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Modeling gross motor developmental curves of extremely and very preterm infants using the AIMS home-video method

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ABSTRACT

Background: Motor development is one of the first signals to identify whether an infant is developing well. For very preterm (VPT) infants without severe perinatal complications, little is known about their motor developmental curves.
Aims: Explore gross motor developmental curves from 3 until 18 months corrected age (CA) of VPT infants, and related factors. Explore whether separate profiles can be distinguished and compare these to profiles of Dutch term-born infants.
Study design: Prospective cohort study with parents repeatedly recording their infant, using the Alberta Infant Motor Scale (AIMS) home-video method, from 3 to 18 months CA.
Subjects: Forty-two Dutch infants born ≤32.0 weeks gestational age and/or with a birthweight (BW) of <1500 g without severe perinatal complications.
Outcome measures: Gross motor development measured with the AIMS.
Results: In total 208 assessments were analyzed, with 27 infants ≥five assessments, 12 with <four, and three with one assessment. Sigmoid-shaped gross motor curves show unidirectional growth and variability. No infant or parental factors significantly influenced motor development, although a trend was seen for the model where lower BW, five-minute Apgar score <7, and Dutch native-speaking parents were associated with slower motor development. Three motor developmental profiles of VPT infants were identified, early developers, gradual developers, and late bloomers, which until 12 months CA are comparable in shape and speed to profiles of Dutch term-born infants.
Conclusions: VPT infants show great intra- and interindividual variability in gross motor development, with three motor profiles being distinguished. From 12 months CA onwards, VPT infants appear to develop at a slower pace. With some caution, classifying infants into motor developmental profiles may assist clinical decision-making.

1. Introduction

Improved care of preterm infants has influenced clinical decision-making tremendously over recent decades [1]. From the moment an infant is expected to be born very premature (VPT) (before 32 weeks gestational age (GA)), clinical decisions are constantly made to support survival and developmental outcomes of the infant at risk [2]. VPT infants are at risk of developmental problems and identifying these problems makes early interventions possible [3–5]. Motor development is one of the markers to identify whether an infant is developing well and as such is one of the first signals to support clinical decision-making regarding starting early intervention [4,6]. However, the course of motor development for both preterm and term-born infants is known to be variable and non-linear, which makes predicting infant motor development and clinical decision-making difficult [7–10].

Research into factors affecting the course of motor development

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supports decision-making in follow-up, shaping early interventions, and decreasing parental concerns [11,12]. For premature infants, factors identified with sufficient evidence of a longitudinal association with gross motor development are mainly perinatal ones [4,13]. Only for the infant factors birthweight (BW) and gestational age (GA) is there strong evidence of a longitudinal association of lower BW and/or lower GA with more delayed gross motor development [5,14–20]. Few social, environmental, and parental factors, like parental education and socioeconomic status, have been subjects of longitudinal studies with premature infants. Further, research on these parental factors mainly concerns those associated with cognitive, and not motor, development [4].

Clustering of data, which enables the creation of profiles based on similarities and differences [21–23], can also contribute to clinical decision-making. Recent research into gross motor curves of typically developing Dutch term-born infants from 3 to 15 months, measured with the Alberta Infant Motor Scale (AIMS), has demonstrated that by using cluster analysis three profiles can be distinguished, based on different gross motor curves. The profiles are termed early developers, gradual developers, and late bloomers [10].

For premature infants, few studies examined distinct profiles in motor developmental trajectories.

Most of these studies, mainly cross-sectional, group premature infants according to their GA: extremely premature (<28 weeks GA), very premature (28–32 weeks GA), and moderate-to-late premature infants (32–37 weeks GA) [24]. Their results support the idea that preterm infants present with lower scores on motor performance, even when corrected for prematurity, than their term-born peers [16]. Other studies with a longitudinal design mainly determine the shape of the motor developmental trajectory with the focus on the (in)stability of longitudinal measurements of VPT infants at risk. For instance, Janssen et al. (2011) reported three profiles in gross motor development measured with the Bayley Scales of Infant Development, 2nd edition (BSID-II) Motor Scale among a sample of 348 preterm infants (≤32 weeks GA) at 6, 12, and 24 months CA. They described these clusters in terms of the (in)stability of the motor trajectory: stable, relatively stable, and unstable classifications [7]. Erikson et al. (2003) reported two profiles for a sample of 165 very low birthweight (VLBW) infants followed over a wider age span, namely from 5 months (CA) to 5.5 years, measured with the Movement Assessment of Infants (MAI): stable or unstable motor development [25]. Lastly, Su et al. (2017) assessed preterm infants with VLBW four times, at 4, 6, 9, and 12 months, with the AIMS, finding three distinct motor profiles: stably normal (53 %), deteriorating (32 %), and persistently delayed (13 %) [26]. These three studies included very premature infants with and without perinatal complications, such as severe intraventricular hemorrhage (IVH), bronchopulmonary dysplasia (BPD), and brain damage [7,25,26].

Little is known about the motor developmental curves of VPT infants without severe perinatal complications. The focus of the present study was on the shape and speed of individual gross motor developmental curves from 3 to 18 months CA in Dutch infants born VPT and/or weighing <1500 g. Within the sample, we explored which factors were related to the course of gross motor curves. Lastly, we examined whether profiles of gross motor development could be distinguished, and how they related to such profiles for a sample of term-born (TB) Dutch infants. The results of this study may contribute to clinical decision-making, shaping early interventions, and informing realistic parental expectations.

2. Methods

2.1. Participants and procedure

In this prospective cohort study, the GODIVA-PIT study (Gross mOtor Development of Infants using home-Video registration with the Aims - following Premature Infants in Time), infant gross motor development was assessed at seven time-points between 3 and 18 months CA. The age of 18 months was chosen to ensure to the inclusion of VPT infants who had reached the milestone of independent walking [27].

In the Netherlands, motor development of premature infants is monitored according to the European Standards of neonatal follow-up. Infants visit the neonatal follow-up clinics spread across the country at the ages of 6, 12, and 24 months CA, and at 5 and 8 years. At 6 and 12 months CA, the AIMS is administered to assess gross motor development [28]. After discharge from the hospital, infants born before 32 weeks GA and/or with a BW <1500 g are advised to participate in the TOP program (Transmural developmental support for VPT infants and their parents), a post-discharge responsive parenting program for VPT infants and their parents performed at home by trained pediatric physical therapists, covered by the Dutch health insurance system [29].

Parents were recruited between May 2017 and December 2019 in the Wilhelmina Children's Hospital (Utrecht), Radboud University Medical Centre (Nijmegen), Isala Hospital (Zwolle), and by TOP pediatric physical therapists throughout the Netherlands. Recruitment took place at the regular neonatal, outpatient follow-up, or during parents' first contact with the TOP therapist.

Infants born before or at 32 weeks GA and/or with a BW of <1500 g who at the start of the study were younger than 7 months CA were eligible for the study. Due to changes in the follow-up protocol at the outpatient clinic of the Wilhelmina Children's Hospital in January 2018 whereby all infants were no longer seen at their term date, and as their first visit was at 6 months, the inclusion criteria were broadened to 7 months of age. Their parents had to understand Dutch language. Exclusion criteria were: a known syndrome, a neuromuscular disorder, severe neuroimaging abnormalities (e.g., cystic periventricular leukomalacia, IVH Grade III or IV), meningitis, bronchopulmonary dysplasia (defined as oxygen supplementation >36 weeks postmenstrual age), congenital anomalies, necrotizing enterocolitis requiring surgical procedures, prolonged tube feeding (defined as beyond hospital discharge), and severe visual or hearing disorder.

When infants met the inclusion criteria, parents were invited to participate in the study and sent information, accompanied by informed consent forms. After approximately a week, parents were contacted and asked if they intended to participate and/or had any questions. If they agreed to participate, parents were asked to return the signed informed consent forms and booklet with information, checklists [30], and instructions were sent to them.

Data for Dutch term-born infants were used retrospectively. These data originated from the GODIVA-KIT (children following in time) study, a prospective longitudinal study with the objective of modeling motor growth and exploring different patterns in gross motor trajectories in a sample of term-born (>37 weeks GA) typically developing Dutch infants from 3 to 15 months, using AIMS raw scores. Data for the GODIVA-KIT study were collected between 2016 and 2018. The present study had a similar protocol but a different population than the GODIVA-KIT study [10].

2.2. AIMS home-video method

Parents used the AIMS home-video method to collect data. This method is validated and reliable for assessing the AIMS [31,32]. Parents received instructions, comprising three instruction videos and a booklet with three corresponding checklists on how and what to record and how to upload their videos to a secure digital server. After uploading, the researcher/pediatric physical therapist (IS) assessed the video using the AIMS and sent parents feedback on their infants' motor development by email. Whenever abnormalities were seen in the infant's motor presentation, the attending physician and/or pediatric physiotherapist were contacted for consultation.

Parents had a window of two weeks to plan a time to record their infant. Before this window began, parents received a reminder by email of the actual dates of the recording window (also noted in the information booklet). An additional reminder was sent one week after the start of the window. Furthermore, parents received the Parental Beliefs questionnaire [33] accompanied by some demographic questions, before the first time of recording, and again when their infant was 15 months CA. Parents were asked to film their infant with the AIMS home-video method five to seven times, depending on the CA of their infant at the start. The interval between recordings was 2 or 3 months (see Fig. 1).

2.3. Measurement

The AIMS measures infant gross motor development from birth until independent walking. It is a norm-referenced observational instrument with good psychometric properties [34]. Most of the 58 items are based on spontaneous movements of the infant in four different postures (supine, prone, sitting, and standing). The actual motor repertoire of the infant is represented by the observed items.

2.4. Ethics

The GODIVA-PIT study was approved by the Medical Ethical Board of the University Medical Centre Utrecht (METC/UMCU) with protocol nr. 17-186/C. Parents gave written informed consent prior to participation. Video data were stored on a secure server at Utrecht University of Applied Sciences.

2.5. Data analysis

Population characteristics were calculated with frequencies, percentages, means, standard deviations (SD), and ranges. Next to the descriptive analysis, characteristics of participating infants and parents, drop-outs and non-participators were compared with a one-way ANOVA. Next, three different components were analyzed: 1) Trajectories of gross motor development and associated factors, 2) Modeling Dutch preterm gross motor profiles and 3) Comparison between Dutch term-born and preterm gross motor profiles.

2.5.1. Trajectories of gross motor development and associated factors

Linear Mixed Model analysis (LMM) was used, suitable for hierarchical data structures such as repeated measures over time. LMM allows observations to be interdependent, and every observation is considered a data point [35,36]. Hence, LMM analysis is considered most applicable for a relatively small sample with missing data points.

The first step in LMM is to explore which model (linear, quadratic, or cubic) fits best. The intercept and slope were allowed to vary across individuals. Therefore, age is considered a random factor with a random intercept because exploration of the gross motor trajectories shows that each infant has a different start and course in motor development. The best fit model is determined by the Akaike information criterion (AIC), which needs to decrease to be a better fit [37].

The second step was LMM with backward selection of factors representing infant and parent characteristics. The characteristics BW, GA, sex, five-minute Apgar score, maternal age, paternal age, maternal education, paternal education, birth order, and parental mother tongue (i.

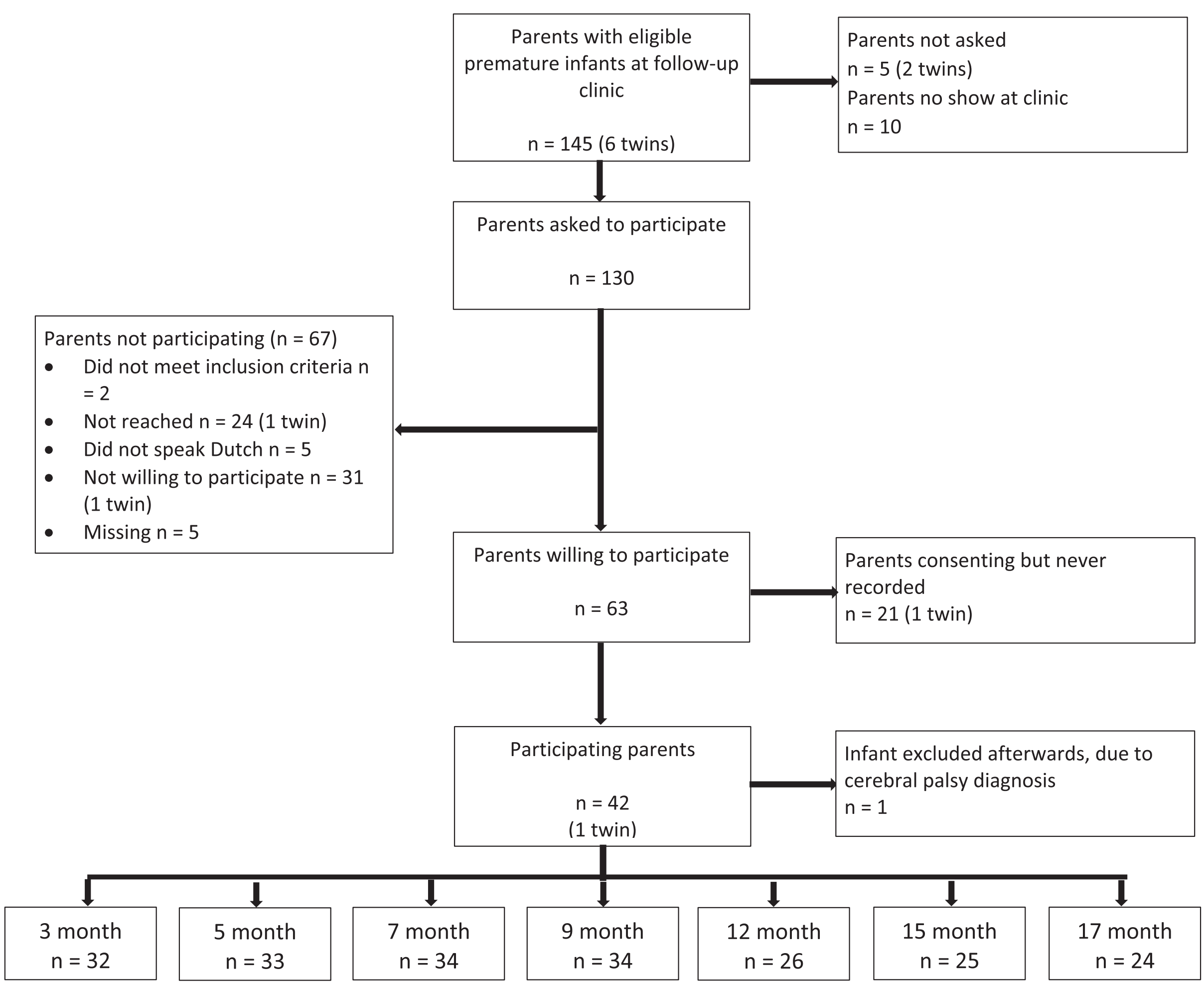

Fig. 1. Flow-chart eligible and participating infants.

e., one or both have mother tongue Dutch) were considered as potential factors influencing gross motor development. BW was divided into three categories: <1000 g, 1000–1499 g, and ≥1500 g. The five-minute Apgar score (Apgar5) comprised two categories: <7 or ≥7. Maternal and paternal age were divided into categories starting from 25 years in steps of 5 years to 40 years of age. Maternal and paternal education had the categories: primary, secondary lower, secondary higher, and tertiary. These factors were assumed to be fixed because they do not change over time. For the factors sex and BW, an interaction effect with age was added. The factors were sequentially deleted, based on the highest *p*-value and $p > 0.05$, from the models to finish with the model that explains the data best. The AIC was decisive in determining the best model with a minimum difference of 3. The factors GA and BW were highly correlated ($r = 0.631$, $p < 0.001$), and also the factors maternal and paternal age were highly correlated ($r = 0.729$, $p = 0.001$). To avoid multicollinearity, GA and paternal age were left out of the analysis. AIMS raw scores were used as the outcome variable because these are not norm-referenced [7].

2.5.2. Modeling Dutch preterm gross motor profiles

We explored whether gross motor profiles similar to those of Dutch term-born infants (i.e., early developer, gradual developer, and late bloomer) could be identified for the preterm infants. A hierarchical cluster analysis, first with a dendrogram and subsequently with K-means cluster analyses, was performed to confirm whether three profiles were a possibility, and infants were assigned to the initial calculated profile. The mean age and standard deviation of independent walking of each profile were calculated. For infants with one or two assessments, the initial calculated profile was compared to the profile based on the age of independent walking ±1SD. An infant was reassigned when the age of independent walking fitted a different profile.

When the age of independent walking was not available, the classification according to the initial analysis was preserved. With ANOVA's tests, the profiles were tested on their differences. Because of the small number of infants in a profile, descriptive analyses were used to gain more insight into the characteristics of the three profiles.

2.5.3. Comparison between Dutch term-born and preterm infant gross motor profiles

To compare the profiles of the Dutch term-born (TB) infants (TB early developer, TB gradual developer, TB late bloomer) with the Dutch premature sample (VPT early developer, VPT gradual developer, VPT late bloomer), at all different ages, a two-way ANOVA was performed to analyze the interactions between the group (Term (TB) or Preterm (VPT)) and developmental profile (early developer, gradual developer or late bloomer).

IBM SPSS statistics package for Windows, Version 25.0. was used for statistical analyses.

3. Results

Fig. 1 shows the flow chart of all infants assessed. A total of 145 infants were eligible, of whom 43, with their parents, participated. Because one infant was diagnosed with cerebral palsy during follow-up, the data of 42 infants were used for analyses. Reasons for not participating were: no show at follow-up, parents not approached, not willing

Table 1
Infant and parent characteristics according to developmental profile: early developer, gradual developer, and late bloomer.

Infant characteristics		Total	Early developer (n = 10)	Gradual developer (n = 27)	Late bloomer (n = 5)
Sex	Male	21	5	13	3
	Female	21	5	14	2
Mean birthweight in grams (±SD)		1205 (±330)	1299 (±319)	1195 (±340)	1073 (±304)
Birthweight category	Extremely low (<1000 g)	11	1	8	2
	Very low (1000–1500 g)	25	6	16	3
	Low (1500–2500 g)	6	3	3	0
Mean gestational age in weeks (±SD)		29.1 (±2.1)	30.4 (±1.3)	28.8 (±2.5)	28.7 (±1.3)
Gestational age category	<28 wks GA	11	1	9	1
	28–30 wks GA	15	2	10	3
	≥30 wks GA	15	7	8	1
	>32 wks GA	1	–	1	–
Delivery	Vaginal delivery	20	4	14	2
	Caesarean section	21	6	12	3
	Not available	1	–	1	1
Five-minute Apgar score	<7	8	2	5	1
	≥7	32	8	20	4
	Not available	1	–	1	–
Age (CA) of independent walking (months)	Mean age	15	12	15	19
	(±SD)	(±2.8)	(±1.27)	(±1.47)	(±2.08)
	(Range)	(11–22)	(11–14)	(12–18)	(17–22)
Parent characteristics					
Maternal age (±SD)		31.9 (±4.0)	30.2 (±3.1)	32.2 (±4.5)	33.6 (±0.9)
Paternal age (±SD)		34.4 (±3.6)	34.6 (±2.5)	34.1 (±4.2)	35.2 (±1.6)
Age category (maternal/paternal)	25–29 years	11/3	3/0	8/3	0/0
	30–34 years	22/15	7/4	11/9	4/2
	35–39 years	5/14	0/4	4/7	1/3
	40–45 years	3/1	0/0	3/1	0/0
	Not available	1/9	–/2	1/7	–/–
Maternal/paternal education	No education	0/0	0	1/0	0/0
	Primary	1/0	0	0/0	0/0
	Secondary lower	0/3	0	0/3	0/0
	Secondary higher	5/9	1/2	4/7	0/0
	Tertiary	27/21	7/6	15/10	5/5
	Not available	9/9	2/2	7/7	–/–
Mother tongue	Dutch	34	7	22	5
	Other	7	3	4	0
	Not available	1	–	1	–

to participate, not speaking Dutch, or not reached after the first contact.

The mean BW was 1205 (±330) grams and infants were born with a mean GA of 29.1 (±2.1) weeks. Boys and girls were equally distributed. 27 infants were assessed at least five times, 12 two to four times and three once. In total, there were 208 assessments (mean times filmed = 4.9). Characteristics of infants and parents are displayed in Table 1.

There were no differences in the infant characteristics (sex, GA, BW, Apgar5, type of delivery) of the infants that dropped out or did not start the study.

3.1. *Trajectories of gross motor development*

Individual motor trajectories of the infants are presented in Fig. 2. All infants show unidirectional growth and a sigmoid-shaped curve. A great deal of variety in acceleration and deceleration is seen at different times, which implies intra- and interindividual variation in gross motor curves. The biggest difference score (AIMS raw score), the mean number of items scored per month, is seen between 5 and 9 months CA (mean diff/months = 4.4 items; range 0–12.5 items), visible in Fig. 2 where the biggest acceleration between 5 and 9 months CA is evident.

The first step in LMM was to fit the best model based on the AIC (AIC = 1208), which was a cubic polynomial (Appendix 1). The second step was backward selection of the infant and parental factors. There was a trend that the model with the best fit (AIC = 1020) included the factors BW ($\beta_1 = -4.10$, $\beta_2 = 0$ 0.004; $p = 0.031$), Apgar5 ($\beta = -3.54$; $p = 0.033$) and parental mother tongue ($\beta = -3.16$; $p = 0.059$) (Table 2). This means that there is a trend that infants with lower BW, having a five-minute Apgar score <7 and having Dutch-speaking parents, are prone to lower AIMS scores. Leaving parental mother tongue out of the model, the factors BW and Apgar5 did not remain significant in the final model (AIC = 1021).

3.2. *Modeling Dutch preterm gross motor profiles*

Cluster analysis confirmed that it was possible to create three different profiles according to the dendrogram. Also, the two-step clustering revealed a good cluster quality when these three profiles were formed (see Appendix 2). K-means cluster analyses with three predefined clusters and excluding cases pairwise was necessary to assign each infant to a profile. In total, three infants, for whom only one or two measurements were available, were reassigned to another profile based on their age of reaching the milestone of independent walking. For the other seven infants with only one or two assessments, the age of independent walking was not available (n = 4) or the infant was correctly allocated in the class (n = 3). At all ages, the ANOVA showed significantly different AIMS raw scores ($p < 0.005$), except for 3 months CA ($p = 0.274$). At 3 months CA, the mean AIMS score for both early developers and late bloomers was 12 ($SD_{early\ developer} = \pm 2.7$; $SD_{late\ bloomer} = \pm 2.1$), for the gradual developers this was 11 (SD = ±2.0).

Table 2
Results of the Linear Mixed Model analysis of the model with the best fit.

	Estimate	SE	*p*	95 % Confidence Interval	
Intercept	5.67	4.07	0.792	−2.36	13.70
Age	1.77	1.28	0.169	−0.76	4.29
Age * Age	0.33	0.14	0.016	0.06	0.60
Age * Age * Age	−0.01	0.00	0.001	−0.02	−0.01
Parental mother tongue	−3.16	1.62	0.059	−6.45	0.124
Apgar5	−3.54	1.58	0.033	−6.77	−0.31
BW <1000	−4.10	2.16	0.031	−8.48	0.28
≥1000	0.00	2.02		−4.09	4.09

Footnote:
For parental mother tongue, 'not Dutch' is the reference group.
For five-minute Apgar score, ≥7 is the reference group.
For BW, ≥1000 g is the reference group.

3.2.1. *Preterm early developers (n = 10)*

For seven infants, the age of independent walking was known with a mean of 12 (±1.27) months CA (range 11–14). For the five infants with available assessments, all had a maximum score at the last assessment. Only one infant (out of four available assessments) had a score of 57 items, the other three already having the maximum AIMS score (58 items) at this age.

3.2.2. *Preterm gradual developers (n = 27)*

For twenty infants, the age of independent walking was known, with a mean age of independent walking 15 (±1.47) months CA (range 12–18). Eight infants (out of 14 available assessments) achieved a maximum AIMS score at 17 months CA.

3.2.3. *Preterm late bloomers (n = 5)*

For four infants, the age of independent walking was known, while, for one, it was known that he was not independently walking by his second birthday (20 months CA). The mean age of independent walking was 19 (±2.08) months CA (range 17–22), and none achieved all items on the assessment at 17 months CA.

Looking at the curves for the different profiles (Fig. 3), it is apparent that the early developers show a quadratic line, with a ceiling effect starting at 12 months CA. For the late bloomers and gradual developers, a more S-shaped curve (cubic line) is seen. Acceleration for the gradual developers starts at approximately 9 months CA and for the late

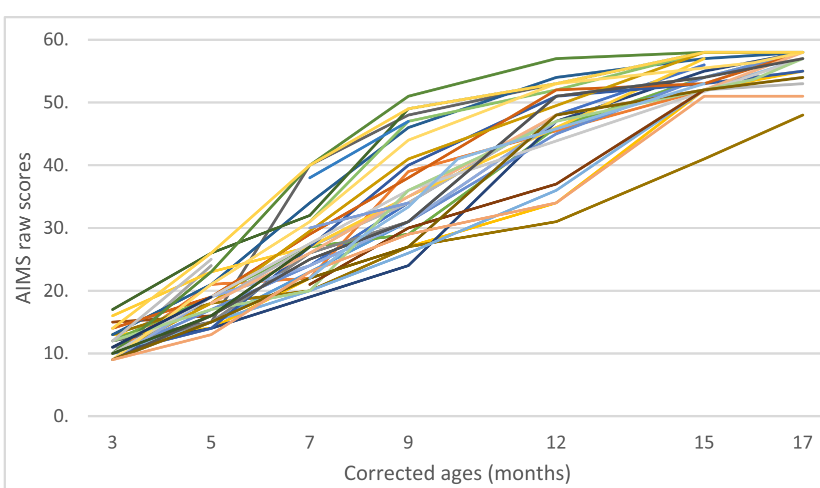

Fig. 2. Individual gross motor developmental trajectories from 3 to 17 months CA in raw AIMS scores.

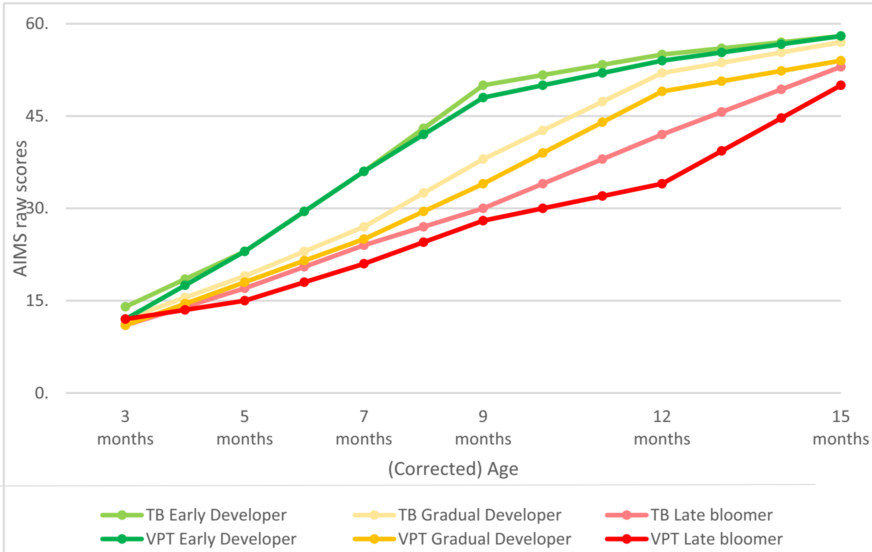

Fig. 3. Comparison of the three different gross motor curves, Early developer, Gradual developer, and Late bloomer, of the term-born (TB) infants and very preterm infants (VPT).

bloomers at 12 months CA. The ceiling effect, deceleration in the curve, for the gradual developers starts at 12 months CA and for the late bloomers at the age of 15 months CA. The developmental curves of the different developmental profiles showed a significant effect of time (AIC 1150; $p = 0.000$) when added to the baseline model (AIC = 1208), which means that the three profiles differ in the pace of gross motor development. According to the ANOVA, there are no significant differences between infant and parental characteristics in the different profiles, probably due to the small number of late bloomers. Therefore, only descriptive statistics for each profile are presented (Table 1).

3.3. Comparison between Dutch term-born and premature infant gross motor profiles

When combining data from the Dutch term-born (TB) and the premature infants (VPT) from this present study (Fig. 3), it is apparent that the shapes of the developmental curves are similar for all three profiles. There are some differences between the developmental pace of the profiles of TB gradual developers and late bloomers and VPT gradual developers and late bloomers. These differences become visible from 12 months CA onwards, where the interaction effect between group (TB or VPT) and profile (early developer, gradual developer or late bloomer) disappears. This implies that the differences in AIMS scores at different ages are explained by the effect of being preterm or term-born and being an early developer, a gradual developer, or a late bloomer. At 12 months (CA), there is a difference between the groups TB late bloomers and VPT late bloomers. There is also a difference in the profiles whereby the late bloomers differ from the early developers (mean difference$_{\text{early-late}} = -7.006$, $p = 0.001$) and the gradual developers (mean difference$_{\text{gradual-late}} = -4.663$, $p = 0.007$).

Scores at the 15 months (CA) assessment showed significant differences between the early developers and both the gradual developers and late bloomers (mean difference$_{\text{late-early}} = -3.870$, $p = 0.010$ and mean difference$_{\text{gradual-early}} = -2.694$, $p = 0.047$).

In Table 3, the comparison of the mean AIMS raw scores of the term-born and preterm infants according to the profiles is shown. In addition, these scores are compared to the Canadian norm references to show which infants are at risk (score below -1SD) or have a motor developmental delay (score </= 5th percentile). The VPT late bloomers show a delay in their gross motor development from the age of 5 months, and the TB late bloomers are at risk of delay from 5 months. Also, the VPT gradual developers are at risk of developmental delay from 5 months (CA). The early developers in both groups (TB/VPT) do not show any (risk of) delay in their gross motor development at any ages.

4. Discussion

This study explored the shape and speed of individual gross motor developmental curves from birth until 18 months CA in a sample of very premature ($\leq$32 wks GA and/or <1500 g BW) Dutch infants. Gross motor curves show unidirectional growth with a sigmoid shape, with interindividual variety. The biggest overall acceleration, as well as the largest variability between infants, was apparent between 5 and 9 months CA. In this sample, none of the infant or parental factors

Table 3
Comparison of the mean raw AIMS scores of the term-born and preterm infants, according to the profiles and the Canadian norms.

Age (CA)	Mean AIMS score (±SD)					
	TB Early developer	PT Early developer	TB Gradual developer	PT Gradual developer	TB Late bloomer	PT Late bloomer
3 months	14 (±2.1)	12 (±2.7)	12 (±1.6)	11 (±2.0)	11 (±1.5)	12 (±2.1)
5 months	23 (±2.8)	23 (±3.9)	19 (±2.8)	*18*[a] *(±2.6)*	*17*[a] *(±3.2)*	***15***[b] ***(±2.2)***
7 months	36 (±5.2)	36 (±4.0)	27 (±2.6)	*25*[a] *(±3.3)*	*24*[a] *(±2.9)*	***21***[b] ***(±1.3)***
9 months	50 (±5.6)	48 (±2.1)	*38*[a] *(±4.2)*	*34*[a] *(±4.5)*	***30***[b] ***(±2.6)***	***28***[b] ***(±1.6)***
12 months	55 (±2.4)	54 (±1.6)	52 (±2.0)	*49*[a] *(±2.3)*	***42***[b] ***(±5.3)***	***34***[b] ***(±2.3)***
15 months	58 (±0.8)	58 (±0.5)	***57***[b] ***(±1.7)***	***54***[b] ***(±2.1)***	***53***[b] ***(±2.9)***	***50***[b] ***(±4.8)***
17 months		58 (±0.0)		***57***[b] ***(±1.7)***		***53***[b] ***(±4.0)***

[a] *Score below −1SD according to the Canadian norm references.*
[b] ***Score below 5th percentile/−2SD according to the Canadian norm references.***

significantly influenced the shape and speed of motor development, with only a trend for the model with the factors BW, parental mother tongue, and five-minute Apgar score being seen. Cluster analysis distinguished three motor developmental profiles, namely early developers, gradual developers, and late bloomers. These profiles show significantly different developmental curves based on the total raw AIMS scores between 5 and 17 months CA. There were no significant differences between the developmental profiles regarding specific characteristics in these groups. Lastly, comparing the developmental profiles of our sample of VPT Dutch infants to those observed earlier in a sample of Dutch term-born infants, a similar shape of the curves was identified until 12 months CA. From 12 months CA onwards, the effect of being a premature infant is different for the gradual developers and for the late bloomers, where the preterm gradual developers and late bloomers appear to develop at a slower pace than the term-born infants, as seen in the delayed acceleration in the curves. For the early developers, there is no difference in the effect of being a term-born or preterm infant. Late bloomers were already showing a developmental delay (according to the Canadian norm references) from 5 months CA, whereas the early developers scored normal at all ages.

4.1. Shape of gross motor curves and factors of influence

Previous studies have reported similar findings concerning the course of gross motor development measured with the AIMS [6,10,38–40]. The acceleration in the curve was as expected since motor development in infancy is faster than at any other time during life [41]. Also, the large interindividual variability in the scores between 5 and 9 months is consistent with what is known about gross motor development as assessed with the AIMS. Furthermore, theories on infant development confirm the plausibility of typical infant development being characterized by variability [42,43].

Based on a previous systematic review of longitudinal studies [13], we explored the influence of several infant and parental factors on gross motor development. No factors of significant influence were found, which is probably due to the small sample size. The trend observed for the child factors BW and five-minute Apgar score to be associated with gross motor development is in line with previous findings. For example, BW is a well-researched factor with a profound and long-lasting influence on motor development, established in multiple longitudinal studies, with lower BW being associated with slower gross motor development [15,20,44]. In the present study, this was replicated in the model of best fit, which showed a lower BW to be associated with slower gross motor development. A five-minute Apgar score $\geq$7 indicates that the condition of the newborn is good to excellent and that the infant is adapting well to the environment [45,46]. A five-minute Apgar score $<$7 is associated with an increased risk of impaired neurodevelopmental outcomes, including motor [47]. A recent study examined the relationship between the five-minute Apgar score on the neurodevelopmental outcome of term-born infants from 8 to 66 months. Results showed that a five-minute Apgar score was inversely associated with neurodevelopmental delay [45]. This is in concordance with the results of our study, where, together with a lower BW and Dutch parental mother tongue, a lower five-minute Apgar score was associated with slower motor development.

Parental mother tongue in our study indicates parents who have a migration background, i.e., that at least one parent was born abroad (the first generation) or born in the Netherlands but whose parents were born abroad (second generation). These parents likely have different cultural backgrounds.

In several studies with the AIMS, cultural background appears to be a factor influencing motor developmental pace. In the Netherlands, infants' gross motor development seems to develop at a slower pace than Canadian and American infants measured with the AIMS [48,49] and Bayley Scales of Infant Development [50]. These cross-cultural differences in the pace of motor development are also observed in other populations [38,51,52]. Because of the small number of infants with non-Dutch native-speaking parent(s) included in our study, it is difficult to draw any conclusions but may explain why this factor approached significance (p = 0.059) in the model with BW and five-minute Apgar score.

Conflicting evidence exists in previous research regarding sex. Some studies reported differences between the development of (premature-born) boys and girls, with boys having more risk of developmental delay than girls [53]. In our study, no differences were found between boys and girls. This agrees with the study of Haastert et al. (2006) where 800 Dutch VPT infants at risk were measured with the AIMS. They reported that only at 7 to 8 months CA a difference was found between boys and girls, with girls scoring higher [38].

4.2. Profiles in gross motor curves

Comparing the results of our study with that of Su et al. in Taiwan where three profiles were also found, it is interesting to see that, at the ages of 9 and 12 months CA, the infants show similar mean AIMS raw scores (26). Since in our study infants with no or only minor complications (IVH I-II), but without BPD and severe brain damage as in the study of Su et al., were included, it would be expected that the Dutch infants would have performed better. However, their sample consists of Taiwanese infants, and previous research seems to show, as stated earlier, Dutch infants develop at a slower pace than in other cultures [48–50].

In our sample of VPT infants, with the same cultural context and methodology as that of the study of Dutch term-born infants by Boonzaaijer et al. [10], three motor developmental profiles were also identified, i.e., early developer, gradual developers, and late bloomers. The curves of these profiles appeared similar in shape to those of the term-born profiles. Surprisingly, the TB and VPT early developers also revealed significant similarities in the speed of their developmental curves. The VPT gradual developers and late bloomers show a decrease in gross motor developmental pace from 12 months CA compared with the TB gradual developers and late bloomers.

To our knowledge, there is little research available that confirms these specific results. The reasons may include that 1) the time frame of the measurements covers only the first year after birth, 2) larger age intervals are used between measurements, and 3) motor developmental analyses are performed on the entire sample, possibly resulting in higher average gross motor scores [7,16,25,26,38].

In a study by Wang et al. (2013) of Taiwanese VLBW infants, with and without PVL, compared to TB infants measured with the AIMS at 6, 12, and 18 months (CA), the former did not score significantly differently from the TB infants from 12 months onwards [54]. Although this study is not fully comparable to our study, it does provide information that there are VPT infants who develop similarly to TB infants.

In the study of Yaari et al. (2006), extremely preterm (n = 18), very preterm (n = 32), and moderately preterm (n = 53) infants were compared to full-term (n = 37) infants at multiple time-points, measured with the Mullen Scales of Early Learning (MSEL). They showed that the TB infants increased in their motor score from 4 months onwards, whereas the EPT and VPT infants showed a decrease in their motor score from 4 to 8 months, an increase from 8 to 12 months, and a decrease from 12 to 18 months again [55]. Despite the difference in measurement instrument, with the Mullen scale being a composite score of which gross motor development is only a part, the results seem to support our findings that the VPT gradual developers and late bloomers decrease in gross motor developmental pace after 12 months CA. A possible explanation for this reduction in gross motor developmental pace is that difficulties in motor performance become gradually evident during the first years of life when more complex abilities start to emerge [56].

4.3. Limitations and strengths

The sample size of the present study is small, making it hard to draw firm conclusions. Moreover, due to the sample size, some analyses could not be performed. Nonetheless, LMM allows all assessments to be included in the analysis which made it possible to investigate gross motor curves and the factors influencing them.

Another limitation might be that most parents were highly educated, making the results unrepresentative of the whole population of parents with preterm infants in the Netherlands. Research indicates that lower socioeconomic status of parents may have a negative influence on motor development of the infant [57–60]. This may imply that our sample has performed better than can be expected of the general population of VPT infants.

Also, the generalizability of the results to the VPT population is not possible, because of the exclusion of infants having severe complications such as BPD, NEC, etc. These infants probably have a less favorable gross motor development, so with our results, one should take that into account [61,62].

A strength of our study was that we gathered data at short age intervals during the first 18 months after birth. This made it possible to detect differences between VPT and TB infants at different ages which may help in decision-making and starting early interventions.

4.4. Clinical implications

Clinical decisions in neonatal follow-up are based on the information (concerns) parents provide, the results of standardized assessments, and the physician's observations [63], knowledge, and experience [64,65]. Altogether, neonatal follow-up not only aims to identify infants with severe gross motor impairments, like cerebral palsy but also to accurately identify infants with less severe gross motor impairments, who might likewise benefit from early intervention [63]. Distinguishing gross motor developmental profiles, combined with a knowledge of infant and parental factors, may help clinical decision-making about pediatric physiotherapy intervention.

4.5. Future research

For future research, it would be interesting to combine a larger data set of term-born infants with preterm-born infants to gain more insight into the range of possible gross motor developmental profiles. Perhaps more profiles will be distinguished, giving more direction for clinical decision-making and start interventions as early as possible. In addition, research should also focus on preterm infants who appear to develop at the same pace as term-born infants. For these early developers, less focus may be required for following their gross motor developmental domain, while still following them on other developmental domains. For the gross motor development follow-ups specific for these early developing infants, it may be a consideration to replace a 'live' assessment with a home-video consultation.

Gaining more insight into which factors explain the different profiles may also be of added value. To do so, we would recommend creating a larger and more representative sample, especially with regards to parental education and ethnicity, but also infants with more severe complications as is seen in clinical practice. We would also recommend considering research on VPT infants without complications at older ages, to gain a better understanding of infants with gross motor developmental problems and associated factors at preschool.

Lastly, with new and advanced technologies [66–68], it is perhaps possible to assess infants' development more frequently. This will give us even more detailed information about infant motor development and perhaps an indication of periods when motor development is subject to change.

5. Conclusion

This study contributes to insights into gross motor development of VPT infants (<32 weeks GA and/or weighing <1500 g) without severe perinatal complications, but still at risk in various other developmental domains. Distinguishing gross motor developmental profiles may contribute to clinical decision-making, shaping early interventions, and supporting realistic parental expectations. Future research should focus on clustering infants and possible explaining factors by assessing gross motor development more frequently.

CRediT authorship contribution statement

Imke Suir: Conceptualization, methodology, formal analysis, investigation, project administration, funding acquisition.
Marike Boonzaaijer: Conceptualization, methodology, investigation, writing.
Ora Oudgenoeg-Paz: Formal analysis.
Paul Westers: Formal analysis.
Linda de Vries: Resources, validation, writing – review & editing, supervision.
Janjaap van der Net: Resources, validation, writing – review & editing, supervision.
Jacqueline Nuysink: Conceptualization, methodology, writing – review & editing, supervision, funding acquisition.
Marian Jongmans: Writing – review & editing, supervision.

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Appendix A. Supplementary data

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