General introduction
GENERAL INTRODUCTION

Theories on motor development

During the first two years of life, children show an impressive development of motor skills such as reaching, grasping, sitting, crawling, standing and walking. Rapidly, they change from supine infants to walking toddlers who are able to explore the world around them. Motor development is a complex process in which many factors play a role. The limited knowledge on the exact processes that are involved in motor development induced a wide range of theories. Traditionally, the process of motor development was explained by the Neuronal Maturation Theory (NMT). According to this theory, at birth all programs involved in motor development are present. As a result of maturation of the central nervous system, motor development is brought about by a gradual unfolding of these programs. This unfolding process is not dependent on environmental factors and there is only a limited role for exercise. Because not all parts of the central nervous system mature at the same time, motor development takes place from proximal to distal and from cranial to caudal direction. Based on these general developmental rules, Gesell and Amatruda described all motor milestones and the ages at which they emerge in their book ‘Developmental Diagnosis’.

In the Dynamic Systems Theory (DST), motor development is considered as a self-organizing process in which all components are equally involved. Motor behaviour is determined by an interplay between many subsystems, such as muscle force, muscle tone, the nervous system, body weight, state and motivation of the infant, context variables and task characteristics. Development is described as ‘a series of states of stability, instability, and phase shifts in the attractor landscape, reflecting the probability that a pattern will emerge under particular constraints’. Phase shifts are brought about by changes in one or more of the involved subsystems, leading to a forced transition of the system to another state. Attractors states are preferred patterns of behaviour, for example patterns of locomotion such as rolling, crawling or walking. Depending on the characteristics of all factors involved, one way of locomotion is the most stable attractor in a certain situation and this attractor has the highest probability of occurring. For example, a child who has been able to walk independently for some weeks will choose the locomotion pattern ‘walking’ in easy circumstances, but will probably switch to crawling when the surface is slippery. In this simplified example, the surface characteristic is regarded as the control parameter, that is the changed factor that makes the system shift to another state. In contrast with NMT, in which the central nervous system has a leading role in the process of motor development, in DST the nervous system is only one of the elements involved.

In the Neuronal Group Selection Theory (NGST) on motor development both genetic, innate factors and environmental influences play a role. According to NGST, typical motor development is characterized by two phases of variability. During the phase of primary variability, variation in motor behaviour is not geared to external conditions. By means of spontaneous, self-generated activity, the primary neuronal networks that are already present at birth and the corresponding motor
repertoires are explored. This can for example be observed in the so-called general movements (GMs). General movements are the most frequent used movement pattern of the fetus and the young infant until the age of approximately four months post term. They are characterised by abundant variation and complexity and are not adapted to the environment nor goal-directed. From three to four months onwards, these general movements are gradually displaced by goal-directed motility, such as reaching movements. This goal-directed motility is at first characterised by abundant variation, for example variation in reaching trajectories, amplitude of movements and movement speed. Gradually, this seemingly random variation decreases and the second phase of motor development, the phase of secondary variability, takes over. In the phase of secondary variability, the child develops the ability to select out of the extensive motor repertoire the best motor strategy in a certain situation, which gives motor behaviour a more efficient impression. Development of this ability to select adaptive motor strategies is dependent on the afferent information brought about by the self-generated activity. In other words, by means of a process of exploration and selection the child develops the capacity to adapt motor behaviour to environmental constraints. This ability to select adaptive motor strategies out of the motor repertoire occurs at function-specific ages.

The process of typical motor development is disturbed in developmental motor disorders, such as cerebral palsy (CP) or developmental coordination disorder (DCD). See below for descriptions of these motor disorders. According to NGST, children with pre or perinatally acquired lesions of the brain, such as children with CP and some children with DCD, exhibit stereotyped motor behaviour with reduced variability. This might be related to a reduction of the repertoire of primary cortical-subcortical neuronal networks. Besides the reduced neural repertoire, motor behaviour of these children is also affected by problems in adaptive selection of the most suitable motor strategies in a certain situation. This might be due to problems in processing afferent, sensory information that are often encountered in children with CP and DCD, as adaptive selection relies on afferent feedback.

**Developmental motor disorders**

Cerebral palsy (CP) is defined as a group of disorders of motor function, movement and posture; it is permanent but not unchanging and is caused by non-progressive lesions or brain abnormalities in the developing/immature brain. It is often associated with severe intellectual deficit (31%), severe visual impairment (11%) and/or seizures (21%). CP is classified as spastic CP, ataxic CP or dyskinetic CP. Spastic CP is the most frequent form of CP (85-90%) and is characterised by at least two of the following three characteristics: abnormal pattern of posture and/or movement, increased tone and pathological reflexes. Spastic CP may be unilateral, involving limbs on one side of the body, or bilateral with involvement of limbs on both sides of the body. Ataxic CP is characterized by abnormal pattern of posture and/or movement in combination with a loss of orderly muscular coordination so that movements are performed with abnormal force, rhythm and accuracy. In dyskinetic CP, abnormal pattern of posture and/or movement is accompanied by involuntary,
uncontrolled, recurring, occasionally stereotyped movements\textsuperscript{18}. Prevalence of CP is 2 to 3 per 1000 live births\textsuperscript{18}. Infants with very low birth weight (below 1500 gram) and/or very preterm birth are at higher risk for development of CP. Due to improved prenatal and neonatal care, the survival of this group of vulnerable infants has increased in the last decennia, possibly leading to an upward trend in the overall prevalence of CP during the 1970s and 1980s. In the recent years trends have been less clear\textsuperscript{18,19}, but the prevalence seems to have stabilized or even decreased\textsuperscript{20}. CP is caused in more than 80\% by brain lesions that can be visualised by brain imaging with magnetic resonance imaging (MRI) or neonatal ultrasound scans. Type and localisation of the brain damage determine the clinical subtype of CP and are related to the presence and severity of associated disabilities\textsuperscript{20}. Often, no specific cause can be identified and it is assumed that a combination of factors is responsible for the brain damage. For a long time, only complications of labour and delivery were considered causal risk factors for CP, but current evidence suggests that intrauterine exposure to infection or inflammation and coagulation disorders could be more important causes\textsuperscript{21}. At present, knowledge on the precise contributors to the risk for CP is still not complete.

Compared to CP, developmental coordination disorder (DCD) is a much less disabling developmental motor disorder, but it still has major impact on daily life and academic achievements. Diagnosis of DCD can be made according to the following DSM-IV criteria\textsuperscript{22}: performance in daily activities that require motor coordination is substantially below that expected, given the person’s chronological age and measured intelligence. This may be manifested by marked delays in achieving motor milestones, dropping things, clumsiness, poor performance in sports, or poor handwriting. The disturbance significantly interferes with academic achievement and/or activities of daily living and is not due to a general medical condition such as CP or muscular dystrophy. If intellectual delay is present, the motor difficulties are greater than would be expected, given the level of delay\textsuperscript{22}. DCD is a common condition with an estimated prevalence of 5 to 6\%\textsuperscript{22}. It is often associated with the presence of signs of minor neurological dysfunction (MND)\textsuperscript{16}.

**Assessment of neuromotor function in infancy**

Infants born very preterm are especially at risk for developmental motor disorders such as CP or DCD\textsuperscript{23-26}. Due to improved prenatal and neonatal care the group of surviving very preterm infants has increased in the last decennia\textsuperscript{23,26}. Follow-up of preterm infants aims at the detection of those infants that could benefit from early intervention at young age, when the brain is characterised by high plasticity\textsuperscript{27,28}. In order to detect those infants, clinicians such as physical therapists, occupational therapists, paediatricians and paediatric neurologists have a wide range of instruments that assess neuromotor function in infancy at their disposal. In chapter 2, a systematic review of existing methods and their psychometric properties is presented. We found that instruments that assess qualitative aspects of motor behaviour, such as the general movement (GM) method\textsuperscript{13,29} and the Test of Infant Motor Performance (TIMP)\textsuperscript{30}, are most promising in terms of prediction of future developmental outcome. However, these two methods are only suitable for infants until the age
of four months. Therefore, we developed the Infant Motor Profile, a qualitative assessment which is applicable throughout infancy until the age of 18 months.

**The Infant Motor Profile**

In the development process of the Infant Motor Profile, we started with precise observation and analysis of video-recordings of spontaneous motor behaviour of typically developing infants from three months until 2 years of age. In addition, we observed video-recordings of infants at high risk for developmental motor disorders such as cerebral palsy. We tried to discern which aspects of motor behaviour differed between typically developing and high-risk infants. With the NGST as theoretical background, we categorized the observed variables into various domains. We defined the items on these variables as precisely as possible and wrote guidelines for the examiner on how to perform the assessment. We viewed and assessed a heterogeneous group of video-recordings of typically and non-typically developing infants at different ages, and step by step we refined the items and the classification into domains. In the end, the Infant Motor Profile had been developed to the form as it is now and the process of validation was started.

The Infant Motor Profile is a video-based assessment of motor behaviour of infants aged 3 to 18 months. It consists of 80 items (see Appendix 1). These items constitute five domains. Two domains are based on ideas of the NGST as described above\textsuperscript{10,11}, the first one is on size of motor repertoire (variation) and the second one is on the ability to select adaptive motor strategies (variability). These domains consist of respectively 25 and 15 items. The other three domains are on movement fluency (seven items), movement symmetry (10 items) and motor performance (23 items), the last one being a more quantitative assessment of motor milestones. Details on the scoring of the items and on calculation of the domain scores are described in chapter 3. The total IMP-score is computed as the mean of the five domain scores. A general principle in calculating the scores on the various domains is that only items that reflect observed motor behaviour are taken into account. This means that for example an item on variability of leg movements during independent walking is only scored if the child indeed is able to walk independently. If not, the item is not taken into account in computing the domain-score. An exception to this rule are the items of the performance domain, which can always be scored. For example, if the child is not able to walk, item 5 of standing and walking is scored as ‘1 = cannot walk’.

**Aim of this thesis**

The aim of this thesis was threefold: first to review existing methods to assess neuromotor function in infancy. The second aim was development of the Infant Motor Profile and the third aim was to investigate its psychometric properties. In order to be able to investigate reliability and validity of the Infant Motor Profile, we performed a longitudinal prospective study on a heterogeneous group of term and preterm born infants from 3 to 18 months. In addition, another group of term born infants had cross-sectional assessments at the same ages.
Main focus is on:
1. Intra- and interobserver reliability of the IMP.
2. Construct validity of the IMP, operationalized as relations between IMP-scores throughout infancy and prenatal, perinatal and neonatal risk factors, including the presence of brain pathology on neonatal ultrasound scans.
3. Concurrent validity of the IMP with the Alberta Infant Motor Scale (AIMS\textsuperscript{31}) and the Touwen Infant Neurological Examination (TINE\textsuperscript{32,33}).
4. Predictive validity of the IMP-scores throughout infancy for neurological outcome at corrected age of 18 months.

**METHODS**

**Study group**

The study sample consisted of a heterogeneous group of term and preterm infants, which is a valuable type of sample when assessing validity of a new instrument. Thirty term born infants with a median gestational age of 40.1 weeks (range 37.6-42 weeks) and a median birth weight of 3588 grams (range 2730-4470 grams) were followed longitudinally and assessed at ages 3, 4, 5, 6, 8, 10, 12, 15 and 18 months. These infants were recruited amongst colleagues and acquaintances of the researchers. A group of 59 preterm infants was followed longitudinally at corrected ages 4, 6, 10, 12 and 18 months. They had all been admitted to the neonatal intensive care unit (NICU) of the Beatrix Children's Hospital of the University Medical Center Groningen (UMCG) 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 approximately less than one hour. Infants with severe congenital anomalies were excluded from the study. Median gestational age was 29.7 weeks (range 25-34.7 weeks) and median birth weight was 1285 grams (range 630-2180 grams). Another group of 116 term infants was recruited at Well Child Centres. These infants had a median gestational age of 40.1 weeks (range 37-43 weeks) and a median birth weight of 3500 grams (range 1960-4660 grams). These infants had cross-sectional assessments at one (n=102), two (n=13) or three (n=1) of the ages of 4, 6, 10, 12 or 18 months. All parents gave informed consent and the project was approved by the local Ethics Committee.

For all infants, socio-economic, prenatal and neonatal data were collected on standardized forms by means of an interview with the parents and consultation of NICU discharge certificates. For the preterm infants, neonatal ultrasounds of the brain were assessed with respect to periventricular leukomalacia (PVL)\textsuperscript{34} and intraventricular haemorrhages (IVH)\textsuperscript{35}. Details on socio-economic and neonatal characteristics of the study groups will be presented in the following chapters.
Assessments

At all ages, the assessment consisted of a video-recording of motor behaviour of approximately 15 minutes. Motor behaviour was assessed in several positions, depending on the age and functional capacities of the child: supine, prone, sitting, standing and walking and reaching, grasping and manipulation of objects. Motor behaviour was spontaneous or was elicited by presenting toys to the infant. On the basis of the video-recording, both the Infant Motor Profile and the Alberta Infant Motor Scale (AIMS) were scored at a later time. The assessment consisted further of an age-specific neurological examination that was carried out after the video-recording. At all ages, except at 18 months, this consisted of the Touwen Infant Neurological Examination (TINE). In TINE, neurological signs are grouped according to age-specific norms into five possible clusters of dysfunction, namely reaching and grasping, gross motor function, brain stem function, visuomotor function and sensorimotor function (consisting of reflexes and muscle tone). Neurological condition is classified as abnormal if there is a distinct neurological syndrome, such as a hemisyndrome, irrespective of number of deviant clusters. Neurological condition is classified as minor neurological dysfunction (MND) if there are two or more clusters of dysfunction. Neurological condition is considered normal-suboptimal when one or two clusters are deviant and normal when no clusters are deviant. At the age of 18 months, the Hempel assessment was used instead of TINE, as TINE is only applicable until the age of 12 to 15 months. The Hempel examination is suitable for preschool children from 18 months until 4 years of age. Similar to TINE, the Hempel assessment classifies neurological signs into clusters of dysfunction, namely fine motor dysfunction, gross motor dysfunction, dysfunctional muscle tone regulation, reflex abnormalities and visuomotor dysfunction. Neurological condition can be classified as abnormal, complex MND (when there is more than one dysfunctional cluster), simple MND (when one cluster of dysfunction is present) or normal (no deviant clusters or the isolated presence of reflex abnormalities).

Outline of the thesis

Chapter 2 consists of a systematic review of available methods to evaluate neuromotor function in infancy and their psychometric properties. The review forms the background to which the Infant Motor Profile was developed. Chapter 3 presents the pilot study on the IMP with description of the instrument and first data on intra and inter observer reliability and concurrent validity. In chapter 4, a small side step is made, and development of adaptive motor behaviour in typically developing infants is investigated with the NGST as theoretical background. Chapter 5 examines construct validity of the IMP, operationalized as the relation of IMP-scores throughout infancy with prenatal, perinatal and neonatal risk factors. Chapter 6 re-assesses reliability and investigates concurrent validity of the IMP with the Alberta Infant Motor Scale (AIMS) and with Touwen Infant Neurological Examination (TINE) and predictive validity for neurological outcome at 18 months. Chapter 7 consists of a general discussion on the IMP and its psychometric properties as presented in this thesis.
REFERENCES


