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Modeling a gross motor curve of typically developing Dutch infants from 3.5 to 15.5 months based on the Alberta Infant Motor Scale

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ABSTRACT

Background: Interindividual variability in gross motor development of infants is substantial and challenges the interpretation of motor assessments. Longitudinal research can provide insight into variability in individual gross motor trajectories.
Purpose: To model a gross motor growth curve of healthy term-born infants from 3.5 to 15.5 months with the Alberta Infant Motor Scale (AIMS) and to explore groups of infants with different patterns of development.
Methods: A prospective longitudinal study including six assessments with the AIMS. A Linear Mixed Model analysis (LMM) was applied to model motor growth, controlled for covariates. Cluster analysis was used to explore groups with different pathways. Growth curves for the subgroups were modelled and differences in the covariates between the groups were described and tested.
Results: In total, data of 103 infants was included in the LMM which showed that a cubic function ($F(1,571) = 89.68$, $p < 0.001$) fitted the data best. None of the covariates remained in the model. Cluster analysis delineated three clinically relevant groups: 1) Early developers (32%), 2) Gradual developers (46%), and 3) Late bloomers (22%).
Significant differences in covariates between the groups were found for birth order, maternal education and maternal employment.
Conclusion: The current study contributes to knowledge about gross motor trajectories of healthy term born infants. Cluster analysis identified three groups with different gross motor trajectories. The motor growth curve provides a starting point for future research on motor trajectories of infants at risk and can contribute to accurate screening.

1. Introduction

In the first two years of human life, gross motor development is the most important indicator of wellbeing and general development [1] and therefore of great importance for early developmental screening. While former theories like Gesell [2] and McGraw [3] assumed uniformity in terms that all infants achieve motor milestones in more or less the same sequence and pace, it has become increasingly clear that variability between and within infants are typical features of motor development in infancy [4,5].

Since the '90s, the dynamic systems theory (DST) provides a foundation for explaining variability in motor development by stating that continuous changes in an infant's body and environmental changes provide different opportunities for development [5]. In this light, numerous studies investigated the impact of child and environmental factors on gross motor development, such as birth weight and gestational age [6], birth order [7,8], caregiving practices [9], affordances in the home [10], maternal age and education [11], and the influence of

Abbreviations: AIMS, Albert Infant Motor Scale; PDMS, Peabody Developmental Motor Scales; IMP, Infant Motor Profile; ASQ-II, Ages and Stages Questionnaire, second edition; MSEL, Mullen Scales of Early Learning; PPT, pediatric physical therapist; LGM, Latent Growth Model; LMM, Linear Mixed Models; ICC, Intraclass Correlation Coefficient; CP, Cerebral Palsy.

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parents' mental wellbeing and beliefs [11,12]. The result of this complex interplay of genetic and environmental factors is that the gross motor development of a child is non-linear in nature. Therefore, to reliably chart motor development and capture the true shape of development, multiple time points have to be assessed and important factors known to be associated with gross motor development should be included in the analysis [5,13].

Few longitudinal studies have been conducted to investigate intra-individual variability in gross motor trajectories. Darrah and colleagues found that babies whose gross motor development was assessed from birth to independent gait showed great variability in their percentile rankings on the Alberta Infant Motor Scale (AIMS) [14]. In a study on 83 children from 9 months till 5.5 years, they reported that the percentile rankings of the Peabody Developmental Motor Scales (PDMS) were best represented by non-linear equations, even though the within-subjects variability decreased after infancy [15]. In a longitudinal study on term (n = 30) and preterm born infants (n = 59), motor performance and movement quality were assessed five times with the Infant Motor Profile (IMP) from 3 to 18 months. Heineman and colleagues found higher IMP scores and a smaller within-participant variability in the term group in comparison to the preterm group. A quadratic function of age was found to be the best fit for the data of the total group in a mixed-effects model [16].

In addition to intra-individual variability in gross motor development, variability between infants has also been observed. For example, the World Health Organization demonstrated a large spread in the time of motor milestone attainment in 816 infants from five countries [17]. The ages at which infants achieved the milestone 'sitting without support' varied from 3.8 months to 9.2 months. The age at which infants started to walk independently showed a range of more than 9 months, from 8.2 months to 17.6 months.

Other studies have tried to identify variation in different pathways in infant motor development. Eldred et al. reported four clusters of infants with similar trajectories of percentile rankings on the PDMS within a group of 66 infants aged 9 months to 5.5 years. The scoring patterns of percentile rankings over time were described as 'robust scores', 'decreasing scores', 'increasing scores', and 'low scores' [18]. Another study that applied latent class analysis on a cohort of 1254 infants, revealed a model with three classes of infants with similar gross motor pathways on the age-equivalent-normcores of the Ages and Stages Questionnaire (ASQ-II) from 4 to 24 months namely, the 1) 'high stable class', (80% of the infants), 2) the 'U-shaped class', and 3) the 'late bloomers' [19]. Nishimura and colleagues used latent class growth analysis in a birth cohort study (N = 952) and found five distinct trajectory patterns in the gross motor scale of the Mullens Scales of Early Learning (MSEL) on seven assessments between 1 and 24 months. The five classes were described as high normal, normal, low normal, delayed, and markedly delayed [20].

In summary, these longitudinal studies suggest that both intra-individual and inter-individual variability in gross motor trajectories are indeed characteristics of typically developing infants. Clinically, interpreting variability is a challenge for pediatric physical therapists (PPT) [18]. When motor development does not follow a stable pattern over time, early prediction of later development would not be reliable. Subsequently, this raises questions about the timing and frequency of developmental surveillance and early intervention [21].

Gross motor trajectories of healthy term-born infants have not yet been studied in the Netherlands. In previous Canadian research conducted by Darrah and colleagues, culturally specific percentile scores of the AIMS were used to examine intra-individual variability. Converting motor outcomes of Dutch infants into percentile scores based on cross-sectional Canadian norms seems not appropriate in the light of cross-cultural differences [22,23]. Besides, methodological research advocates the use of change scores to describe growth in motor outcome over time, rather than derived percentile scores intended to provide a normative evaluation of skills [24].

So, in contrast to previous research, this study aims to model a motor growth curve using the raw test scores of the AIMS in typically developing (Dutch) infants. This method is expected to shed new light on motor development by showing growth beyond the norm scores. The following control variables will be included in the analysis: birth weight, gestational age, birth order, maternal education, and maternal employment.

The growth curve can serve as a point of departure for future research on developmental trajectories of Dutch infants at risk for delays such as preterm born infants or infants with congenital heart diseases [25,26]. Furthermore, identifying different pathways of typically developing infants can support clinicians to estimate whether or not the observed motor behavior is within the normal range.

Therefore, the specific objectives of this study were:

- To model motor growth in a population of typically developing Dutch infants from 3.5 to 15.5 months using AIMS raw scores.
- To explore different patterns in gross motor trajectories within a population of typically developing infants from 3.5 to 15.5 months.

2. Participants and methods

2.1. Design and participants

This study had a prospective longitudinal design. Parents of healthy term-born infants were invited through open registration from May 2016 and April 2018 leading to a convenience sample. Recruitment took place by distributing flyers at birth centers, day-care centers, well-baby clinics, and maternity care offices in the larger cities of the Netherlands. Also, communication channels on social media were used to inform parents about the study. Infants born before 37 weeks of gestational age or diagnosed with pathology were not eligible to enter the study. Only parents with sufficient understanding of the Dutch language to read the informed consent and the instructions were included in the study. Either parents or legal representatives had to sign informed consent. Ethical approval for the study was obtained from the medical ethics committee of the University Medical Centre in Utrecht, the Netherlands (METC number 16/366C).

2.2. Procedure and measures

To collect data on parent and infant characteristics, online questionnaires were sent by email at the infants' ages of 3.5, 5.5, 15.5, and 18 months. Infant characteristics included gender, birth weight, gestational age, and birth order (1 = firstborn, 2 = second-born, 3 = third and fourth child). Furthermore, questions about perinatal events and treatment by a paramedical or medical specialist were also collected by parental reports.

Information about parents that was obtained included age, education, occupation, and native language. Parental age was reported in five categories: 20–24, 25–29, 30–34, 35–39, and 40–45 years. The highest level of parental education was reported in five categories: no education, primary, lower secondary, higher secondary, and tertiary education which is equivalent to a university degree. The occupation of parents was categorized according to a Standardized Classification of Professions in the Netherlands (SCB, 2010) into six categories (Table 1).

Gross motor development was assessed with the AIMS at 3.5, 5.5, 7.5, 9.5, 12.5, and 15.5 months. Internationally, the AIMS has been a preferred measure for over 30 years [25] and is considered reliable and valid with Intraclass Correlation Coefficients (ICC) of 0.992 and 0.987 for inter-and intra-rater reliability, respectively [28]. In terms of concurrent validity, ICC's were established of 0.98 with the Bayley Scales of Infant and Toddler Development [29], and 0.97 with the PDMS [28,30]. The AIMS consists of 58 items, divided into 4 subscales: prone (21 items), supine (9 items), sitting (12 items), and standing (16 items). To determine a total raw score, the infants' spontaneous movements have

Table 1
Demographic characteristics of infants and parents.

Infant characteristics		M (SD)	Range	N
Gender	Female	64 (61.5%)		103
	Male	39 (38.5%)		
Birth weight		3528.3 g (409.3)	[2780–4560 g]	103
Gestational age		39.9 weeks (1.3)	[37–42 weeks]	103
Birth order	1st	55 (52.9%)		
	2nd	38 (36.5%)		
	3rd	8 (8.7%)		
	4th	2 (1.9%)		103
Perinatal events according to parents[1]	No	85 (82.5%)		103
	Yes	18 (17.5%)		
(Para) medical treatment reported by parents at 3.5 months[2]		12 (11.5%)		103
(Para) medical treatment reported by parents at 15.5 months[3]		7 (7.7%)		90

Parent characteristics		Maternal	Paternal	N
Parental age	20–24 years	2 (1.9%)	1 (1%)	103
	25–29 years	16 (15.5%)	13 (12.6%)	
	30–34 years	53 (51.5%)	31 (30.1%)	
	35–39 years	24 (23.3%)	42 (40.8%)	
	40–45 years	8 (7.8%)	12 (11.7%)	
	Single parent (NA)		2 (1.9%)	
Parental education	No education	0 (0%)	2 (1.9%)	103
	Primary	0 (0%)	0 (0%)	
	Secondary lower	1 (1%)	1 (1%)	
	Secondary higher	13 (12.6%)	15 (14.4%)	
	Tertiary	89 (86.4%)	83 (79.7%)	
	Single parent (NA)		2 (1.9%)	
Parental professional classification	No profession	6 (5.8%)	2 (1.9%)	103
	Elementary	1 (1.0%)	1 (1.0%)	
	Lower	4 (3.9%)	4 (3.9%)	
	Secondary	15 (14.6%)	13 (12.6%)	
	Higher	54 (52.4%)	62 (60.2%)	
	Scientific	23 (22.3%)	21 (20.4%)	
Native language	Dutch	99 (96.1%)		103
	Other	4 (3.9%)		

[1] Perinatal events reported by parents were: delivery by vacuum pump, maternal blood loss during delivery, non-progressing birth, emergency Cesarean section, uterus rupture and releasing placenta, maternal high blood pressure, meconium in amniotic fluid.
[2] (Para) medical treatment at 3.5 months: suspect for congenital hip dysplasia (orthopedist), postural preference of the head (PPT or osteopath or chiropractor), crying (osteopath), brachycephalic (PPT).
[3] (Para) medical treatment at 15.5 months: motor delay (PPT), bowel complaints/cow's milk allergy (manual therapist), ear- and lung infections, diarrhea (mesologist), feeding problems, low weight (dietist).

to be observed in the four positions. The total score can be converted to a percentile rank and a *Z*-score. The norm population on which the references are based comprised of 2022 infants from Alberta, Canada observed in 1994 [31]. From a Canadian re-evaluation in 2014, the authors concluded that the norm references are still valid for the Canadian population [32]. Lately, in several countries, norm reference studies have been carried out to evaluate cultural validity [22,33,35]. Very recently, Dutch AIMS norm scores were reported based on video observations of 1697 infants [23].

To enable the collection of longitudinal data on motor development, the AIMS home-video method for parents was used [36]. Parents received instructions (see Appendix A) on how to position their baby and what movements to prompt. Parents were notified by email when they had to make a home video and upload it to a secured web portal. Parents were given a two-week window to make the video and reminders were sent once within the window. From the web portal, the videos were assessed with the AIMS by a trained PPT/researcher and parents received feedback on the development of their infant either by email or telephone. Four PPT/researchers, who performed the assessments, attended two training sessions of 3 h to ensure the reliability of scoring the AIMS assessments. The agreement between the two main observers was found to be 97.8% on the scored items of eight infants. Adjusting this outcome for chance with Cohen's Kappa, the agreement was 0.95, which is almost perfect [34]. During the study, difficulties in scoring were reviewed and discussed to ensure continuing consensus on item level.

The concurrent validity of the AIMS home-video method was established with a mean difference of 0.46 items between live- and video-observations and an excellent ICC agreement of 0.99. The Standard Error of the Measurement was calculated to be 1.48 items and the smallest detectable change was 3.88 items [36]. Parents' experiences with the longitudinal use of the home-video method were evaluated and found to be both feasible and acceptable [37].

2.3. Statistical analysis

First, data were explored visually and descriptive statistics were applied. Initially, Latent Growth Modeling (LGM) was used to model motor growth. However, these models did not adequately fit the data (Appendix B). A Linear Mixed Model analysis (LMM) was considered to be a good alternative because it considers the dependence of repeated measures within one infant and allows for a variable number of observations [39]. When modeling growth in a multilevel model, both variability within and between subjects is taken into account. To determine the overall shape of developmental change, linear, quadratic, and cubic functions were fit according to the strategy suggested by Singer and Willet [39]. The intercept and slope were allowed to vary across individuals. To select the best model, the Likelihood Ratio Test was used [40]. The most parsimonious model was controlled for the infant factors: birth weight, gestational age, and birth order as well as for the maternal factors: age, education, and employment status. To do so, a backward selection of variables was used with a $p < 0.05$ as selection criteria to control for their effect on the shape of the curve. For these variables, fixed effects were assumed [38].

After visual inspection of the individual motor trajectories, a hierarchical cluster analysis was applied to identify different groups of infants showing similar patterns in gross motor development, based on the AIMS raw motor scores at 3.5, 5.5, 7.5, 9.5, 12.5, and 15.5 months. To group infants with similar trajectories, the between-groups linkage method was applied with a Euclidean distance measure [41]. The optimal number of clusters was determined by a dendrogram and an agglomeration schedule. Subsequently, a K-means cluster analysis was computed to fine-tune the clusters. The characteristics of the groups were described and one-way ANOVA's and Kruskal-Wallis tests with post hoc analysis were applied to indicate differences in continuous and categorical variables between the groups. Finally, LMM was applied to model growth curves of the developmental clusters including their interaction with time. Statistical analyses were performed with IBM SPSS Statistics for Windows, Version 25.0.

3. Results

In total, trajectories of 103 infants were included in the analysis. Of these, 18 infants missed one assessment, ten infants missed two assessments and two infants missed three assessments of the six assessments in total. Since the primary reason for the missing assessments concerned holidays, moving to a new house, or the busyness of parents, the missing data were considered random. Over time, there was a slight increase in missing data, which is common in longitudinal studies. The maximal attrition rate of 14.6% at 15.5 months was within acceptable limits [42]. Because LMM allows for the inclusion of subjects with missing data [38], only infants with <3 assessments available (n = 12) were excluded because fitting a higher-order function would not be possible on only two time points. The characteristics of infants and parents are displayed in Table 1.

3.1.1. Individual trajectories of gross motor development

The mean total raw scores on the AIMS are displayed in Table 4 (Appendix) and the individual trajectories in Fig. 1. Unidirectional growth is visible for all infants in a sigmoid-shaped curve and accelerations and decelerations at different times in the individual growth curves. At 3.5 months, the standard deviation of the raw AIMS scores is lower compared to the assessments that follow. A ceiling effect of the test is present at 15.5 months because 51 of 88 infants had reached the total score of 58 items. At 12.5 months, 10 of 91 infants had reached the total test score. Between 7.5 and 9.5 months the mean change score was the largest, amounting to 11.2 items (5.6 items/month), indicating that most infants accelerate in their motor growth between these time points. If the total AIMS scores of this sample are compared to both the Canadian norms [28] and the recently introduced Dutch AIMS norms [23] on a P5 cut-off point, it appears that none of the participating infants scored below the 5th percentile at any time point on the new Dutch AIMS norms. If we look at the Canadian norms, a different picture emerges. At each time point, except for 3.5 months, there is a considerable number of infants scoring below the P5: 11% at 5.5 months, 6% at 7.5 months 24% at 9.5 months, 20% at 12.5 months, and 42% at 15.5 months.

3.1.2. Modeling a gross motor growth curve of infants aged 3.5 to 15.5 months

A nonlinear function, a cubic polynomial, yielded the best fit for the overall data (F (1,571) = 89.68, $p < 0.001$). The curve represents the average scores predicted by the model and is characterized by an initial slow growth in AIMS scores followed by an overall acceleration till 12.5 months with a subsequent deceleration from 12.5 months to 15.5 months (see Fig. 2). Using a backward selection ($p < 0.05$) the covariates were added to the model. None of the covariates remained in the final model even though the overall effect of birth order showed a trend (F (2,104.83) = 2.35, $p = 0.10$) with a marginally significant difference between firstborn infants and infants that are third or fourth in birth order ($\beta = 2.33$, SD = 1.28, $p = 0.07$).

3.1.3. Patterns of gross motor trajectories

Cluster analysis delineated three groups, and visual inspection confirmed that these clusters were clinically relevant. The K-means cluster analysis needed seven iterations to converge. The three clusters were labeled as follows:

1. Late bloomers (n = 23) (22.3%) who mostly do not start accelerating in motor growth before 9.5 months and although a lot of catching up growth can be observed in this group, about 90% of the infants did not achieve all items on the test at 15.5 months.
2. Gradual developers (n = 47) (45.6%), with a more even motor growth. Most children in this group achieve all items before 15.5 months.
3. Early developers (n = 33) (32%), who show rapid motor growth before the age of 9.5 months and have achieved all items of the AIMS well before 15.5 months and in some cases before 12.5 months.

3.1.4. Modeling growth curves on developmental groups

The individual growth curves of the Late bloomers (n = 23), Gradual developers (n = 47), and Early developers (n = 33) showed a significant effect of time when the clusters were added to the baseline model (Fig. 3). Significant interactions between time and groups showed that each group follows a unique line and that the slopes are not parallel. The Early developers have higher change scores at the beginning of the curve. At the end of the curve, their change scores diminish due to the ceiling effect of the test. The Late bloomers' change scores are smaller at the beginning with an evident increase towards the end of the curve. The Gradual developers progress in an almost linear manner.

A significant interaction was present between the Early developers and Late bloomers at the end of the curve. The individual variance within the groups was found to be 2.78 items on the 58-item scale of the AIMS ($\sqrt{\text{residuals}}$). The estimates of the cubic growth over time of the groups as well as the total group are provided in Table 2.

The differences in birth weight, gestational age, birth order, maternal education, and maternal employment in the three developmental groups are shown in Table 3. Significant differences between the

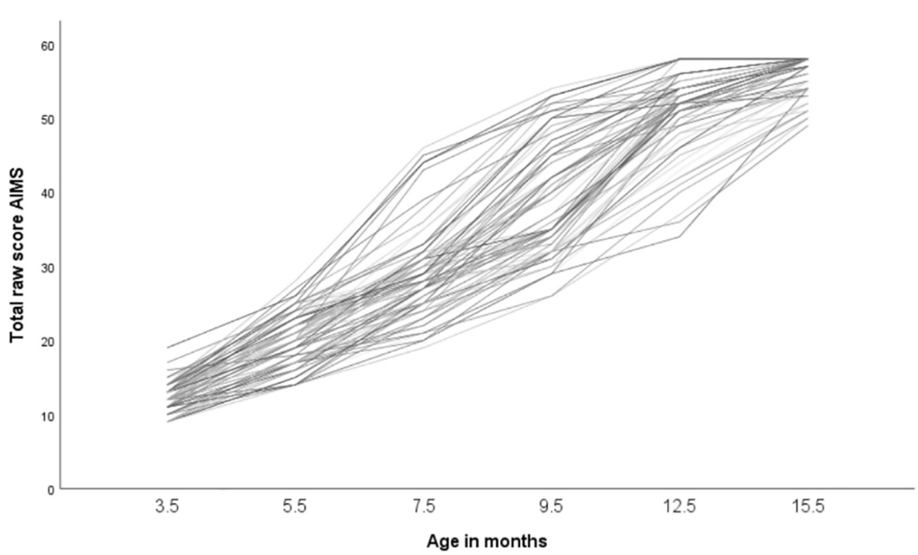

Fig. 1. Individual trajectories 3.5–15.5 months in raw AIMS scores [0–58] (N = 103).

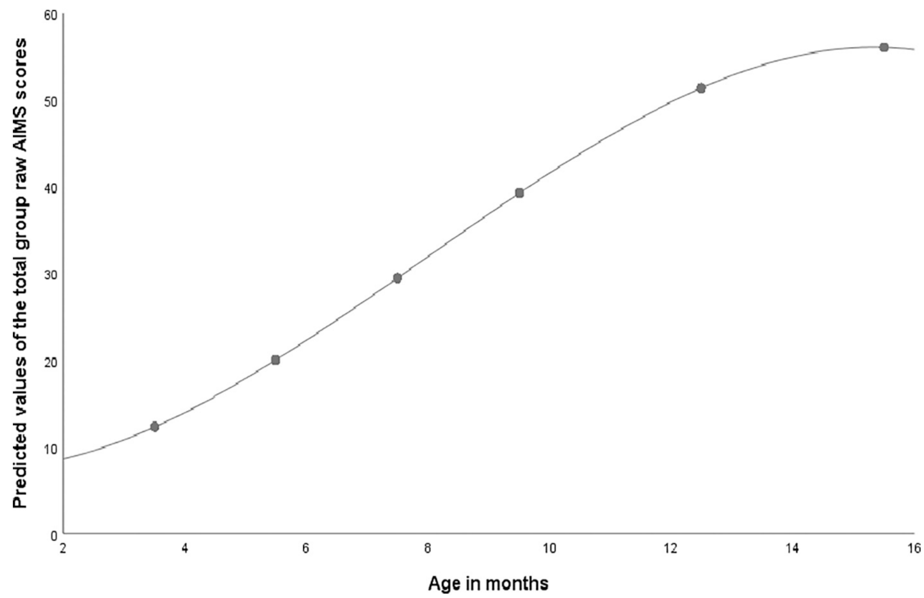

Fig. 2. Growth curve of gross motor development 3.5–15.5 months (N = 103).

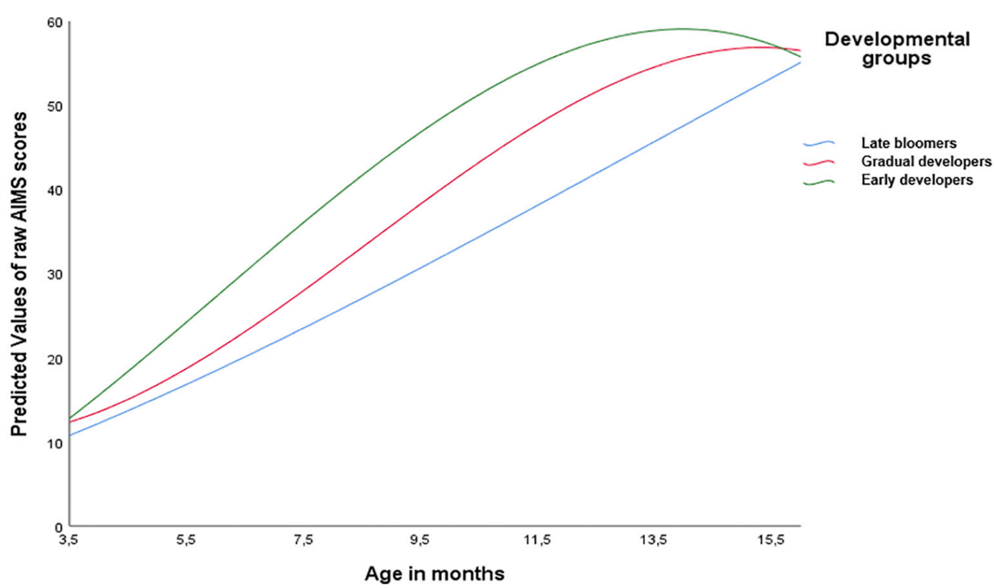

Fig. 3. Growth curve of gross motor development of Late bloomers, Gradual developers and Early developers 3.5–15.5 months (N = 103).

groups were found for birth order, maternal education, and maternal employment. Late bloomers showed a significantly higher mean birth order compared to Gradual developers. Mothers of Early developers had significantly lower education than mothers of Gradual developers. The maternal employment classification of the Gradual developers was significantly higher compared to the Late bloomers (Table 3). The mean scores on the AIMS assessments significantly differed between the groups at each time point. This was also the case for the motor milestones achievement of sitting without support, crawling, and independent walking (see Appendix Table 4).

4. Discussion

This study aimed to model a motor growth curve of healthy term-born Dutch infants from 3.5 to 15.5 months on the AIMS and to examine patterns in inter-individual motor growth. The trajectories showed unidirectional growth in motor scores with individually-timed accelerations and decelerations. A growth curve with a cubic function was the best fit for the longitudinal data of 103 infants. No significant effects were found for the control variables. Three groups with distinct gross motor patterns were identified: 1) Early developers, 2) Gradual developers, and 3) Late bloomers. Significant interaction with time was found. Testing background variables between the groups, significant differences for maternal education, maternal employment, and birth order were found.

4.1. To model a gross motor curve

The main objective of this study was to model a gross motor curve for Dutch infants based on the AIMS. Initially, LGM was applied because this technique includes intra-individual correlation and can analyze the effect of a predictor variable on the developmental trajectory of individuals. LGM revealed that neither linear, cubic nor quadratic, or sigmoidal growth functions adequately fitted the data (see Appendix B)

Table 2
Growth curve outcomes for three developmental groups.

	Estimate	*SE*	*p*	*95% CI*	
Intercept	12.78	0.57	0.000*	11.66	13.89
Time	5.37	0.41	0.000*	4.57	6.17
$Time^2$	0.24	0.08	0.005*	0.07	0.40
$Time^3$	−0.03	0.00	0.000*	−0.04	−0.02
Groups					
Late	−2.04	0.85	0.016*	−3.70	−0.37
Gradual	−0.45	0.71	0.527	−1.85	0.95
Groups × Time					
Late	−2.52	0.62	0.000*	−3.74	−1.30
Gradual	−3.22	0.52	0.000*	−4.23	−2.20
Groups × $Time^2$					
Late	−0.14	0.13	0.284	−0.40	0.12
Gradual	0.35	0.11	0.001*	0.14	0.57
Groups × $Time^3$					
Late	0.03	0.01	0.000*	0.01	0.04
Gradual	−0.01	0.00	0.232	−0.02	0.01
Residuals	7.47	0.49	0.000*	6.56	8.50
Intercept variance	0.43	0.44	0.323	0.06	3.16

Legend: SE = standard error; p = significance; CI = confidential interval.
Footnote: 'Early developers' is the reference group.
* $p < 0.05$.

probably because of the small sample size and a lack of variance at the beginning and the end of the trajectories. Even though LMM estimates covariates effects more straightforwardly than LGM does, LMM proved to be a good alternative because of the possibility to include cases with missing data [43].

In a study by Rosenbaum and colleagues, motor growth curves were created for children with Cerebral Palsy (CP) based on the Gross Motor Function Measurement using LMM. Five distinct curves were found, based on 2632 assessments of 657 children with CP. Rosenbaum et al. concluded that the motor growth curves provided means for prognosis and planning interventions for clinicians [44]. In our study, the motor growth curve is based on 571 assessments of 103 infants. Even though the motor growth curve has prognostic value because of the longitudinal nature of the data, a larger sample size including infants at risk would be needed to create a more robust growth curve of gross motor development for Dutch infants including cut-off points.

In the LMM analysis, no main effect of the covariate birth order on motor development was found although a trend was revealed ($p = 0.10$), and a post hoc test showed that the difference between the motor development of firstborn infants and infants with a birth rank of >2 just did not reach significance ($p = 0.07$). Testing differences between the three developmental groups, the mean birth order of the Late Bloomers was significantly higher ($M = 1.91$, SD = 0.67) in comparison to the mean birth order of the Gradual developers ($M = 1.47$, SD = 0.69). Both these findings imply that in a larger sample, the variable birth order may very well show a significant effect on the shape of the gross motor curve.

The finding that infants with a higher birth order were less advanced in their motor development compared to infants that were lower in birth order is in agreement with findings from earlier studies [7,8,10]. According to the prevailing theoretical concept, the explanation for the delay is that with the presence of siblings, parents' resources are more limited [8]. Parents have to divide their time and attention between the siblings, which can result in a less stimulating environment and therefore causing a more delayed motor development for the youngest sibling. In contrast, the competing imitation theory expects a positive influence of the presence of older siblings caused by the enriched environment the older sibling provides in the opportunities of imitation of behavior and play. However, there is no evidence yet that confirms that infants engage in new motor repertoire based on imitation [8]. Berger and Nuzzo found evidence that the impact of older siblings on gross motor development could be both negative and positive, and might depend on unique family characteristics like the age differences between the siblings and the parental expectations regarding motor development [8]. Based on the results of this study and the above-described evidence from previous cross-sectional studies, the role of birth order in gross motor development deserves more attention in future research.

In the present study, motor development was not predicted by any of the child factors or environmental factors. This might be explained by the homogeneous composition of the sample that consisted solely of term-born infants and parents who were generally higher educated. A large body of longitudinal research into the motor development of prematurely born infants, shows that child factors such as low birth weight and a short gestation period have a major and long-term negative impact on motor development [6,24,26]. This in contrast to the impact of environmental factors on motor development, which is not so evident and seems to be more transient [9,10,45]. Perhaps the less pronounced impact of environmental factors only becomes apparent when high-impact factors of the child are absent, as is the case in the present study with only term-born infants. This assumption is in line with the study of Roze and colleagues, who found that the development of healthy term-born children appeared to be more susceptible to variations in environmental factors such as maternal social economic status than factors within the child [46].

Table 3
Differences in gender, birth weight, gestational age, birth order, maternal education and employment in the three developmental groups.

	Total group		Developmental groups and comparisons between groups			
	Mean (SD) or number (%)	N	Late bloomers N = 23 Mean (SD)	Gradual developers N = 47 Mean (SD)	Early developers N = 33 Mean (SD)	Overall *p*-value
Gender (% female)	61.5%	103	62.5%	66%	54.4%	0.653
BW (g)	3528.28 (409.28)	103	3558.17 (404.96)	3508.68 (389.01)	3534.46 (444.14)	0.886
GA (weeks)	39.86 (1.25)	103	39.92 (1.06)	39.77 (1.34)	39.97 (1.26)	0.755
Birth order (1–4)	1.58 (0.68)	103	1.91[a] (0.67)	1.47[a] (0.69)	1.50 (0.62)	0.016*
Maternal age (1–5)	3.14 (0.83)	103	3.22 (0.90)	3.19 (0.80)	3.03 (0.83)	0.576
Maternal education (1–5)	3.85 (0.38)	103	3.82 (0.40)	3.98[a] (0.15)	3.71[a] (0.52)	0.005*
Maternal employment (0–5)	3.74 (1.22)	103	3.35[a] (1.30)	3.98[a] (1.19)	3.67 (1.19)	0.027*

[abc]Significant difference between groups with the same letter.
* Significant differences in post hoc analysis ($p < 0.05$).

4.2. Explore different patterns in gross motor trajectories

The second aim of this research was to explore different patterns in gross motor trajectories. Cluster analysis provided a means to confirm the presence of groups in the sample. Several studies analyzing developmental data of infants also reported the opportunities of this analysis to identify infants at risk that would benefit from early intervention [18,47].

As in previous studies in which three [19], four [18], or five [20] different groups of motor trajectories were identified, three groups were identified in the present study. However, because the measuring instruments and the statistical techniques to identify groups of developmental trajectories are quite different, the findings of the studies are difficult to compare with the findings of the current study. Valla et al. and Nishimura et al. both used Latent Class Analysis in large cohort-based populations [19,20] on outcomes on the gross motor domains of the ASQ-II and the MSEL, respectively. Despite these differences and the description of five classes, the classes that Nishimura et al. identified in the normal range (high normal, normal, and low normal) are comparable to the three classes that were found in the current study. The cohort-based inclusion of infants at risk explains the presence of the extra two groups in the study of Nishimura et al. that are not present in this study: delayed and markedly delayed [20].

Even though Valla and colleagues also identified three groups in their sample that included infants at risk, the use of the ASQ-II makes the results hard to compare. The ASQ-II is a parent-completed developmental screening instrument that evaluates gross motor development on six age-specific items. Although the ASQ-II is a useful diagnostic tool to observe developmental delay, it does not assess gross motor behavior in a direct and more specific manner as the AIMS does. Eldred et al. applied a cluster analysis on the percentile scores of the PDMS and reported the identification of four distinct groups [18]. Even though the analysis to identify groups and the population were quite similar to the present study, the use of the percentile scores, especially the increase and decrease of percentile scores, make a comparison of the outcomes difficult.

The identification of the Late bloomers is also relevant for clinical practice. This group, which made up more than 20% of the total sample, is very likely to be seen in practice because of the delayed pathway they follow. From 9.5 to 15.5 months, between 70% and 85% of the Late bloomers scored at least once below −1.65 SD on the Canadian AIMS norms [31].

Despite this slower start, most Late bloomers caught up in their motor growth and started walking at a mean age of 16 months.

When we applied the new Dutch AIMS norms, none of the Late bloomers scored below the P5. This finding is notable and could be partly explained by the inclusion of about 7% prematurely born infants in the Dutch norm sample while our sample consisted only of healthy term-born infants. Besides this, the new Dutch AIMS norms are considerably lower than the Canadian norms [23]. Despite the very recent introduction of the new Dutch AIMS norms, the Canadian norms values are still much applied in Dutch clinical practice. Therefore, we think it is important to inform PPT's, pediatricians, and parents, that most of these Late bloomers, despite their poorer progress in the first 9.5 months, catch up in motor development and probably do not need intervention.

Future longitudinal research should also include infants at risk for a motor delay to confirm the presence of the three groups of typically developing infants that were identified in this sample. In addition, this longitudinal study showed once more that results from one single assessment should be interpreted with caution and that clinical reasoning should also include the parents' request for help and a qualitative motor observation [48].

4.3. Strengths and limitations

The longitudinal design from 3.5 to 15.5 months with six assessments on gross motor behavior, adds to the strength of this study. As the attrition remained within acceptable limits, this study also confirms that collecting data longitudinally using home videos made by parents is feasible. The AIMS home-video method provided observations of infant motor behavior that were ecologically valid and with a low burden for both infants and parents [37]. The videos of the assessments enabled deliberation on difficult items between researchers, which increased the reliability of the motor assessment scores. Because time-scheduled home visits were not necessary, investment in time and costs were low.

There were also some limitations to the use of the AIMS in this study. Firstly, at the age of 12.5 months, the distribution of the AIMS raw scores was skewed due to the ceiling effect of the test. This skewness increased at 15.5 months when the majority of infants had reached the end of the test which decreased the discriminative value of the outcomes. With most items located roughly between the ages of five to twelve months, it was confirmed that the AIMS is less sensitive at the beginning and the end of the test [27,28]. Subsequently, the shape of the individual trajectories is partly the product of the distribution of items in the four subscales of the AIMS. Therefore, it is important to keep in mind that these motor trajectories are based on the AIMS measurement tool specifically.

Modeling growth curves for Late bloomers, the Gradual developers, and the Early developers was challenging due to the smaller sample size of each group. The significant interaction between Early developers and Late bloomers is more the product of the chosen model, a cubic polynomial, than a reflection of reality. At 15.5 months, the group of Early developers is too small to pull the cubic function into the straight line that represents the ceiling effect of the test. Despite this, the chosen model was the best approximation of reality.

The generalizability of the outcomes beyond the study sample should be carefully considered due to the small size and an overrepresentation of parents with advanced education. Even though the evidence is inconclusive [49], several studies do report maternal education as a factor that is associated with gross motor development [11,45,50].

4.4. Implications for future research

Further longitudinal research is required with both healthy infants and infants at risk for delay. Digital innovations should be applied to increase the feasibility of data collection to enable researchers to follow large representative samples in and outside Western society. Research questions should be twofold: 1) to contribute to a deeper understanding of factors that are associated with gross motor development in typically developing infants to develop effective interventions, and 2) to model growth curves that are both culturally- and illness-specific to guide professionals in the field.

5. Conclusion

LMM proved to be a useful statistical technique to model gross motor curves of AIMS scores. Applying cluster analysis, three groups with different gross motor trajectories were identified in the data: Early developers, Gradual developers, and Late bloomers. The distinction of these groups within a sample of typically developing infants is clinically relevant because this underlines the presence of variation in gross motor development within the normal range. Furthermore, this study shows that modeling gross motor growth curves is an interesting point of departure for follow-up studies in populations of infants at risk for delay. The development of illness-specific gross motor profiles will improve clinical decision-making for PPT's and pediatricians. It will also support parents to build adequate expectations of their baby's development.

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CRediT authorship contribution statement

Marike Boonzaaijer: Conceptualization, Methodology, Investigation, Formal analysis, Data curation, Writing – original draft, Writing – review & editing, Validation. **Ora Oudgenoeg-Paz:** Methodology, Formal analysis, Writing – original draft. **Imke Suir:** Conceptualization, Methodology, Investigation, Writing – original draft. **Paul Westers:** Methodology, Formal analysis, Writing – original draft. **Jacqueline Nuysink:** Conceptualization, Methodology, Investigation, Formal analysis, Writing – original draft, Writing – review & editing, Validation. **Michiel Volman:** Conceptualization, Methodology, Investigation, Formal analysis, Writing – original draft, Writing – review & editing, Validation. **Marian Jongmans:** Conceptualization, Methodology, Investigation, Formal analysis, Data curation, Writing – original draft, Writing – review & editing, Validation.

Declaration of competing interest

None declared.

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