Early motor repertoire and long-term neurological outcome
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Quantitative aspects of the early motor repertoire in preterm infants: do they predict minor neurological dysfunction at school age?

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Abstract

Background: Qualitative aspects of the motor repertoire, at 11-16 weeks post-term are predictive for minor neurological dysfunction (MND) at 7 to 11 years of age. Predictive value of quantitative aspects is unknown so far.

Aim: To investigate whether quantitative aspects of the motor repertoire between 6 and 24 weeks post-term also have predictive value for neurological outcome at 7 to 11 years of age.

Study design: Prospective cohort study.

Subjects: Preterm infants from whom several quantitative aspects of the motor repertoire were assessed between 6 and 24 weeks post-term.

Outcome measures: Neurological outcome at 7-11 years of age was assessed according to Touwen's neurological examination. Children were classified as neurologically normal, or as having complex MND or cerebral palsy (CP).

Results: Eighty-two children were included. At 7 to 11 years of age 15 children (18%) had developed CP, 49 (60%) were neurologically normal, and 18 (22%) had MND. Multiple logistic regression analysis showed that, when the qualitative aspects of the motor repertoire known to predict neurological outcome were taken into account, only the asymmetric tonic neck (ATN) posture provided additional predictive value. In case of normal fidgety movements (FMs) accompanied by an abnormal concurrent motor repertoire, the presence of an obligatory ATN increased the risk for developing complex MND to 75%; absence of an obligatory ATN reduced the risk to 15% (p<0.05).

Conclusions: Quantitative aspects of the motor repertoire at 11-16 weeks post-term, in particular the presence of an obligatory ATN posture, contribute to the prediction of neurological outcome at 7 to 11 years of age.

Introduction

Neurological and developmental sequelae are common in infants born preterm. However, the early identification of individual infants at highest risk remains difficult. Recently, Spittle et al. reviewed the clinimetric properties of neuromotor assessments for preterm infants during the first year of life. They showed that Prechtl's assessment of the quality of general movements (GMs) offers the best combination of reliability, sensitivity and specificity for predicting cerebral palsy (CP) in the early months. For prediction of minor neurological dysfunction (MND) in preterm infants, the quality of the early motor repertoire between 2 and 5 months post-term has also been shown to have some predictive value. Using Prechtl's method, several qualitative aspects of the motor repertoire at 11-16 weeks post-term have been found to be related to neurological status at 7 to 11 years of age. The quality of fidgety movements (FMs, continuous small movements of moderate speed in all directions, normally present between 9 and 16 weeks post-term) has the greatest predictive value. Abnormal FMs (FMs with exaggerated speed, amplitude and jerkiness) identify those infants who run a high risk for developing MND (60-70%). When FMs are normal, the quality of the concurrent motor repertoire provides additional information. Normal FMs at 11-16 weeks post-term accompanied by a smooth, variable concurrent motor repertoire are a marker for a normal outcome: the risk for developing MND is low (5%). If the concurrent motor repertoire is monotonous, the risk for developing MND increases to approximately 30%. Qualitative aspects of the motor repertoire clearly improve our ability to predict MND at school
The quantity of the early motor repertoire in preterm infants

age. However, while Prechtl’s method focuses on qualitative aspects of the motor repertoire, it also takes quantitative aspects into account, for example, differences in the frequency with which normal and abnormal movement and postural patterns are displayed. The question then arises whether quantitative aspects of the motor repertoire can further improve the accuracy of prediction. The goal of this study was to investigate whether the quantitative aspects of the motor repertoire between 6 and 24 weeks post-term have predictive value for neurological outcome at 7 to 11 years of age.

Methods

Subjects

The study group consisted of 82 infants (50 boys and 32 girls) born preterm between September 1992 and October 1997 and admitted to the Neonatal Intensive Care Unit (NICU) of the Beatrix Children’s Hospital of the University Medical Center of Groningen (UMCG). The infants were members of a larger group of 99 infants who were included in prospective studies on the prognostic value of the quality of GMs for neurological and developmental findings. The results of these studies have been reported previously. All infants were born before 34 weeks gestational age and written parenteral consent was obtained in the first week after birth. Exclusion criteria were chromosomal abnormalities, congenital malformations and infants who died before 6 weeks post-term age. The study group can be considered a representative sample of the preterm infant population in our NICU (tertiary referral centre) during the mid-nineties. Seven infants died during the first few months after birth, mostly due to severe respiratory problems such as bronchopulmonary dysplasia. Conditions which could interfere with normal neurological development became apparent in three infants (two infants: blindness due to retinopathy of prematurity; one infant: Duchenne muscular dystrophy). Five of the remaining 89 infants could not be traced. Two families refused to participate. Obstetrical and neonatal data are listed in Table 1, grouped according to the neurological status at school age. The ethical review board of the UMCG approved the study.

Recording and evaluation of the motor repertoire between 6 and 24 weeks post-term

Video recordings, approximately 10 minutes long, were made of the infants at approximately 6-8 (n=60), 12-14 (n=73) and 18-21 weeks (n=53) during the post-term period. The timing and frequency of the video recordings differed for a few infants for logistic or family reasons. The recordings were made either at the outpatient clinic or at home, during periods of active wakefulness between feeds, with the partly dressed infants lying in supine position.

In toto, 214 recordings (median 3 per infant, mean duration 9:01 minutes) were available for analysis. The recordings of all infants were ordered according to increasing post-term age and evaluated offline by JLMB, AFB and CE according to Einspieler et al. This evaluation took 10 to 15 minutes. Two of the observers were unaware of the infant’s clinical history and neurological status; one knew the infant’s clinical history but was unaware of the neurological status at school age. The motor
Chapter 4

repertoire could not be evaluated in 10 of the 214 recordings (4.7%), due to crying, sleepiness or hiccups.

Three quantitative aspects of the motor repertoire were assessed during different runs of the videotapes: the presence and normality of various movement patterns, the presence and normality of various postural patterns and the age adequacy of the motor repertoire.

The presence and normality of movement patterns

Between 6 and 24 weeks post-term, the typical movement repertoire consists of diverse movement patterns, which increase in number and variety with age. Specific movement patterns identified in previous studies include wiggling-oscillating movements, saccadic movements, kicking, swipes, Table 1. Clinical characteristics and risk factors of the study group, according to neurological findings at school age. Data are expressed as median (P25-75), or N (%).

<table>
<thead>
<tr>
<th></th>
<th>Children who developed normally or simple MND</th>
<th>Children who developed complex MND</th>
<th>Children who developed CP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number</td>
<td>49</td>
<td>18</td>
<td>15</td>
</tr>
<tr>
<td>Gestational Age</td>
<td>30.1 wk (28.6 – 31.7 wk)</td>
<td>28.9 wk (27.8 – 31.0 wk)</td>
<td>28.7 wk (27.7-30.0 wk)</td>
</tr>
<tr>
<td>Birth Weight (BW)</td>
<td>1160 g (950 – 1343 g)</td>
<td>1165 g (898 – 1333 g)</td>
<td>1220 g (870-1460 g)</td>
</tr>
<tr>
<td>Male infants</td>
<td>23 (47)</td>
<td>12 (67)</td>
<td>12 (80)</td>
</tr>
<tr>
<td>IUGR (BW &lt; P5)</td>
<td>12 (24)</td>
<td>4 (22)</td>
<td>1 (7)</td>
</tr>
<tr>
<td>Prenatal steroids</td>
<td>34 (71)</td>
<td>11 (61)</td>
<td>9 (60)</td>
</tr>
<tr>
<td>Apgar score at 5'</td>
<td>8 (8 – 9)</td>
<td>8 (5 – 8.3)b</td>
<td>6 (5 – 7)b</td>
</tr>
<tr>
<td>Umbilical pH</td>
<td>7.28 (7.25 – 7.31)</td>
<td>7.26 (7.21 – 7.33)</td>
<td>7.26 (7.21 – 7.33)</td>
</tr>
<tr>
<td>Ventilator support</td>
<td>(IPPV of HFOV)²</td>
<td>23 (47)</td>
<td>11 (61)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>15 (100)b,d</td>
<td></td>
</tr>
<tr>
<td>Septicaemia</td>
<td>17 (35)</td>
<td>7 (39)</td>
<td>5 (33)</td>
</tr>
<tr>
<td>ICH¹ gr1-2</td>
<td>11 (22)</td>
<td>6 (33)</td>
<td>2 (13)</td>
</tr>
<tr>
<td>ICH¹ gr 3-4</td>
<td>none</td>
<td>none</td>
<td>5 (33)b,c</td>
</tr>
<tr>
<td>PVL² gr1</td>
<td>19 (39)</td>
<td>14 (78)b</td>
<td>8 (53)</td>
</tr>
<tr>
<td>PVL² gr 2-3</td>
<td>none</td>
<td>none</td>
<td>4 (27)b,c</td>
</tr>
<tr>
<td>BPD³</td>
<td>11 (22)</td>
<td>5 (28)</td>
<td>9 (60)b</td>
</tr>
<tr>
<td>Postnatal steroids</td>
<td>3 (6)</td>
<td>4 (22)</td>
<td>9 (60)b,c</td>
</tr>
</tbody>
</table>

¹ IUGR is intra-uterine growth restriction, birth weight according to the Dutch weight centiles of Kloosterman.44
² IPPV is intermittent positive pressure ventilation, HFOV is high frequency oscillatory ventilation.
³ ICH is intracranial haemorrhage graded according to Papile et al.45
⁴ PVL is periventricular leukomalacia graded according to de Vries et al.46 PVL grade 1 is also called prolonged flaring.
⁵ BPD is Bronchopulmonary dysplasia, defined as oxygen dependency at 36 weeks postmenstrual age.

a P< 0.05, compared with infants who developed normally or simple MND
b P< 0.01, compared with infants who developed normally or simple MND
c P< 0.05, compared with infants who developed complex MND
d P< 0.01, compared with infants who developed complex MND

reertoire could not be evaluated in 10 of the 214 recordings (4.7%), due to crying, sleepiness or hiccups.
The quantity of the early motor repertoire in preterm infants

The presence and normality of postural patterns
The presence and the normality of nine different postural patterns were scored. Normal patterns included variable hand and finger postures. Abnormal postures included a predominantly flat posture, extensor postures, predominant fisting, abnormal finger spreading and limited finger movements. The presence of the asymmetric tonic neck (ATN) posture was also recorded. When it was present, we noted whether spontaneous flexion of the extended arm was or was not possible (obligatory ATN). A score for presence and normality of postural patterns was derived from the relative frequency of normal and abnormal patterns, being normal when more normal than abnormal patterns were observed, and abnormal when more abnormal than normal patterns were observed.

The age-adequacy of the concurrent movement repertoire
The occurrence of several specific movement patterns provided the basis for scoring the presence or absence of antigravity movements, movements of the arms and/or legs towards the midline, and fiddling movements. In combination with the number of movement and postural patterns observed, this reflects the age-adequacy of the concurrent motor repertoire, which can be judged to be age-adequate, reduced or absent. This is a quantitative measurement: the sum of several movement patterns which reflects normal neurological development. Excluded were those movement patterns which are usually present such as smiles, mouth movements and tongue movements. With this in mind, the age-adequacy of the concurrent motor repertoire was scored absent when less than five movement patterns were observed, reduced in case five or six observed movement patterns were observed and age-adequate in case seven or more movement patterns were observed.

Motor optimality score
Together, the quality of the FMs (normal, abnormal or absent), the age-adequacy of the concurrent motor repertoire, the presence and normality of movement and postural patterns and the quality of the concurrent motor repertoire (normal or abnormal) between 6 and 24 weeks post-term,
provide the basis for calculating the composite motor optimality score. This score can range from a minimum of 5 points to a maximum (optimal) of 28 points (see addendum). The scores for the three quantitative items (presence and normality of movement and postural patterns and age-adequacy of the concurrent motor repertoire) provided the basis for calculating a quantitative sub-score which can range from 3 to 12 points.

**Inter-scorer reliability**

To check inter-observer reliability, 145 randomly selected recordings were assessed by three observers. Cohen's kappa was 0.89 for the age-adequacy of the concurrent movement repertoire. Observers disagreed over the presence of some normal and abnormal movement patterns in 16 recordings (11%). In those 16 recordings, with a median number of 10 movement patterns per recording, one (n=14) or two (n=2) movement patterns were not scored by either one of the observers. Observers disagreed over the presence of normal and abnormal postures in 15 recordings (10%). In those recordings, with a median of 4 postural patterns per recording, one postural pattern was not scored by one of the observers.

**Assessment of neurological and motor findings at 7 to 11 years of age**

At 6 years of age, 15 children were diagnosed with CP according to Hagberg's criteria. A neurological examination according to Touwen was performed between 7 and 11 years of age on the remaining 67 children. This examination is designed to detect signs of minor neurological dysfunction. Following Hadders-Algra, six subcategories of function were assessed: posture and muscle tone, reflexes, choreiform dyskinesia, coordination and balance, fine manipulative ability and rarely occurring dysfunctions, including an excess of associated movements. The children were classified as neurologically normal, simple MND, or complex MND. Simple MND denoted the presence of dysfunction in one or two subcategories, and complex MND the presence of dysfunction in more than two subcategories. Since simple MND has limited clinical and functional significance, as opposed to complex MND, the normal and simple-MND groups were analysed as a single group. Further, because the aim of the study was to evaluate the significance of the quantitative aspects of the movement repertoire for minor neurological deficits, the analysis was performed both with and without the children with CP.

**Data analysis**

For further analysis, we clustered the video recordings between the ages of 6-10 weeks post-term (early fidgety movements' period), 11-16 weeks (mid-fidgety movements' period) 17-24 weeks (late or post-fidgety movements' period). If two recordings were made of the same infant during the same age period, the recording closest to the median age of the particular age period was selected as reported previously by Bruggink et al. The associations between the motor optimality scores and the scores for the three quantitative
components of the motor repertoire in each age period and the neurological status at school age were investigated. Because the aim of the study was to evaluate the significance of quantitative aspects of the movement repertoire for mild neurological deficits, the analysis was performed both with and without the children with CP. When significant correlations with a quantitative score were found, the analysis was extended to the specific movement or postural patterns on which the score was based.

A multiple logistic regression was performed to determine which aspects of the movement repertoire showed the strongest independent associations with the later neurological status.

Statistical analysis
Statistical analysis was performed using SPSS package for Windows, version 14.0. Fisher’s exact test and Chi² test for trend were used to evaluate the associations between normal and abnormal movement and postural patterns and the age adequacy of the motor repertoire on the one hand and neurological findings at school age on the other. The Kruskal-Wallis test and the Mann-Whitney U test were applied to evaluate the associations between motor optimality scores, clinical data and later neurological findings. To assess the influence of the different clinical, movement-quality-related factors and movement-quantity-related factors on later neurological findings, backward multiple logistic regression analysis was performed. Only factors that were significant in the univariate analyses were included in the model. Throughout the analyses $p<0.05$ (two-tailed tested) was considered to be statistically significant.

Results

The neurological findings at school age
At follow-up, 15 children had developed cerebral palsy. Of the remaining 67 children, 36 were neurologically normal, 13 had developed simple MND and 18 had complex MND. For the purpose of clarity, those infants who developed normally and those who developed simple MND are referred to as “normal” in the rest of this paper.

Association between the quantitative aspects of the motor repertoire between 6 and 24 weeks post-term and neurological findings at school age.
1. Motor optimality score
The association between the motor optimality scores in each age-period and neurological status at school age is presented in Figure 1. Figure 1a shows the composite motor optimality score with both qualitative and quantitative aspects. Figure 1b shows the motor optimality score based on the scores for the quantitative components.

The motor optimality scores of normal and CP infants differed substantially during all age-periods. The scores of normal and complex MND infants differed only at 11-16 weeks post-term. This was
true both with and without the quality of FMs included in the scores. The associations between the neurological findings and each of the quantitative components of the motor optimality score were further analysed to identify which components differentiated between normal and complex MND children.

2. **Normal and abnormal movement patterns**

The number of normal movement patterns increased gradually in all infants (Figure 2), but was consistently lower in infants later classified as CP than in infants later classified as normal. Infants later classified as complex MND also showed slightly, but significantly, fewer movement patterns at 11-16 weeks than infants later classified as normal. Further, more detailed analysis showed that several clusters of normal movement patterns also differentiated these two groups (Figure 3). Movements of arms and legs towards the midline, and antigravity movements (the latter nearly significant, Fisher’s exact test $p=0.07$), emerged earlier in normal infants than in infants who later developed complex MND with the developmental courses diverging most noticeably at 11-16 weeks. Abnormal movement patterns were rare and decreased in number between 6 and 24 weeks in all groups. They were more frequent in all age periods in infants later classified as CP. However, they did not differentiate infants later classified as normal or complex MND.

3. **Normal and abnormal postural patterns**

The number of normal and abnormal postural patterns in each age period is shown in Figure 4.
The quantity of the early motor repertoire in preterm infants

Figure 2. Association between number of movement patterns at post-term ages of 6-10 weeks, 11-16 weeks and 17-24 weeks and neurological findings at school age. A) For normal movement patterns. B) For abnormal movement patterns. Differences between groups were tested by Kruskal Wallis and Man Whitney U tests. (* = \(p<0.05\); ** = \(p<0.01\); *** = \(p<0.001\)).

Figure 3. Association between the frequencies of several clusters of normal movement patterns at post-term ages of 6-10 weeks, 11-16 weeks and 17-24 weeks and neurological findings at school age. A) For midline movements. B) For antigravity movements. C) For leg midline movements. D) For fiddling movements. Differences between groups were tested by the Chi\(^2\) test for trend (** = \(p<0.01\)).
Chapter 4

Figure 4. Association between postural patterns at post-term ages of 6-10 weeks, 11-16 weeks and 17-24 weeks and neurological findings at school age. A) For normal postural patterns. B) For abnormal postural patterns. Differences between groups were tested by Kruskal Wallis and Man Whitney U tests. (* = \(p<0.05\); ** = \(p<0.01\); *** = \(p<0.001\)).

Figure 5. Association between frequencies of several normal and abnormal postural patterns at post-term ages of 6-10 weeks, 11-16 weeks and 17-24 weeks and neurological findings at school age. A) For predominant flat posture. B) For variable finger postures. C) For extended arm posture. D: For obligatory ATN posture. Differences between groups were tested by the Chi² test for trend test. (* = \(p<0.05\); ** = \(p<0.01\); *** = \(p<0.001\)).
The quantity of the early motor repertoire in preterm infants

Infants later classified as normal displayed slightly but significantly more normal postural patterns at all age periods, and fewer abnormal postural patterns at 11-16 and 17-24 weeks than infants who developed CP. They also displayed more normal postural patterns and fewer abnormal patterns than infants who developed complex MND at 11-16 weeks. The difference between the numbers of normal and abnormal postural patterns, an item on the motor optimality score, differentiated normal from complex MND infants at 11-16 weeks. (Chi²-test for trend = 4.5, p < 0.05).

More detailed analysis identified 1 normal and 3 abnormal postural patterns which contributed to the difference (Figure 5). The presence of an obligatory ATN posture at 11-16 weeks post-term was the most striking, occurring in 35% of infants who developed complex MND, as opposed to 7% of infants later classified as normal.

A predominantly flat posture and predominantly spontaneous extended arm postures were also observed more frequently in infants who developed complex MND than in infants later classified as normal, whereas variable finger postures were observed less frequently in those who developed complex MND than those later classified as normal. However, these differences failed to reach statistical significance, with p-values around 0.06 – 0.16, 2-sided.

4. Age-adequacy of the motor repertoire

The association between the age-adequacy of the concurrent motor repertoire and the neurological findings at school age is shown in Table 2. The age-adequacy of the concurrent motor repertoire was reduced or absent at all age periods in 11 of the 13 infants who later developed CP. While reduced age-adequacy at some period was not uncommon in infants later classified as normal, reduced adequacy between 11 and 16 weeks post-term was strongly associated with the neurological condition at school age, differentiating both infants who later developed CP and infants who later

<table>
<thead>
<tr>
<th>Post-term age (weeks)</th>
<th>Age adequacy of the motor repertoire</th>
<th>Neurological findings at school age</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Normal/Simple MND</td>
<td>Complex MND</td>
</tr>
<tr>
<td>6-10</td>
<td>Age-adequate</td>
<td>18</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>Reduced/absent</td>
<td>16</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>34</td>
<td>15</td>
</tr>
<tr>
<td>11-16</td>
<td>Age-adequate</td>
<td>32</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Reduced/absent</td>
<td>11</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>43</td>
<td>17</td>
</tr>
<tr>
<td>17-24</td>
<td>Age-adequate</td>
<td>23</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Reduced/absent</td>
<td>11</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>34</td>
<td>10</td>
</tr>
</tbody>
</table>

Table 2. Association between age-adequacy of the motor repertoire at post-term ages of 6-10 weeks, 11-16 weeks and 17-24 weeks and neurological findings at school age. The numbers in the boxes refer to the number of infants. For all age periods, these associations were significant. (6-10 weeks post-term: Chi² test for trend = 8.8, p < 0.01; 11-16 weeks post-term: Chi² test for trend = 26.7, p < 0.001; 17-24 weeks post-term: Chi² test for trend = 7.7, p < 0.01).
developed complex MND from the infants later classified as normal. Twenty-six of 37 infants (70%) with reduced age-adequacy at 11-16 weeks developed abnormally (35% CP and 35% complex MND), as opposed to 4 of 32 (11% complex MND) of infants with an age-adequate repertoire (Fisher’s exact test, p<0.001).

5. Prognostic value of several characteristics of the motor repertoire at 11-16 weeks for later complex MND (logistic regression)

Several aspects of the motor repertoire at 11-16 weeks had prognostic value for the development of complex MND. Since the different aspects of the motor repertoire are likely to be interdependent, we performed a multiple logistic regression analysis to investigate which aspects contributed independently to the development of complex MND. Infants who had developed CP were excluded from the analysis, leaving 60 infants recorded at 11-16 weeks, for further analysis. Aspects of the motor repertoire which had shown significant associations with later neurological outcome, quality of FMs, quality of the concurrent motor repertoire, age-adequacy of the motor repertoire, quality of postural patterns, obligatory ATN posture and presence of movements towards the midline were entered as predictors. Only the quality of FMs (LR 14.5; 95% CI 3.0 - 70, p=0.001) and presence of an obligatory ATN posture (LR 15.7; 95% CI 2.7 - 90, p=0.002) remained in the model.

Because abnormal FMs preceded complex MND in 64% of cases, we repeated the analysis without the infants who had abnormal FMs at 11-16 weeks (N=48), to learn more about the basis of complex MND in children with normal FMs. Again, aspects of the motor repertoire which had shown

<table>
<thead>
<tr>
<th>Quality of FMs at 11-16 weeks post-term</th>
<th>Quality of the concurrent motor repertoire at 11-16 weeks post-term</th>
<th>Absence or presence of an obligatory ATN posture</th>
<th>Neurological findings at school age</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal FMs</td>
<td>Smooth and variable</td>
<td>absent</td>
<td>Normal/ Simple MND</td>
<td>20</td>
</tr>
<tr>
<td>Abnormal: monotonous, jerky and/or stiff</td>
<td>absent</td>
<td>present</td>
<td>Complex MND</td>
<td>1</td>
</tr>
<tr>
<td>Abnormal: monotonous, jerky and/or stiff</td>
<td>absent</td>
<td>present</td>
<td>Cerebral Palsy</td>
<td>20</td>
</tr>
<tr>
<td>Abnormal: monotonous, jerky and/or stiff</td>
<td>absent</td>
<td>present</td>
<td></td>
<td>8</td>
</tr>
<tr>
<td>Absent FMs</td>
<td>Abnormal: monotonous, jerky and/or stiff</td>
<td>absent</td>
<td></td>
<td>10</td>
</tr>
<tr>
<td>Absent FMs</td>
<td>Abnormal: monotonous, jerky and/or stiff</td>
<td>present</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Total</td>
<td>43</td>
<td>17</td>
<td>13</td>
<td>73</td>
</tr>
</tbody>
</table>

Table 3. Association between various characteristics of the motor repertoire at 11-16 weeks post-term and neurological findings at school age. For normal FMs, in conjunction with an abnormal movement character, the association between presence or absence of an obligatory ATN posture and neurological findings at school age was significant. (Chi2 test for trend = 9.6, p=0.002)
significant associations with later neurological outcome in this subgroup – quality of the concurrent motor repertoire, age-adequacy of the motor repertoire, obligatory ATN posture, predominant flat posture, presence of leg movements towards the midline and presence of antigravity movements - were entered as predictors. The presence of an obligatory ATN (LR 8.6; 95% CI 1.3 - 59, \(p=0.028\)), quality of the concurrent motor repertoire (LR 10.5; 95% CI 1.0 - 110, \(p=0.05\)) and the presence of antigravity movements (LR 0.080; 95% CI 0.007 – 0.91, \(p=0.028\)) remained in the model at \(p<0.05\).

When the analysis was repeated with the clinical variables added to the model (Apgar score at 5 minutes, presence of prolonged flaring), both Apgar scores at 5 minutes and an obligatory ATN remained at \(p<0.05\).

The prognostic value of the quality of FMs in combination with quality of the concurrent motor repertoire and (absence or) presence of an obligatory ATN posture at 11-16 weeks post-term for neurological findings at school age is shown in Table 3. If both FMs and quality of the concurrent motor repertoire were normal, only 5% of infants developed complex MND. If FMs were normal but the concurrent motor repertoire was abnormal, the absence or presence of an obligatory ATN became relevant as predictor: 15% of infants in whom obligatory ATN was absent developed complex MND or worse, in contrast to 75% of the infants in whom obligatory ATN was present. When FMs were abnormal or absent, the presence of obligatory ATN posture was of no additional predictive value.

**Discussion**

The present study demonstrates that, in infants born preterm, quantitative aspects of the motor repertoire at 11-16 weeks post-term contribute to the prediction of neurological outcome at 7 to 11 years of age. However, of all movement and postural patterns, only the ATN posture contributed independently to neurological outcome. We found that if an infant had normal FMs but an abnormal concurrent motor repertoire, the presence of an obligatory ATN increased the risk of developing complex MND or worse to 75%, whereas absence of an obligatory ATN reduced the risk to 15%. The ATN posture was of no additional predictive value when FMs were abnormal or absent.

Previous studies of preterm infants have shown that the obligatory ATN posture disappears around 3 months post-term age.\(^{25,26}\) Delay in reaching this developmental milestone could be a sign of impaired maturation of the nervous system. Presence of an obligatory ATN posture could also be a sign of neurological damage. Zafeiriou et al.\(^{27}\) reported that the ATN posture persists longer in CP infants than in infants who develop normally. They also found retention of the ATN reflex in infants with developmental delay.\(^{27}\) This is in accordance with our findings that a persistent ATN posture, in combination with normal FMs and an abnormal concurrent motor repertoire, has predictive value for the development of MND.

The association between neurological outcome and the persistence of an obligatory ATN posture may also reflect the crucial role of motor activity in normal neurological development. It restricts the
infant’s ability to interact with the world and to explore the spontaneous motor repertoire during a vulnerable period in development.\textsuperscript{28,29}

Significant differences in the quantitative aspects of the motor repertoire between infants classified normal and infants with complex MND were seen only at 11-16 weeks post-term, a finding which emphasises the importance of this period as a period of major transformation of the nervous system.\textsuperscript{29,30}

During this period the infant becomes adapted to the requirements for the extrauterine life.\textsuperscript{30}

Impairments in the quality of the motor repertoire around 3 months post-term age have previously been shown to be highly predictive for severe neurological damage.\textsuperscript{29,31}

Earlier we demonstrated that specific qualitative aspects of the early motor repertoire at this age are also predictive for minor neurological dysfunction.\textsuperscript{5} In this study we have shown that while the qualitative aspects of the motor repertoire are the strongest predictor for the development of minor neurological damage, when considered in conjunction with qualitative aspects, quantitative aspects can increase the accuracy of prediction. Previously, quantitative aspects of the spontaneous motor repertoire, during fetal, preterm and term age, have also been found to be inferior to qualitative aspects as predictors.\textsuperscript{8,32-34}

Quantitative aspects of the motor repertoire between 11 and 16 weeks post-term also differentiated between infants who developed MND and those who developed CP. This underlines the validity of the motor optimality score. For clinical purposes CP can already correctly be identified, at this age, by the absence of FMs.\textsuperscript{31} Therefore the contribution of the other components of the motor optimality score to the prediction of CP is relatively low.

Conclusions

In conclusion, we found that several aspects of the early motor repertoire at 11-16 weeks post-term were related to clinically relevant MND at 7 to 11 years of age. The results of the present study and our previous study on the qualitative aspects of the quality of the motor repertoire \textsuperscript{5}, suggest the following practical approach for identifying whether or not a preterm infant is at risk for later complex MND. First, the assessment of the quality of FMs, between 11-16 weeks post-term, is important. Abnormal FMs identify infants who run a high risk for developing complex MND (60-70\%). Infants with normal FMs require a closer look at the quality of concurrent movements. If FMs are normal at 11-16 weeks post-term, a smooth, variable concurrent motor repertoire is a marker for a normal outcome and the risk for developing MND is low (5\%). If the concurrent motor repertoire is abnormal, the presence of a spontaneous obligatory ATN posture identifies the infants at high risk for developing MND (75\%), whereas the absence of an obligatory ATN is associated with a relatively low risk for MND (15\%). Our findings enable the early identification of individual preterm infants at significantly increased risk for the development of MND and thus offer opportunities for early intervention and treatment. They also enable the early identification of individual preterm infants at very low risk for development of MND.
References


Assessment of Motor Repertoire - 2 to 5 months
Christa Einspieler and Arie Bos, the GM Trust 2000

Name: .................................................................
born: ......................................................... PMA: ......................................... BW: ........................................
Recording Date: ............................................. Age: ...........................................

Observed movement patterns:
- fidgety movements
- swiping movements
- wiggling-oscillating movement
- saccadic arm movements
- kicking
- excitement bursts
- cha-cha-cha movements
- smiles
- mouth movements
- tongue movements
- head rotation

Observed postural patterns:
- head in midline (20°)
- symmetrical
- spontaneous ATNR absent or could be overcome
- body and limbs flat on surface

Movement character (global score):
- smooth and fluent
- jerky
- monotonous
- tremulous

Motor Optimality List:

1. Fidgety Movements
   - normal
   - abnormal
   - absent

2. Repertoire of co-existent other movements
   - age-adequate
   - reduced
   - absent

3. Presence and normality of individual movement patterns
   - N > A
   - N = A
   - N < A

4. Presence and normality of individual postural patterns
   - N > A
   - N = A
   - N < A

5. Quality of the concurrent motor repertoire
   - smooth and fluent
   - abnormal, not cramped-synchr.
   - cramped-synchronized

Motor Optimality Score:
from 28 to 5

[Score]