Development of adaptive motor behaviour in typically developing infants

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ABSTRACT

Aim: During motor development, infants learn to select adaptive motor strategies out of their motor repertoire. The aim of this study is twofold: first, to investigate whether the presence of adaptive motor behaviour can be observed reliably, and second, to explore the ages at which clinically observable transition to adaptive motility emerges for four specific motor functions: abdominal progression, sitting motility, reaching, and grasping.

Methods: The reliability part of the study included 38 assessments of term and preterm infants in the age range of four to 18 months. The longitudinal prospective study included 30 term born typically developing infants with nine assessments between three and 18 months. On the basis of standardized video-recordings of spontaneous motor behaviour, the presence of adaptive motor strategies was scored.

Results: Intra- and interobserver reliability were good. Clinically observable transitions to adaptive selection started to emerge from six months onwards and peaked between eight and 15 months. Transitions developed gradually and occurred at specific ages for different motor functions.

Conclusion: Transition to adaptive motor behaviour can be observed reliably. Adaptive motor behaviour develops gradually from six months onwards at function-specific ages. Comparison of our results to literature showed that changes measured by neurophysiologic methods precede clinically observed transitions.
INTRODUCTION

During the first years of life, children show an impressive development of motor skills like sitting, crawling, standing, walking, reaching and grasping. Rapidly, the child’s motor repertoire expands, which enables the child to start exploration of the world. Motor development is a complex process in which many factors play a role. The limited knowledge on processes governing motor development induced a wide range of developmental theories. Theories differ especially with respect to the roles of ‘nature’ and ‘nurture’. Neuromaturationist theories for instance attribute major part of development to endogenous, genetic factors, whereas environmental and contextual factors dominate in the Dynamic Systems Theory. The Neuronal Group Selection Theory (NGST) is a theory which stresses the complex, continuous and cascadic interaction between information from the genetic script and environment.

According to the Neuronal Group Selection Theory (NGST), motor development is characterised by two phases of variability. Development starts with the phase of primary variability which can be observed during fetal life and early infancy. During this phase, all possibilities of the innate neural networks are explored by means of self-generated activity and movements are neither adapted to environmental constraints nor dependent on sensory feedback. In the fetus, newborn and young infant this can be observed in General Movements: movements with great complexity and variation in which all body parts are involved. These general movements are present until about four months of age, after which goal-directed motility gradually takes over. The emerging goal-directed motility such as reaching, grasping and crawling, is characterised by large variability at first. For each motor function all possible motor strategies and their corresponding neural networks are explored. At function-specific ages, infants start to select more adaptive motor strategies. Motor behaviour becomes more efficient and adapted to the task requirements and environmental characteristics. This phase of adaptive selection is called the phase of secondary variability. In this phase, there is still abundant variability in motor behaviour, which serves the purpose of adaptation of the movements to specific task and environmental characteristics.

Age of transition from primary to secondary variability differs for different motor functions. Sucking patterns, for example, are already adaptive around term age, i.e. at 37 to 40 weeks gestational age, while transition from primary to secondary variability for postural adjustments during supported sitting occurs between three and eight months. Reaching movements of infants aged four months are characterised by large variability in movement trajectories. Around the age of seven months, infants start to select straighter and more efficient reaching movements, indicating that for reaching the transition from primary to secondary variability lies approximately between four and seven months. These examples illustrate that secondary variability for basic motor functions emerges during infancy. However, development of secondary variability continues until adolescence. During this period, the child gains the capacity to fine-tune motor output to specific requirements and characteristics of task and environment.
The above presented data on ages of transition from primary to secondary variability are based on exact registration techniques such as electromyography (EMG) and kinematical recordings. These techniques allow precise measurement of timing of changes in muscle patterns involved in postural adjustments or straightening of reaching movement trajectories. No research has been conducted on when transition from primary to secondary variability becomes clinically observable. We hypothesize that changes measured by neurophysiologic methods precede clinically observable transitions. Changes in motor behaviour recorded with exact registration techniques represent the early phases of selection, while clinical observation shows when a certain pattern is selected during the majority of movements. Knowledge on clinical observable transitions is of clinical relevance. We recently demonstrated that the assessment of variation and the ability to select adaptive motor strategies is a useful tool to assess neuromotor integrity (Infant Motor Profile\textsuperscript{14}).

**Aim of the study**
The aim of this study was twofold. First, to investigate whether the presence of adaptive motor behaviour can be observed reliably (intra- and interobserver reliability). Second, to explore the ages at which clinically observable transition to adaptive motility emerges in typically developing infants for four specific motor functions: abdominal progression, sitting motility, arm movements during reaching and hand motility during grasping and manipulation. The four motor functions are part of the IMP assessment\textsuperscript{14}. The emergence of adaptive motor behaviour in the four motor functions was studied as part of entire IMP assessments.

**METHODS**
The reliability part of the study included 38 cross-sectional assessments of term and preterm infants in the age range of four to 18 months. The longitudinal prospective study included 30 term born typically developing infants with nine assessments between three and 18 months. The study groups are described in detail below. On the basis of standardized video-recordings of spontaneous motor behaviour, the presence of adaptive motor strategies was assessed.

**Participants in the reliability study**
We studied whether the presence of adaptive motor behaviour can be observed reliably in 19 term infants and 19 preterm infants. The term group in the reliability study consisted of 6 girls and 13 boys. Median gestational age was 40 weeks (range 38 – 42 weeks) and median birth weight was 3588 grams (range 3070 – 4200 grams). The preterm group consisted of 6 girls and 13 boys, median gestational age was 29.9 weeks (range 27.1 – 32 weeks) and median birth weight was 1165 grams (range 585 – 2120 grams). Three of the preterm infants had serious brain lesions on neonatal brain ultrasound: two had signs of cystic periventricular leukomalacia\textsuperscript{15} and one had intraventricular haemorrhage with ventricular dilatation (grade III)\textsuperscript{16}. The preterm infants had been admitted to the
neonatal intensive care unit (NICU) of the Beatrix Children’s Hospital of the University Medical Center (UMC) in Groningen between December 2003 and January 2005. The infants were assessed at one of the following ages: 4, 6, 10, 12 or 18 months. At 4, 6 and 10 months three full term and three preterm infants were included, at 12 months four full term and four preterm infants and at 18 months six full term and six preterm infants. The 38 videotapes were scored by two observers independently (KRH and MHA) to assess interobserver agreement. To determine intra-observer agreement, the sample was scored twice by one observer (KRH) with an interval of one month.

Participants in the study on emergence of adaptive motor behaviour
Thirty typically developing infants were included in the study on the emergence of adaptive motor behaviour (12 girls and 18 boys). They were recruited at well baby clinics and amongst acquaintances. They were born at term (gestational age at birth 40.1 weeks (median value), range 37.6 to 42 weeks) without pre or perinatal complications with a median birth weight of 3588 grams (range 2730 to 4470 grams). The infants were followed longitudinally and assessments took place at ages 3, 4, 5, 6, 8, 10, 12, 15 and 18 months. Of 19 of these infants one assessment was included in the reliability study as described above. Attrition rate was very low, only at 5 and 8 months one of the 30 infants had no assessment, due to minor illness of the child or scheduling problems with the parents. At 6 months arm and hand motility during reaching and grasping could not be assessed for two of the 30 infants due to fatigue of the child. All parents signed informed consent and the research project was approved by the Ethics Committee of the University Medical Center Groningen.

Procedures
Each assessment consisted of a video recording of in total 15 minutes of spontaneous motor behaviour in supine, prone, sitting, standing and walking, depending on the child’s age and functional capacities. The order of the conditions was not fixed, but was adapted to the child’s interest. Motor functions were only assessed if the infant was able to perform it independently, e.g. showed abdominal progression, sat independently, showed successful reaching or showed successful grasping. Table I shows the four items of the Infant Motor Profile and the definitions used for determining whether motor behaviour can be classified as adaptive motor behaviour for the four specific motor functions (abdominal progression, sitting motility, arm movements during reaching and hand motility during grasping and manipulation). Scoring is dichotomous: either the motor behaviour is scored as ‘no selection’ or as ‘adaptive selection’ (Table I).

Abdominal progression was elicited with toys. Besides crawling, wriggling and pivoting movements were also considered as forms of abdominal progression. Wriggling movements are small, quick, twisting and turning movements of the body without specific use of arms and/or legs resulting in spatial displacement, while the abdomen remains in contact with the support surface. Pivoting movements result in spatial displacement around the centre of the body, i.e. around a vertical axis through the umbilicus. Older infants who showed crawling were encouraged
Sitting motility was only assessed if infants were able to sit independently. To observe sitting motility, reaching movements and rotation movements of the trunk were elicited by presenting toys at various distances, in various directions and at various heights, e.g. close to the trunk of the infant, at arm length and a bit further at different heights in front and to the sides of the sitting infant. Sitting behaviour of children who were able to sit up independently was observed during spontaneous motor activity while they were moving into various body positions.

To assess the infant’s ability to reach, grasp and manipulate objects, small toys were presented to the infant seated on the parent’s lap. If the child was able to grasp objects in the midline at arm
length distance, toys were presented in different positions to elicit different reaching and grasping movements. Type of grasping and variation in grasping were assessed by presenting objects of various sizes and forms. A small cupboard with drawers with small handles was presented to the older infants to observe fine manipulation skills. Toys used were not standardised, but commercially available small (approximately the size of the infant’s hand) puppets, animals, toy cars and balls (See figure 1).

Figure 1: Examples of toys used in the Infant Motor Profile assessment.

Statistical analyses
To determine intra- and interobserver reliability, Cohen’s kappa’s were calculated. Criteria of Landis and Koch were used which state that $\kappa > 0.80$ is considered very good, $0.61 < \kappa < 0.80$ is good, $0.40 < \kappa < 0.60$ is moderate and $\kappa < 0.40$ is poor. To explore the ages of transition, i.e., the age at which motor behaviour changed from no selection to adaptive selection, the non-parametric Sign or Friedman tests for related samples were used. Throughout the analyses, differences with a p-value < 0.05 were considered to be statistically significant (two-tailed testing).

RESULTS

Reliability
For the item on adaptive selection during abdominal progression, intra- and interobserver agreement were very good (See Table II for Kappa and 95% confidence intervals). This was also the case for the item on sitting motility. The item on arm motility during reaching showed good intra- and interobserver agreement. For the item on hand motility, intra-observer reliability was moderate, while interobserver agreement was very good.
Chapter 4

Emergence of adaptive motor behaviour

In the development of abdominal progression, the transition from variable, non-adaptive behaviour to adaptive behaviour was observed between 8 and 15 months (Friedman, p < 0.0005). This means that at the age of 15 months virtually all children selected adaptive crawling strategies (Figure 2). For sitting motility (Figure 3) transition from exploratory, variable behaviour without selection to adaptive selection started from 6 months onwards. At 8 months 33% of infants showed adaptive sitting motility, which increased to almost 90% of infants at 10 months (Friedman test 6 to 10 months: p<0.0005). Transition to adaptive selection of arm movements during reaching occurred in a majority of infants between 6 and 8 months (Sign test: p < 0.0005). However, in the period from

<table>
<thead>
<tr>
<th>Item</th>
<th>Intra-observer agreement</th>
<th>Interobserver agreement</th>
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<tbody>
<tr>
<td></td>
<td>Kappa</td>
<td>95% CI</td>
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<tr>
<td>Abdominal progression</td>
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<td>0.69-0.99</td>
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<tr>
<td>Sitting motility</td>
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<tr>
<td>Reaching movements</td>
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<td>0.42-0.94</td>
</tr>
<tr>
<td>Hand motility during grasping</td>
<td>0.56</td>
<td>0.23-0.88</td>
</tr>
</tbody>
</table>

CI: confidence interval

Figure 2: Variability of abdominal progression: presence of adaptive selection.

Hatched parts of bars represent percentage of infants showing no selection of crawling patterns and black parts represent percentage showing adaptive selection of crawling patterns. White parts represent the percentages of infants showing no abdominal progression. ** Significant increase in adaptive selection between 8 and 15 months (Friedman: p<0.0005). The three developmental steps from 8 to 10, 10 to 12 and 12 to 15 months were also statistically significant (Sign test: p = 0.03, p = 0.002 and p = 0.001, respectively).
Figure 3: Variability of sitting motility: presence of adaptive selection.
Hatched parts of bars represent percentage of infants showing no selection of sitting motility and black parts represent percentage showing adaptive selection of sitting motility. White parts represent the percentages of infants that are not able to sit independently. * Significant increase in adaptive selection between 6 and 10 months (Friedman: p<0.0005). The two steps from 6 to 8 and from 8 to 10 months were also statistically significant (Sign test 6 to 8 and 8 to 10 months: p = 0.02).

Figure 4: Variability of arm movements during reaching: presence of adaptive selection.
Hatched parts of bars represent percentage of infants showing no selection of arm movements and black parts represent percentage of infants showing adaptive selection of arm movements. White parts represent the percentages of infants showing no reaching movements. Asterisks indicate significant increase in adaptive selection (Sign test): * p = 0.02 and ** p < 0.0005.
60 weeks to 12 months about 10% to 25% of infants continued to show variable reaching movements. Not until 15 months, all infants showed adaptive reaching movements (Sign test: p = 0.02; Figure 4). For hand motility during grasping transition from variable, non-adaptive to adaptive motor behaviour was observed between 15 and 18 months (Sign test: p < 0.0005; Figure 5).

**DISCUSSION**

This study illustrated that transition to selection of adaptive motor behaviour can be reliably observed and that this transition emerges around the age of 6 months and peaks between 8 and 15 months. The transition develops gradually and occurs at specific ages for different motor functions.

**Findings**

Intra and interobserver reliability of all items were good to very good, except intra observer reliability for the item on hand motility during grasping, which was moderate. The latter may have been an expression of a learning effect.

For abdominal progression, clinically observable transition to selection of adaptive crawling strategies started at 8 months of age. At 15 months, almost all children showed adaptive crawling patterns on hands and knees. Adolph et al.\textsuperscript{20} also found decreasing movement variability with increasing weeks of crawling experience. More experience with prone position and practice of crawling accelerates selection of adaptive crawling patterns\textsuperscript{20-22}. Development of crawling continues...
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beyond infancy. With respect to sitting motility, we know from literature that selection of the complete EMG pattern, in which all dorsal neck- and trunk muscles are activated synchronously, emerges between 4 and 6 months. The present study showed that transition to adaptive sitting motility is clinically observable between 6 and 10 months of age. This indicates that selection of a preferred postural adjustment pattern measured by EMG precedes the clinical observable transition. Development of postural control is not finished during infancy; it has a protracted course that lasts at least until adolescence.

Our study showed that clinically observable transition from variable, exploratory reaching movements to straighter, adaptive reaching movements emerged between six and eight months, but not until 15 months all typically developing children showed adaptive reaching movements. Kinematic data from literature showed rapid straightening of movement trajectories around the age of four to six months, again preceding the clinical observed transition we found. Stable patterns of temporal coordination start to develop from 12 to 15 months onwards until the age of three years, illustrating the long course of development of secondary variability during which fine-tuning of the reaching movements to the specific task requirements occurs.

For hand motility during grasping, transition to secondary variability occurred for more than 70 percent of children between 15 and 18 months. Corticospinal connections are crucial for the development of skilled hand and finger movements. Direct cortico-motoneuronal projections already develop in the first months of postnatal life and allow for voluntary independent finger movements. Thereafter, corticospinal projections become fine-tuned, a process that includes the disappearance of the majority of ipsilateral connections which is finished by the age of 24 months. During the process of activity-dependent remodeling of the corticospinal connections, adaptive hand motility emerges from 15 months onwards. But again, fine-tuning of grasping movements continues at least until the age of eight to ten years.

Strengths and limitations of the study
A strength of this study is its longitudinal prospective character. For closer monitoring of developmental changes, it would have been better to have more frequent assessments, for example each month. However, time intervals between assessments were especially short during the first year of life when motor development has a rapid course. Another strength was the very low attrition rate. A limitation of the reliability study is that only two assessors participated. They were not blinded with respect to term or preterm status of the infant. However, they were unaware of any details of the child’s clinical history or results of neonatal ultrasounds of the preterm infants. A weakness of the longitudinal part of the study is the relatively small sample size, especially because variability within and between typically developing infants can be quite large. Nevertheless, we were able to detect the ages of transition. In the current study, we compared the clinically observed ages of transition with data in the literature available on changes measured by neurophysiologic methods. It would
have been interesting and possibly more exact if the same children had had the neurophysiological assessments and the clinical observations. This could be done in further research.

**CONCLUDING REMARKS**

During the first half year of life, infant motor behaviour is characterised by variation and exploration. Transition to clinically observable adaptive motor behaviour develops gradually from six months onwards at function-specific ages. By comparing our results to literature, we found that changes measured by neurophysiologic methods precede the clinically observed transitions. Changes in motor behaviour recorded with exact registration techniques represent the early phases of selection, while clinical observation shows when a certain pattern is used during the majority of movements. It would be interesting to perform further research on ages of transition in infants with a high risk for developmental motor disorders such as cerebral palsy (CP) or developmental coordination disorder (DCD). These children can have difficulties with processing afferent, sensory information and experience problems in fine-tuning and adapting motor behaviour\(^5,28-29\). This could possibly be reflected in delayed or impeded transition to secondary variability. If so, age of transition could be a useful clinical parameter of neuromotor condition.

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