The Infant motor profile
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GENERAL DISCUSSION

This thesis presents the Infant Motor Profile (IMP), a recently developed qualitative assessment of motor behaviour in infancy. The IMP is based on ideas of the Neuronal Group Selection Theory (NGST) which states that motor development is characterised by exploration of the primary variable motor repertoire and selection of adaptive motor strategies out of this repertoire\(^1,2,3\). The IMP consists of 80 items that are grouped into five domains: size of the repertoire (variation), adaptive selection (variability), movement fluency, movement symmetry and motor performance.

This thesis had three aims: 1) review of existing methods for the assessment of neuromotor function in infancy, 2) development of the IMP and 3) assessment of the psychometric properties of the IMP. The first two aims are primarily outlined in chapters 1 and 2. The present discussion will mainly focus on the third aim. First, the findings with respect to the psychometric properties of the IMP will be commented. Next, some methodological considerations with respect to study group and assessments will be discussed. Last, future research topics and concluding remarks will be presented.

Psychometric properties of the IMP

To assess the psychometric properties of the IMP, we performed a longitudinal prospective study on a heterogeneous group of term and preterm born infants aged 3 to 18 months. In addition, another group of term born infants had cross-sectional assessments at the same ages. Assessments consisted of the IMP, the Alberta Infant Motor Scale (AIMS\(^4\)) and an age-specific neurological examination (Touwen Infant Neurological Examination\(^5,6\) (TINE) at 4, 6, 10 and 12 months corrected age and Hempel assessment at 18 months corrected age\(^7\)).

Intra- and interobserver reliability of the IMP

Intra- and interobserver reliability of the IMP were assessed in the pilot study (chapter 3) and in the study described in chapter 6. In the pilot study, intra- and interobserver reliability were satisfactory in the persons who developed the IMP. To test whether it was possible to train a new, inexperienced assessor, we trained a master student without prior experience in infant motor development. Reliability of the total IMP score was very good and reliability of the different domains varied from moderate (ability to select and fluency) to good and very good (size of the repertoire (variation), symmetry and performance). We found that scoring of the IMP can be learnt reliably after good training; a typical training course would consist of basic instructions followed by assessment of about 100 videorecordings with feedback by an experienced supervisor at regular intervals. No prior experience with developmental assessment of infants is required. The amount of training needed is comparable to for example the training required for the General Movement method\(^8\). Reliability of the IMP is comparable to that of other methods for assessment of neuromotor function in infancy\(^9\), such as the Touwen Infant Neurological Examination\(^6\), Alberta Infant Motor Scale\(^4,10,11\) (AIMS), Bayley...
Variability in IMP scores at different ages (within-participant variability) was especially large in the preterm infants. It seems that infants with atypical motor development have less stable developmental trajectories than typically developing infants, underscoring the need of repeated assessments especially in high-risk groups, as atypical development can easily be missed with a single assessment. This finding is possibly not limited to the IMP assessment, but also valid for other developmental motor assessments and has consequences for the organization of clinical follow-up of high risk infants.

In the preterm group, higher socio-economic status was associated with higher IMP scores. Highly educated parents probably provide both favourable genetic factors and a stimulating environment. The latter is especially important for children at high biological risk of developmental problems, such as preterm infants. Early intervention should therefore especially be targeted at this group of vulnerable children with both biological and social risk factors for developmental problems, as these children are most likely to benefit from it. Unfortunately, it appears that especially these children with high social risk are less likely to receive early intervention in practice.

Figure 1 in chapter 5 shows large differences in IMP scores between term and preterm infants, but even more pronounced differences within the preterm group. In general, a small part of the preterm group has IMP scores comparable to the term infants. This small part is expected to have a

Scales of Infant Development and Peabody Developmental Motor Scale. Intra- and interobserver agreement of infant motor assessment are not perfect, which could give clinicians the inconvenient impression of subjectivity. However, it should be kept in mind that other assessments that are used in daily clinical routine do not have a perfect reliability as well (e.g. assessment of neonatal head ultrasound scans) or are subject to an expectancy bias (e.g. interpretation of plantar reflexes in adults).

**Construct validity of the IMP**

Construct validity of the IMP was investigated in chapter 5. Construct validity is the extent to which an instrument measures the theoretical construct of interest, in this case neuromotor function. Construct validity was operationalized as the relation of IMP scores with pre-, peri- and neonatal variables, including the presence of brain pathology on neonatal ultrasound scans of the brain. A longitudinal prospective study in a group of term and preterm born infants from age 4 to 18 months was performed. Gestational age, socio-economic status and 5-minute Apgar score were significant determinants of IMP scores throughout infancy in the total group of infants. In the group of the preterm infants, IMP scores were strongly affected by the presence of serious brain lesions on neonatal ultrasounds and by socio-economic status. We also found a clear increase of IMP scores with increasing age, which implies that the IMP is able to detect and reflect age-related changes in motor development. These findings strongly contribute to construct validity of the IMP and make it more plausible that the IMP indeed measures the construct of interest, namely neuromotor function.

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more or less typical motor development. Many of the preterm infants have lower IMP scores than the term infants throughout infancy, but they do develop most of the motor skills, though at a later time, with a less variable repertoire to choose from than the typically developing infants. This could possibly be the group of children that develops minor motor disorders such as DCD at a later age, when more complicated fine motor skills, such as writing or using scissors, and gross motor skills involving fine balancing are required in daily and school activities. Whether these later motor problems are already reflected in the IMP scores in infancy has yet to be investigated.

A small number of the preterm infants had clearly low IMP scores from the start and did only develop some basic motor skills throughout infancy, with IMP scores hardly rising or even lowering throughout infancy (Figure 1 chapter 5). These are the children with a seriously hampered motor repertoire due to brain lesions who were diagnosed with CP. It would be interesting to use the IMP in this group of children during or after application of early intervention, in order to evaluate changes in neuromotor function. This is currently done in a study on the effect of COPCA, a newly developed physiotherapeutic early intervention programme, in a group of high risk infants.

As mentioned above, the ability to detect age-related changes in motor development contributes to the construct validity of an instrument for assessment of neuromotor function. In chapter 4 the development of adaptive motor behaviour in typically developing infants was described. For this study, the longitudinal group of term infants had nine assessments between the ages of 3 and 18 months. The emergence of adaptive selection of motor patterns was investigated in four specific motor functions, namely abdominal progression, sitting motility, arm movements during reaching and hand motility during grasping and manipulation. We found that transition to clinically observable adaptive motor behaviour developed gradually from age 6 months onwards, with a peak between 8 and 15 months. It occurred at specific ages for the different motor functions. It would be interesting to perform further research on ages of transition in infants with a high risk for developmental motor disorders such as CP or DCD. In these children transition to secondary variability could possibly be delayed or impeded, as they can have difficulties with processing afferent, sensory information and can experience problems in fine-tuning and adapting motor behaviour. Further research on this subject is needed to make out whether age of transition to secondary variability could be a useful clinical parameter of neuromotor condition.

Concurrent validity of the IMP

Concurrent validity of an instrument is the extent to which scores on the instrument relate to scores on another instrument that assesses the same construct. It is important to note that instruments available for infant motor assessment differ in focus on the aspects of neuromotor function that are assessed, depending on the theoretical background of the instrument (see review in chapter 2). Good concurrent validity of a new instrument with established instruments contributes to the idea that the new instrument indeed measures neuromotor function, as the established instruments are supposed to do so. As the focus of the IMP is partly on different aspects of neuromotor function than
established instruments, namely size of repertoire (variation) and selection of motor behaviour, we did not expect perfect concurrent validity between the IMP and established instruments. In chapter 6, concurrent validity of the IMP with the Alberta Infant Motor Scale (AIMS), the Touwen Infant Neurological Examination (TINE) and Hempel neurological examination (at 18 months) was investigated. The total IMP score correlated to a moderate extent with the AIMS. Correlation between AIMS and IMP was highest for the performance domain of the IMP, as both the performance domain of the IMP and the AIMS assess motor achievements in a quantitative way. Concurrent validity between IMP and neurological examination (TINE or Hempel) was very good: infants with normal neurological condition had higher IMP scores than infants with minor neurological dysfunction or abnormal neurological condition. Differences in IMP scores were especially found between infants with complex MND or abnormal neurological condition and infants with normal or normal - suboptimal neurological condition. Complex MND, in contrast with simple MND, has clinical relevance and is associated with pre- or perinatal adversities\(^{25,26}\). All in all, the results on concurrent validity of the IMP are satisfactory and therefore confirm that the IMP, in line with other infant motor assessments, is able to measure various aspects of neuromotor function.

In the study on concurrent validity of the IMP with the neurological examination, we noticed that the total IMP score was not always the most optimal reflection of the neuromotor functioning of the child, especially for the infants with an abnormal neurological condition and a very limited motor repertoire. In these infants, scores on the performance domain were generally low. As a result, scores on the adaptive selection domain were relatively high, as only the limited motor performance that the child did show was assessed with respect to adaptive selection. This leads to a relatively high total IMP score, which is not a good reflection of the overall poor neuromotor function. In this light, in future studies for example during application of early intervention, especially in children with a very high risk for developmental motor disorders such as CP, more attention should be paid to the individual scores on the different domains and not only to the total IMP scores. Possibly, it is better to leave the score on the domain on adaptive selection out of the total IMP score during at least during the first six month of age, as adaptive selection of motor behaviour for most of the motor functions only starts to emerge from this age onwards. We think the studies described in this thesis were not significantly hampered by this, as only a limited number of infants in the preterm group developed CP. However, this issue needs further research and it would be interesting to investigate the development of IMP domain scores throughout infancy and the relation of domain scores with pre, peri and neonatal variables, including results of brain imaging.

**Predictive validity of the IMP**

Predictive validity of an instrument is the extent to which the scores on the instrument now predict future outcome\(^{27}\). Predictive validity of the IMP for neurological outcome at 18 months was described in chapter 6. We found a very high sensitivity of IMP scores throughout infancy for predicting CP at 18 months. Positive predictive value of the IMP for neurological outcome at 18 months was low,
but negative predictive value was high, implying that IMP scores above the 5th percentile almost certainly excluded abnormal neurological outcome at 18 months. It is important to realize that predictive values of a test strongly depend on the prevalence of the disorder, e.g. CP, in the study population28. Therefore, predictive values observed in our sample cannot be extrapolated to the general population. In addition, it makes comparison of predictive validity of different infant motor assessment methods difficult, as investigations on predictive validity of different tests are generally done in different study populations.

Prediction of developmental outcome at an early age is difficult and will never be perfect, because change is one of the main characteristics of the developing brain. To optimize prediction of neuromotor outcome in children at high risk for developmental motor disorders, it is probably best to combine multiple, complementary tools, which focus on different aspects of neuromotor function, such as neurological examination, assessment of milestones and assessment of qualitative aspects of motor behaviour, in addition to neuroimaging and neurophysiological techniques9. As mentioned above, repeated assessments are mandatory, especially in high-risk groups, because of large variability in expression of neuromotor dysfunction over time6.

Methodological considerations

Study group

The study group consisted of three samples of infants: two longitudinal groups of respectively term and preterm infants and one group of term infants with cross-sectional assessments. The longitudinal term group was relatively small with only 30 infants that were assessed nine times between the ages of 3 to 18 months. In spite of the small sample size, we were able to detect ages of transition for different motor functions in the study on development of adaptive selection in typically developing infants (Chapter 4). The very low attrition rate (<1% of assessments were missed) was very valuable in this respect. But it should be kept in mind that the inclusion procedure may have introduced a selection bias. The infants were recruited amongst colleagues and acquaintances of the researchers: socio-economic status was relatively high, neurological condition of the infants was remarkably good and parents were highly motivated to participate which yielded the very low attrition rate. The cross-sectional term group consisted of 116 infants who were recruited at several Well Child Centres in a region were socio-economic living standards were relatively high as well. The percentage of infants with signs of neonatal distress such as meconium staining (16%) or CTG abnormalities (7.5%) was somewhat high, possibly because concerned parents of children with a history of minor perinatal events have a stronger motivation to participate in developmental research.

The preterm group consisted of 59 infants who 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. Due to the limited capacity of our department for the intensive follow-up scheme, there was a maximum number of infants that could be included per month for logistical reasons. Therefore, not all of the eligible infants were approached for inclusion. By approaching parents at random, 59 infants were eventually included. Unfortunately, it was not well recorded how many parents of the eligible group actually were approached for the current study, how many refused to participate and for which reasons. This may have introduced a non-response bias. Therefore, we compared our sample with established reference groups of preterm infants to investigate representativeness of the sample retrospectively. We did find comparable gestational age, birth weight, frequency of Apgar score at 5 minutes below 7 (15%) and the need for ventilatory support (68%). Our preterm sample showed a relatively high percentage of infants small for gestational age (34%) and Caesarean deliveries. The latter could be due to the increased tendency over the years to deliver very preterm infants by Caesarean section. The high percentage of infants born small for gestational age is common in tertiary referral centres, such as the NICU in the University Medical Center (UMC) in Groningen. This is due to the preterm birth of intra-uterine growth retarded children, in whom obstetrical interventions take place on the basis of fetal distress. For our study, however, this may have induced selection of relatively more vulnerable children.

The preterm group had a lower socio-economic status than the term group, in accordance with social disadvantage being considered a risk factor for preterm birth. Attrition rate amongst the preterm infants was higher than in the longitudinal term group, but still very acceptable (5% of assessments were missed compared to <1% of assessments for the term group). All in all, strengths of our study with respect to the study group were the mainly longitudinal character of the data and the overall low attrition rate. Limitations were a possible selection bias of term infants with relatively high socio-economic status and a fairly high percentage of small for gestational age preterm infants. However, the study sample consisted of a heterogeneous group of infants, which is a valuable type of sample when the study purpose is assessment of validity of a new instrument. We think that our current study group does suit this goal, but should not be used e.g. to generate reference values for IMP scores, because of a non-optimal recording of non-response in the preterm group and therefore a possible bias.

Assessments
An important limitation of the study is that the assessors were not blinded to group allocation with respect to term or preterm status of the infant. This was mostly for practically reasons, as recruitment of infants, scheduling appointments and performing the assessments was for the larger part done by KRH, with help of colleagues and master students. Even so, if assessors would have been blinded to term or preterm status, group allocation could have become obvious to them because of the characteristic appearance of preterm infants. Still, as so many infants were enrolled in the study, assessors were not aware of details on clinical and developmental history. During the
scheduled assessment, a video-recording was made of spontaneous motor behaviour and an age-specific neurological examination was carried out. IMP and AIMS were scored on the basis of the video-recording in different sessions, a long time after the data collection and the large part of AIMS assessments were scored by master students (with adequate supervision). It is unlikely that appraisal of the results of neurological examination, IMP and AIMS has mutually influenced each other.

**Future research**

To date, the IMP has only been used in research settings. The results described in this thesis indicate that the IMP is well able to discriminate between typically developing infants and infants at high risk for developmental motor disorders. Predictive validity for neurological outcome at 18 months was satisfactory in our study group. Due to these characteristics, addition of the IMP to clinical follow-up of high-risk infants could be valuable. An important requirement for possible clinical application of the IMP is the generation of norm-scores at different ages in a large, representative cohort of typically developing infants without relevant perinatal and neonatal risk factors. Another requirement is a precise description of all IMP items with corresponding definitions, which is also indispensable for future training courses.

Some issues that need to be addressed in further research were already mentioned in the earlier sections of this chapter. Two other interesting research topics are described below. First, it would be of interest to investigate application of the IMP in other groups of infants with a high risk for developmental motor problems, for example infants with term asphyxia or infants born late preterm (gestational age between 34 and 36 weeks). The last group is especially at risk for minor, more subtle motor problems, which could possibly be detected already at young age with the IMP. It would also be appealing to study how the IMP performs in other children with an atypical course of motor development, e.g. children with inborn errors of metabolism or children with Prader-Willi syndrome with related hypotonia, and to investigate whether IMP scores in infancy can predict future neurological and developmental outcome.

Second, it would be interesting to unravel the relation of IMP scores with (neonatal) brain imaging. In the current thesis, the relation of IMP scores with results of neonatal brain ultrasounds was examined, and we found that serious brain pathology on cranial ultrasound, such as cystic periventricular leukomalacia (PVL) or intraventricular haemorrhage (IVH) grade III or IV was clearly associated with lower IMP scores throughout infancy. Debate exists on whether magnetic resonance imaging (MRI) is superior with respect to prediction of future developmental outcome compared to neonatal cranial ultrasound scanning. In a large study, abnormal findings on magnetic resonance imaging (MRI) at term age were found to be strong predictors of adverse neurodevelopmental outcome at two years of age. Besides identifying diffuse white matter injury, which is common in very preterm infants and clearly associated with impaired motor outcome, MRI is also able to detect specific abnormalities, for example abnormal myelination of the posterior
limb of the internal capsule (PLIC), that are associated with impaired motor development. Much research on the relation between term MRI abnormalities and developmental outcome is still in progress. It would be very interesting to use the IMP as a follow-up tool in this field, as we expect that the IMP will not only be able to detect infants at high risk for major developmental disorders such as CP, but could possibly also detect infants with minor developmental motor problems. Future studies should investigate whether specific types of MRI abnormalities are associated with lower IMP scores, especially lower scores on the variation domain. Low scores on the variation domain might be a reflection of impaired cerebral connectivity, but further research is definitely needed to elucidate this issue.

Concluding remarks
This thesis presents the Infant Motor Profile (IMP), a recently developed qualitative assessment of motor behaviour for infants aged 3 to 18 months. Its psychometric properties including reliability, construct validity, concurrent validity and predictive validity were investigated. With respect to the three purposes for which the IMP was developed (chapter 6), we can conclude that the IMP is well able to discriminate between typically developing infants and infants with high risk for developmental motor disorders. The ability of the IMP to evaluate motor function over time should be further explored by applying the method in intervention studies. Prediction of developmental motor outcome at an early age will always remain difficult, since change is one of the main characteristics of the developing nervous system. In our study population, predictive validity of the IMP was satisfactory. Future studies should be directed at generating norm-scores for the IMP and determining clinical applicability.
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