Construct validity of the Infant Motor Profile: 
Relation with prenatal, perinatal and neonatal risk factors

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ABSTRACT

Aim: The Infant Motor Profile (IMP) is a qualitative assessment of motor behaviour of infants aged 3 to 18 months. The aim of this study was to investigate construct validity of the IMP, through the relation of IMP scores with pre-, peri- and neonatal variables, including the presence of brain pathology indicated by neonatal ultrasound imaging of the brain.

Methods: A longitudinal prospective study was performed in a group of 30 term born (12 females and 18 males; median gestational age 40.1wks, range 37.6-42wks) and 59 preterm infants (25 females and 34 males; median gestational age 29.7wks, range 25-34.7wks). IMP assessments were performed at (corrected) ages of 4, 6, 10, 12 and 18 months. Socio-economic and perinatal data were collected, which, in the case of preterm infants, included information on periventricular leukomalacia and intraventricular haemorrhage based on neonatal cranial ultrasounds. Data were analysed by fitting mixed-effects models.

Results: Gestational age, socio-economic status and 5-minute Apgar score were significant determinants of IMP scores in the total group of infants (p-values resp. <0.001, 0.002 and 0.042 respectively). In the subgroup of preterms, IMP scores were significantly affected by brain lesions on neonatal ultrasound (p<0.001) and socio-economic status (p=0.001).

Interpretation: The findings support the construct validity of the Infant Motor Profile: IMP scores are clearly associated with relevant determinants of neuromotor function.
INTRODUCTION

The Infant Motor Profile (IMP) is a recently developed qualitative assessment of motor behaviour of infants aged 3 to 18 months. It may be used for early detection and developmental evaluation of infants with a high risk for developmental motor disorders such as cerebral palsy or developmental coordination disorder. Infants born very preterm are especially at risk for these developmental motor disorders. Owing to improved prenatal and neonatal care, the survival of very preterm infants has increased in the last decennia. Follow-up of preterm infants aims at detection of those infants that could benefit from early intervention at young age, when the brain is highly plastic.

The IMP is based on ideas of the Neuronal Group Selection Theory (NGST) of motor development. According to NGST, typical motor development starts with the phase of primary variability with exploratory, variable motor behaviour. Children with pre- or perinatally acquired brain damage show more stereotyped motor behaviour with considerably less variation. During development, infants learn to select adaptive motor strategies out of their motor repertoire and to adapt motor behaviour to the environment. This phase of adaptive selection is called secondary variability. Children with developmental motor disorders often have problems in selecting adaptive motor strategies. Two domains of the IMP are based on the NGST-principles of motor development; they deal with variation of motor behaviour (size of repertoire) and the ability to select motor strategies (variability). Three additional domains assess movement fluency, movement symmetry and motor performance.

The IMP assessment consists of video-recording of approximately 15 minutes of spontaneous motor behaviour in supine, prone, sitting, standing, and walking condition, depending on age and functional capacities of the infant. In addition, reaching, grasping and manipulation of objects are tested in the supine and sitting positions. The 80 items of the IMP are scored based on the video recording. The 80 items constitute the subscores on the five domains: size of repertoire (variation), ability to select (variability), movement fluency, movement symmetry and motor performance. The mean of the five subscores is the total IMP score (Appendix I).

In our pilot study on the IMP, we described the theoretical background of the method, its domains and items, and details of scoring procedures. In addition, we have published first data on the reliability and concurrent validity of the IMP with the Alberta Infant Motor Scale (AIMS) and Touwen neurological examination. Intra- and interobserver reliability for total IMP score were good (Spearman's rho 0.9 for both; 95% confidence intervals 0.8–0.9 and 0.8-1.0 respectively). Concurrent validity of the IMP with the AIMS was very high for the performance subscale and moderate for the total IMP score. Concurrent validity of the IMP with the Touwen examination was very good, with a clear inverse relationship between IMP scores and the degree of neurological dysfunction.

The present study focuses on construct validity. Construct validity is the extent to which items of the instrument reflect the theoretical construct of interest, in this case neuromotor function. Parameters of construct validity with respect to neuromotor function are the relation of test scores
with prenatal, perinatal and neonatal adversities and correlation with results from brain imaging. The aim of the present study was to investigate construct validity of the IMP, through the relation of IMP scores with prenatal, perinatal and neonatal variables, including the presence of brain pathology indicated by neonatal ultrasound imaging of the brain. To this end, we performed a longitudinal prospective study in a group of term and preterm infants from the age of 4 to 18 months.

**METHODS**

**Participants**

We included a longitudinal study group of 30 term and 59 preterm infants. The term infants (12 females and 18 males) were recruited from amongst colleagues and acquaintances of the researchers. The preterm infants had been admitted to the neonatal intensive care unit of the Beatrix Children’s Hospital of the University Medical Center in Groningen between December 2003 and January 2005. Inclusion criteria were: gestational age below 35 weeks, singleton or twin, parents with appropriate understanding of the Dutch language, and travel distance between the child’s home and the hospital of < 1 hour. Infants with severe congenital anomalies were excluded from the study. During the time interval mentioned above, 148 infants were eligible for inclusion. Owing to the limited capacity of our department, only a limited number of infants could be included in the intensive follow-up scheme each month. Therefore, not all of the eligible infants were approached for inclusion. By approaching parents at random, 59 infants were eventually included. The project was approved by the local ethics committee. All parents of the infants gave informed consent.

**Procedures**

Longitudinal assessments were performed at (corrected) ages of 4, 6, 10, 12 and 18 months. Assessments consisted of a video-recording of approximately 15 minutes of spontaneous motor behaviour. Motor behaviour was recorded while supine, prone, sitting, standing, and walking, depending on the age and functional capacity of the infant. Reaching, grasping and manipulation of objects were evaluated in supine and in (supported) sitting positions. The IMP assessments were carried out by one of the examiners (KRH or KJM). The examiners knew whether an infant was born at term or preterm, but were not aware of any of the perinatal and neonatal details. The 80 items of the IMP were scored on the basis of the video recording. In this paper, only the total IMP scores are addressed.

Socio-economic, perinatal and neonatal data were collected for all infants on standardized forms by means of an interview with the parents and by consulting neonatal intensive care unit discharge certificates. Socio-economic status (SES) was defined by the sum score of four variables describing educational and professional level of father and mother, all expressed on a scale from 0 (lowest) through 2 (highest). Neonatal ultrasounds of the brain of the preterm infants were assessed with respect to periventricular leukomalacia (PVL) and intraventricular haemorrhage (IVH). PVL was
classified according to De Vries et al.\textsuperscript{14}: grade I; transient periventricular echodensities persisting for more than 7 days; grade II; transient periventricular densities, evolving into small localised frontoparietal cysts; grade III; periventricular densities, evolving into extensive periventricular cystic lesions; and grade IV; densities extending into the deep white matter evolving into extensive cystic lesions. IVH was classified according to Volpe\textsuperscript{15}: grade I; haemorrhage confined to the subependymal germinal matrix; grade II; haemorrhage into the lateral ventricles without ventricular dilatation; grade III; IVH with ventricular dilatation; and grade IV; IVH with parenchymal involvement (venous infarction). PVL grade II or worse and/or IVH grade III or worse were classified as serious brain lesions. ‘Small for gestational age’was defined as birthweight compared to gestational age below the 10\textsuperscript{th} percentile\textsuperscript{16}.

Statistical analyses
For comparison of background characteristics of term and preterm groups we used the Mann-Whitney U test or the Pearson chi-squared test. Analyses to test the association between risk variables and IMP scores at different ages were performed with the Mann-Whitney U test for categorical variables and Spearman’s rho correlation for continuous variables. Variables that correlated with IMP scores with a Spearman’s rho correlation of 0.20 or more at more than one of the five assessed ages, or a Mann-Whitney U test with p-value of < 0.05 at one or more of the five assessed ages were entered in a mixed-effects analysis\textsuperscript{17}. This analysis makes it possible to describe the change of the IMP scores over time and in relation to perinatal and neonatal variables. It takes into account the dependence between observations from the same infant, and it can also take into account dependence between twins. Children for whom outcomes at some time-points were missing were still included in the analysis by entering non-missing data at these time-points; the analysis assumes that missing values do not affect the outcome (‘missing at random’ assumption\textsuperscript{18}). The results of neonatal sonography of the brain were investigated in a separate analysis, as these measurements were available only in the preterm group. In selecting the best-fitting models, we used 0.05 as the nominal level of significance.

RESULTS
Table I shows socio-economic and neonatal characteristics of the term and preterm infants. Thirty-five of the preterm infants were singletons and 24 were twins. Nine pairs of twins participated in the study; the remaining six had lost their twin sibling. The attrition rate was low: in the preterm group two children missed assessment at two of the five time-points and 11 children at one time-point. Reasons for missed assessments were scheduling problems with the parents or minor illness of the infant. In the term group no assessment was missed. The preterm infants generally had a higher chance to be born small for gestational age, to be delivered by Caesarean section, more signs of fetal distress at birth, and a lower 5-minute Apgar score than the infants born at term. Preterm and term infants did not significantly differ in SES and maternal age.
Table 1: Socio-economic and neonatal characteristics of term and preterm groups

<table>
<thead>
<tr>
<th></th>
<th>Term</th>
<th>Preterm</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of children</td>
<td>30</td>
<td>59</td>
<td></td>
</tr>
<tr>
<td>Males/Females, n</td>
<td>18/12</td>
<td>34/15</td>
<td>0.831</td>
</tr>
<tr>
<td>Maternal age (years), mean (SD)</td>
<td>32.8 (4.1)</td>
<td>31.8 (5.2)</td>
<td>0.514</td>
</tr>
<tr>
<td>SES a, median (range)</td>
<td>5 (0-8)</td>
<td>4 (0-8)</td>
<td>0.265</td>
</tr>
<tr>
<td>Twins, n (%)</td>
<td>0</td>
<td>24 (41)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Gestational age wks, median (range)</td>
<td>40.1 (37.6-42)</td>
<td>29.7 (25-34.7)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Birthweight g, median (range)</td>
<td>3588 (2730-4470)</td>
<td>1285 (630-2180)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Small for gestational age b, n (%)</td>
<td>2 (6.7)</td>
<td>20 (33.7)</td>
<td>0.005</td>
</tr>
<tr>
<td>Caesarian section, n (%)</td>
<td>3 (10)</td>
<td>33 (55.9)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Signs of fetal distress c, n (%)</td>
<td>5 (16.7)</td>
<td>30 (50.8)</td>
<td>0.002</td>
</tr>
<tr>
<td>Apgar score at 5 min, median (range)</td>
<td>10 (9-10)</td>
<td>9 (4-10)</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

a SES = socio-economic status, sum score of four variables describing educational and professional level of father and mother, all expressed on a scale from 0 (lowest) through 2 (highest).
b Small for gestational age is defined as birthweight compared with gestational age below 10th centile 14.
c Presence of at least one of the following factors: meconium staining, cardiotocography abnormalities, acidaemia during delivery (arterial umbilical pH below 7.05).

Associations in the total group

Throughout infancy, preterm infants had significantly lower IMP scores than term infants (Mann-Whitney U; p<0.001). No significant difference in IMP scores was found between males and females. Figure 1 depicts the individual IMP curves in the term and preterm groups. Univariate analyses showed a significant relation between IMP and SES, gestational age, signs of fetal distress, Caesarian section, and birthweight.

Figure 1: Individual Infant Motor Profile curves in the term (left) and preterm (right) groups.

IMP scores in the preterm group are, in general, lower and show a larger within-participant variability than in the term group (p<0.001).
Construct validity of the Infant Motor Profile section, and 5-minute Apgar score at nearly all five time-points. These variables were entered into the mixed-effects model. The data were well described by a model (see Table II) which included, as fixed effects, a quadratic function of age (reflecting a substantial increase in IMP scores with increasing age), gestational age, SES and 5-minute Apgar score. A nearly equally well-fitting model was obtained by replacing gestational age with birthweight or with preterm status. The best-fitting model also included a random intercept, a random linear age effect, and a within-participant variance that was larger in the preterm group than in the term group \( p<0.001 \). We also fitted a mixed model including an additional random factor for family to account for dependence of twins. The results obtained with this multilevel model were rather similar to those obtained without taking twin status into account. We have decided to present the simpler model that does not take twin status into account.

**Associations in the subgroup of preterm infants**

Neonatal ultrasound was available for 57 of the 59 preterm infants. Serious brain pathology was observed in six infants: one infant had cystic PVL, four infants had IVH grade IV, and one infant had

**Table II: Regression analysis of Infant Motor Profile scores (term and preterm infants, \( n = 76^a \))**

<table>
<thead>
<tr>
<th>Regression coefficient</th>
<th>Standard error</th>
<th>p-value</th>
<th>95%-confidence interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>47.6</td>
<td>2.22</td>
<td></td>
</tr>
<tr>
<td>Age (mo)</td>
<td>2.16</td>
<td>0.165</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Age(^2) X10(^{-2})</td>
<td>-5.70</td>
<td>0.734</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Gestational age (wks)</td>
<td>0.478</td>
<td>0.068</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>SES(^b)</td>
<td>0.427</td>
<td>0.131</td>
<td>0.002</td>
</tr>
<tr>
<td>Apgar 5 min</td>
<td>0.535</td>
<td>0.258</td>
<td>0.042</td>
</tr>
</tbody>
</table>

\( ^a \) For 12 term infants 5-minute Apgar score was missing and for one infant no complete data were available on SES.

\( ^b \) SES = socio-economic status, sum score of four variables describing educational and professional level of father and mother, all expressed on a scale from 0 (lowest) through 2 (highest).

**Table III: Regression analysis of Infant Motor Profile scores in the preterm group (\( n = 56^a \))**

<table>
<thead>
<tr>
<th>Regression coefficient</th>
<th>Standard error</th>
<th>p-value</th>
<th>95%-confidence interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>64.0</td>
<td>1.36</td>
<td></td>
</tr>
<tr>
<td>Age (mo)</td>
<td>2.52</td>
<td>0.223</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Age(^2) X10(^{-2})</td>
<td>-7.22</td>
<td>0.981</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Brain lesions</td>
<td>-6.33</td>
<td>1.28</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>SES(^b)</td>
<td>0.588</td>
<td>0.173</td>
<td>0.001</td>
</tr>
</tbody>
</table>

\( ^a \) Two preterm infants did not undergo neonatal ultrasonography, and for one infant no complete data were available on SES.

\( ^b \) SES = socio-economic status, sum score of four variables describing educational and professional level of father and mother, all expressed on a scale from 0 (lowest) through 2 (highest).
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middle cerebral artery infarction on the right side. Infants with serious brain lesions had significantly lower IMP scores at ages 4, 6, 10, and 18 months than infants without serious abnormalities on neonatal ultrasound (Mann-Whitney U test: p=0.002, 0.003, 0.01 and 0.004 respectively). The mixed-effects analysis revealed that lower IMP scores in the preterm group were associated with serious brain lesions on ultrasound and with SES (Table III).

DISCUSSION

Our study revealed clear associations between prenatal, perinatal and neonatal adversities and IMP scores at ages 4 to 18 months in term and preterm infants. In preterm infants serious brain pathology on neonatal ultrasound was strongly related to lower IMP scores. These findings support the construct validity of the IMP.

The strengths of the study are its longitudinal character and the low attrition rate. The study group was explicitly heterogeneous with respect to neuromotor function, which is valuable in assessing validity of a new instrument. The weaknesses of the study are the relatively small sample size of the term group and the missing Apgar scores for 12 term children. Therefore, we recommend that the study be replicated with a larger sample of term infants. A further limitation of the study is that the assessors were not blind with respect to term or preterm status of the infant. However, the assessors were unaware of any details of the child's clinical history or results of neonatal ultrasonography.

To investigate whether the group of preterm infants included in this study was representative for a Dutch neonatal intensive care unit population in a tertiary referral centre, we compared it with established reference groups of preterm infants. We found that gestational age, birthweight, frequency of Apgar score at 5 minutes below 7 (15%) and the need for ventilatory support (68%) were similar. Our sample showed a relatively high percentage of infants small for gestational age and of Caesarean deliveries. The latter could be a result of the increased tendency over the years to deliver very preterm infants by Caesarean section.

The IMP scores were most strongly affected by preterm birth. Preterm birth is a major risk factor for major and minor neurodevelopmental disabilities. Both types of disability may largely interfere with daily activities and academic achievements. The clear influence of this important risk factor on IMP scores contributes to construct validity of the IMP. In the total group of infants, a low 5-minute Apgar score was associated with low IMP scores. In fact, the Apgar score was never intended to be used to predict neurodevelopmental outcome, but mainly the risk of neonatal death. The Apgar score reflects the condition of the infant shortly after delivery, and could be interpreted as an indicator of the infant's ability to adapt to the novel situation of extraterrestrial life. In the preterm group, the presence of a serious brain lesion had a greater effect than the Apgar score on later IMP performance.

Preterm infants showed more individual variations in IMP scores over time than term infants. The
more variable developmental trajectories in preterm infants presumably reflect that developmental progress in infants with atypical brain function is less stable than in infants with typical brain function\textsuperscript{23}. In other words, atypical brain function is expressed differently at different ages. The inconsistent expression of atypical motor behaviour emphasizes the need of repeated assessments in high-risk infants.

Serious brain lesions on ultrasound, such as cystic PVL or IVH, were associated with lower IMP scores throughout infancy. According to NGST, brain lesions lead to a reduction of available neuronal networks, which results, in particular, in reduced variation of motor behaviour and an impaired ability to select adaptive motor behaviour. The presence of serious brain lesions on neonatal ultrasound is a strong predictor of later neurodevelopmental disability\textsuperscript{24}.

We found a clear increase in IMP scores with increasing age, which implies that the IMP is able to detect and reflect age-related changes in motor development (i.e., higher levels of performance and better abilities to select adaptive motor behavior). This contributes considerably to the construct validity of an instrument for assessment of motor development\textsuperscript{25}.

In our study, higher SES was associated with higher IMP scores in the group of infants as a whole and in the preterm group separately. No relation between maternal education and motor development in infancy was found in a study on healthy, term born infants\textsuperscript{26}, but lower SES was clearly associated with the presence of the complex form of minor neurological dysfunction at school age\textsuperscript{27}. Highly educated parents probably provide both favourable genetic factors and a healthy and stimulating environment for the child. The latter is especially important for children at high biological risk of developmental disorders, such as preterm infants\textsuperscript{28}.

In conclusion, this study supports the construct validity of the IMP. IMP scores were clearly related to relevant risk factors for developmental motor problems. These findings support the use of the IMP in clinical follow-up of high risk infants.

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