant neurodevelopmental sequelae in children born preterm. IQ scores are 4 to 10 points lower for children born at gestational ages of <32 weeks, compared with their term peers. It is estimated that, for each week of shorter gestation below 32 weeks, IQ scores are ~1.7 points lower. This increases to 2.5 points for each week below 27 weeks. These impairments become more evident at school age, when children face more complex cognitive demands.

It is difficult to identify infants at risk for poor cognition at an early age. Although global white matter damage on MRI scans is common among children born preterm and gray matter volumes also are diminished, clear associations of cognition with pathologic changes on neuroimaging scans have not been demonstrated.

The method described by Prechtl et al for the qualitative assessment of general movements (GMs) in infants is a reliable, sensitive, noninvasive method for assessment of brain integrity at a young age. Assessment of GMs is based on gestalt perception that takes into account the complexity and variability of movements. The quality of GMs during early infancy has been found consistently to be a powerful predictor of motor disorders in later childhood. However, the predictive value of the quality of GMs for cognition is still unclear. The objective of this study was to investigate whether the quality of the early motor repertoire to 17 weeks after term had predictive value for intelligence and performance at school age.

### METHODS

#### Subjects

The study group consisted of children who were born preterm between September 1992 and October 1997 and were admitted to the NICU of the University Medical Center Groningen (Groningen, Netherlands). They were members of a group of 92 infants who were included in prospective cohort studies of the prognostic value of the quality of GMs for major motor impairments at school age and minor neurologic dysfunction. The University Medical Center Groningen institutional ethical review board approved the study. All infants were born at gestational ages of <34 weeks, and written parental consent was obtained in the first week after birth. Seven infants died, mostly as a result of severe respiratory problems as seen in bronchopulmonary dysplasia. Conditions that might interfere with normal neurologic development became apparent for 3 infants (blindness attributable to retinopathy of prematurity, n = 2; morbus Duchenne, n = 1). Five of the remaining 82 infants could not be traced, and 2 refused to participate. We excluded 15 infants who developed cerebral palsy by 6 years of age, on the basis of the criteria described by Bax et al, because major motor deficits may confound the relationship between the quality of GMs and cognitive development. The final study group consisted of 60 children, including 36 boys (60%) and 24 girls (40%), with a median gestational age of 30.0 weeks (range: 25–33 weeks) and a median birth weight of 1130 g (range: 595–1800 g) (Table 1). Educational levels of the parents ranged from elementary to tertiary level (Table 1). The mothers of 36 children (60%) had low educational levels (maximum of <12 years of vocational school). At school age, 16 children had developed minor neurologic dysfunction and 44 children were in normal neurologic condition. The included children can be considered typical of preterm infants who were admitted to the tertiary NICU of the

### TABLE 1 Clinical Characteristics and Risk Factors of Study Group, According to Cognitive Findings at School Age

<table>
<thead>
<tr>
<th>N</th>
<th>TIQ of ≥85</th>
<th>TIQ of &lt;85</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age of IQ assessment, median (range), y</td>
<td>9.2 (7.1–10.4)</td>
<td>8.6 (7.2–11.2)</td>
</tr>
<tr>
<td>Maternal educational level, median (range), y</td>
<td>10 (6–17)</td>
<td>11 (6–16)</td>
</tr>
<tr>
<td>Paternal educational level, median (range), y</td>
<td>11 (9–17)</td>
<td>11 (8–16)</td>
</tr>
<tr>
<td>Low maternal education (&lt;12 y), n (%)</td>
<td>28 (62)</td>
<td>8 (53)</td>
</tr>
<tr>
<td>Gestational age, median (range), wk</td>
<td>30.0 (25.7–33.7)</td>
<td>30.0 (27.1–33.4)</td>
</tr>
<tr>
<td>Birth weight, median (range), g</td>
<td>1120 (640–1800)</td>
<td>1215 (595–1610)</td>
</tr>
<tr>
<td>Male, n (%)</td>
<td>24 (53)</td>
<td>12 (80)</td>
</tr>
<tr>
<td>IUGR, n (%)</td>
<td>14 (31)</td>
<td>2 (13)</td>
</tr>
<tr>
<td>Prenatal corticosteroid treatment, n (%)</td>
<td>28 (62)</td>
<td>11 (73)</td>
</tr>
<tr>
<td>Appar score at 5 min, median (range)</td>
<td>8 (5–10)</td>
<td>8 (2–10)</td>
</tr>
<tr>
<td>Umbilical pH, median (range)</td>
<td>7.26 (6.98–7.39)</td>
<td>7.28 (7.20–7.42)</td>
</tr>
<tr>
<td>Ventilatory support (IPPV or HFOV), n (%)</td>
<td>25 (56)</td>
<td>7 (47)</td>
</tr>
<tr>
<td>Septicemia, n (%)</td>
<td>15 (44)</td>
<td>3 (20)</td>
</tr>
<tr>
<td>ICH grade 1 or 2, n (%)</td>
<td>12 (27)</td>
<td>3 (20)</td>
</tr>
<tr>
<td>PVL grade 1, n (%)</td>
<td>20 (44)</td>
<td>8 (53)</td>
</tr>
<tr>
<td>Ventrilucemegaly (ultrasonography), n (%)</td>
<td>1 (2)</td>
<td>2 (13)</td>
</tr>
<tr>
<td>BPD, n (%)</td>
<td>12 (27)</td>
<td>4 (27)</td>
</tr>
<tr>
<td>Postnatal corticosteroid treatment, n (%)</td>
<td>6 (13)</td>
<td>1 (7)</td>
</tr>
</tbody>
</table>

IUGR indicates intrauterine growth restriction, on the basis of birth weight, according to the Dutch weight percentiles described by Kloosterman. IPPV indicates intermittent positive pressure ventilation; HFOV, high-frequency oscillatory ventilation. ICH indicates intracranial hemorrhage, graded as described by Papile et al. PVL indicates periventricular leukomalacia, graded as described by de Vries et al. PVL grade 1 is also called prolonged flaring. BPD indicates bronchopulmonary dysplasia, defined as oxygen dependency at postmenstrual age of 36 weeks.

* P = .078.

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**ARTICLES**
Recording of Motor Repertoire

Video recordings of the infants (60 minutes) were made in weeks 1 and 2 after birth and then at weekly intervals until discharge. Additional recordings (10 minutes) were made at term (postmenstrual age of 38–42 weeks), between 3 and 8 weeks after term, and between 11 and 17 weeks after term. These recordings were made during periods of active wakefulness between feedings, with the partly dressed infants lying in the supine position.

For each infant, a median of 10 recordings (interquartile range: 8–11 recordings) were available for analysis. All recordings were evaluated off-line by Drs Bruggink and Bos, according to the methods described by Einspieler et al. One of the observers was unaware of the infant’s clinical history and developmental status; one knew the infant’s clinical history but was unaware of the developmental status at school age.

Assessment of Quality of GMs to 8 Weeks After Term

The quality of the GMs was assessed as normal or abnormal. Normal GMs are characterized by complexity, variability, and fluency, whereas abnormal GMs display reduced complexity, variability, and fluency. Previously, interobserver reliability was high (κ values between 0.8 and 0.9). We clustered the results into 5 categories on the basis of the individual developmental trajectories of GM quality, that is, (1) consistently normal; (2) abnormal, normalizing during the preterm period; (3) abnormal, normalizing during the term period (postmenstrual age of 38–42 weeks); (4) abnormal, normalizing during the early postterm period (between 3 and 8 weeks after term); and (5) consistently abnormal to 8 weeks after term.

Assessment of Quality of Motor Repertoire at 11 to 17 Weeks After Term

From these recordings, we assessed the quality of fidgety movements (FMs). Normal FMs are continuous small movements of moderate speed in all directions, which are obligatory present between 9 and 16 weeks after term but in many cases are present as early as 6 weeks and as late as 20 weeks. Apart from FMs, the quality of the concurrent motor repertoire was assessed according to the methods described by Bruggink et al. The quality of FMs was classified as normal or abnormal. We distinguished between 2 types of abnormal FMs, that is, abnormal FMs (FMs with exaggerated speed, amplitude, and jerkiness) and absent FMs. The quality of the concurrent motor repertoire was assessed as normal or abnormal on the basis of the performance of all movement and postural patterns. The concurrent motor repertoire was scored as normal if it was smooth, fluent, and variable and as abnormal if it was monotonous, jerky, tremulous, or cramped. A previous study showed high interobserver reliability (κ = 0.91). We clustered the results into 5 categories on the basis of the individual developmental trajectories of GM quality, that is, (1) normal FMs and normal concurrent motor repertoire, (2) normal FMs and abnormal concurrent motor repertoire, and (3) abnormal or absent FMs and abnormal concurrent motor repertoire. When FMs were abnormal or absent, the concurrent repertoire was abnormal.

Assessment of Cognitive Function at 7 to 11 Years of Age

The Wechsler Intelligence Scale for Children III, Dutch version, was administered at 7 to 11 years. We used 4 verbal subcales (similarities, vocabulary, information, and arithmetic) and 3 performance subcales (picture arrangement, block design, and object assembly). Verbal IQ (VIQ), performance IQ (PIQ), and total IQ (TIQ) scores were calculated by using the formula described by Sattler. School performance also was determined. We documented whether the children had repeated ≥1 class or attended special education.

Statistical Analyses

Statistical analyses were performed by using SPSS 16.0 (SPSS Inc, Chicago, IL). IQ scores were normally distributed, in contrast to scores of the quality of GMs. The Mann-Whitney U test, Spearman rank test, and Kruskal-Wallis test were used to relate IQ scores to the quality of GMs. For categorical variables, the χ² test for trend or Fisher’s exact test was used. Sensitivity, specificity, and positive and negative predictive values for the quality of GMs as a marker for later abnormal IQ scores (<75) were calculated. Backward stepwise logistic regression was used to determine whether assessments of GMs could predict intelligence at school age, with controlling for clinical and social factors (factors with P values of <.1 in univariate analyses were included in the final model). Two-tailed P values of <.05 were considered to be statistically significant.

RESULTS

Developmental Trajectories of GM Quality

Eighteen children (30%) had consistently normal GMs; for another 4 children (7%), GMs normalized before term (Fig 1). Fifteen children (25%)
had abnormal GMs during the preterm period but normalized GMs at term \((n = 14)\) or in the early postterm period \((n = 1)\). Twenty-three children \((38\%)\) had consistently abnormal GMs to 8 weeks after term.

At 11 to 17 weeks, the quality of FMs and the concurrent motor repertoire could not be assessed for 3 children because of crying, sleepiness, or hiccups. Of the remaining 57 children, 30 \((53\%)\) had normal FMs and a normal concurrent repertoire, 16 \((28\%)\) had normal FMs and an abnormal repertoire, 10 \((18\%)\) had abnormal FMs, and 1 \((2\%)\) had absent FMs. With increasing postmenstrual age, the proportion of infants with normal GMs increased significantly \((x^2\text{ for trend test}, P < .001)\).

**Cognitive Findings at School Age**

The median age of the children during testing was 9.0 years \((\text{range: } 7.1–11.2 \text{ years})\). The median TIQ was 93 \((\text{range: } 67–113)\), VIQ 96 \((\text{range: } 68–117)\), and PIQ 92 \((\text{range: } 65–119)\). Fifteen children \((25\%)\) had low IQ scores \(<85\). Five children \((8\%)\) attended schools for special education. Another 16 children \((27\%)\) had repeated classes in primary school. Children with low IQ scores were more likely to be outside their proper grade level \((9 \%(60\%)\) of 15 children\), compared with children with normal IQ scores \((12 \%(27\%)\) of 45 children\); \(P = .022\). Among the 21 children \((16 \%(44\%)\) of all boys\) and 5 girls \((21\%\) of all girls\); \(P = .097\) who were not attending school at their proper grade level, 14 \((39\%)\) had mothers with low educational levels and 7 \((29\%)\) mothers with normal educational levels (not significant).

**Relationship Between GM Quality and Findings at School Age**

TIQ scores for the children, categorized according to the individual developmental trajectories of GM quality to 8 weeks after term, are displayed graphically in Fig 2. When the quality of GMs normalized before 8 weeks after term, the median TIQ was 100 \((\text{range: } 75–113)\), VIQ 95 \((\text{range: } 72–117)\), and PIQ 102 \((\text{range: } 69–119)\). There were no differences in TIQ, VIQ, and PIQ between children who demonstrated consistently normal GMs and children who demonstrated initially abnormal GMs that normalized before 8 weeks after term (Figs 2 and 3). For children who demonstrated consistently abnormal GMs to 8 weeks after term, IQ scores were lower; the median TIQ was...
There was no association between the quality of FMs and concurrent repertoire at 11 to 17 weeks after term and TIQ scores \( (P = .129) \) (Fig 4).

School performance also was associated with the quality of GMs. Nine (24%) of 37 children for whom GMs normalized repeated class or attended special education, compared with 12 (52%) of 23 children for whom GMs did not normalize before 8 weeks after term \( (P = .05) \).

When a TIQ score of 85 was taken as the cutoff point for abnormal cognition, the quality of GMs between term and 8 weeks after term was a marker for cognitive function at school age (Table 2). Sensitivity was 67% (95% CI: 43%–91%), specificity, 71% (95% CI: 58%–84%), positive predictive value, 43% (95% CI: 23%–63%), and negative predictive value, 86% (95% CI: 75%–97%).

Of the 10 children with consistently abnormal GMs and abnormal cognition, 7 were boys (70%) and 6 (60%) had mothers with low educational levels. Twelve children with consistently abnormal GMs were not attending school at their proper grade level. Of those children, 9 were boys (75%) and 10 (83%) had mothers with low educational levels.

The likelihood ratio of consistently abnormal GMs to 8 weeks after term for a low TIQ was 4.9 (95% CI: 1.4–17.2; \( P = .01 \)), which explained 15.6% of the variance in the TIQ scores. When gender and educational level of the parents were entered into the model, only the quality of GMs remained in the model. In that model, the likelihood ratio of consistently abnormal GMs to 8 weeks after term for a low TIQ was 4.9 (95% CI: 1.3–17.6; \( P = .02 \)), which explained 22.4% of the variance. Regarding school performance (special education and repeat classes), the likelihood ratio of consistently abnormal GMs was 3.4 (95% CI: 1.1–10.3; \( P = .03 \)), which explained 10.6% of the variance.

**DISCUSSION**

The present study demonstrates that intelligence at school age is associated with the quality of GMs during early infancy for children born preterm. In particular, the quality of GMs during the early postterm period proved to be a marker for intelligence at school age. When GMs normalized before or at term, IQ scores were within normal limits. However, when GMs were consistently abnormal to 8 weeks after term, IQ scores at school age were an

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**TABLE 2** Relationships Between Quality of GMs to 8 Weeks After Term and IQ Scores at School Age

<table>
<thead>
<tr>
<th></th>
<th>IQ of &lt;85</th>
<th>IQ of ≥85</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Consistently abnormal</td>
<td>10</td>
<td>13</td>
<td>23</td>
</tr>
<tr>
<td>GMs to 8 wk after term</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Normal GMs before 8</td>
<td>5</td>
<td>32</td>
<td>37</td>
</tr>
<tr>
<td>wk after term</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>15</td>
<td>45</td>
<td>60</td>
</tr>
</tbody>
</table>

Sensitivity was 67% (95% CI: 43%–91%); specificity, 71% (95% CI: 58%–84%); positive predictive value, 43% (95% CI: 23%–63%); and negative predictive value, 86% (95% CI: 75%–97%).
The VIQ.1,6,27,28 language functions, as measured with the PIQ, were worse than complex term-equivalent age was observed.29 An cerebral white matter on MRI scans at after term and abnormalities of the e1361 e1361 the most-commonly observed brain ab-
e1361 Diffuse damage of the white matter is e1361ly.26,27 Executive functions, as measured with the PIQ, were worse than complex language functions, as measured with the VIQ.1,6,27,28

The abnormal quality of GMs during the early postterm period may reflect injury or developmental disruptions of brain areas involved in cognitive development.1,4 Recently, a clear association between abnormal GMs at 1 to 3 months after term and abnormalities of the cerebral white matter on MRI scans at term-equivalent age was observed.29 An association between abnormal GMs and gray matter abnormalities was not observed.29

Diffuse damage of the white matter is the most-commonly observed brain abnormality in preterm infants.2,20,30 White matter damage results in hypomyelination, neuronal disease, and widespread axonal degeneration in the cerebral cortex, thalamus, basal ganglia, and cerebellum, which can be seen as early as term-equivalent age.4,57 Several studies showed that cerebral white matter damage in particular was related to cognitive dysfunction at school age for preterm infants, usually in the absence of major motor deficits.6,30,32 In most studies, the relationship of cognitive function to cerebral white matter pathologic features is at least as strong2 or even stronger than that to cerebral gray matter pathologic features.5,29,30

We did not find any associations between neuroimaging results and low IQ scores. This can be explained by the fact that we did not perform MRI and white matter abnormalities often remain invisible on ultrasound scans. Also, because we excluded children who developed cerebral palsy, the prevalence of severe ultrasonographic abnormalities in our group was low: no children had grade 3 or 4 intracranial hemorrhage or cystic periventricular leukomalacia, and only 3 children had mild ventriculomegaly. Our data indicate that use of a consistently abnormal motor repertoire detects considerably more children with low IQ scores than does use of severe ultrasound abnormalities. This is consistent with previous studies with preterm children that reported a high prevalence of cognitive impairments in the absence of major abnormalities on neuroimaging scans and in the absence of major motor deficits.3,4,66

The present study is among the few that investigated the association between motor development at such a young age and cognition at school age. Some studies showed a significant association between motor development and cognitive abilities at a later age (eg, 4 years).33,34 Our results support the idea that reduced complexity and variability of GMs, as an expression of cerebral white matter damage,14 is the motor correlate of impaired cognitive functioning, particularly cognitive functions relying on widely distributed cortical networks.35 This may reflect vulnerability in the critical time frame during which the human cerebrum develops rapidly. Normally, the cerebral cortical volume increases ~4 times during the third trimester of pregnancy and the first postnatal weeks.4 Diffuse cortical white and gray matter damage may result in volumetric deficits in multiple cortical regions,36 and this has been related to a wide variety of cognitive deficits observed at follow-up evaluations.7,36 Our results also may reflect the crucial role of motor activity in normal cognitive development. A possible interpretation might be that motor activity during the early postterm period (as reflected by GMs) plays an important role in the early development of cognition.37 Some aspects of the motor repertoire at 3 to 4 months after term are associated with cognitive outcomes at school age.58 Rapid brain development in the early months is accompanied by equally rapid psychological development.39 Infants’ exploration of the environment with several motor strategies, integrating and refining neural input and output, may lead to better neurologic development.40 The absence of a complex, variable motor repertoire at this particular age might hamper infants’ abilities to interact with the surrounding world. This implies that the quality of the early motor repertoire is a measure of the extent to which spontaneous movements facilitate or inhibit infants’ interactions during a phase in which sensorimotor activity drives perceptual and cognitive development.41

Clinical and social factors did not contribute to the prediction of intelligence at school age. Only male gender showed a trend toward lower IQ scores. A similar association between intelligence and gender was reported previously.1,27 Boys have higher rates of cognitive disabilities,1 and estimates are that very low birth weight boys have IQ scores up to 10 points lower than those of girls.27 Socio-economic status of the parents and gestational age also are associated with intelligence among preterm infants.1,2 We could not confirm these findings. This may be because of the relatively small sample size. However, even large studies have failed to identify risk factors, other than prematurity, for the development of cognitive deficits in the absence of major motor disabilities.2,42,43 Assessment of the quality of GMs at term and in the early postterm period may be helpful in determining the individual risk of pre-
term infants for developing clinically relevant cognitive impairment at school age. There are some limitations in the present study. First, these results cannot be generalized and need to be confirmed with other groups of children. For example, we did not include a term group. A second limitation might be the selection of infants who had taken part in several earlier studies. However, we consider the children in the present study to be a representative sample from a tertiary NICU. A final limitation is the study sample size. The results are based on data from a small group of children from a single center. However, the lower-average mean IQ scores for the participants were similar to those found in other follow-up studies of children born preterm.1,2

CONCLUSIONS
The quality of GMs during the early postterm period is a marker for intelligence at school age. The integrity of areas of the brain involved in abnormal GMs during the early postterm period may be important for cognitive development at school age. This also may reflect the crucial role of motor activity in normal cognitive development. Our findings enable the early identification of individual preterm infants at increased risk for cognitive impairment and individual preterm infants at low risk.

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