

# Toddler motor performance and intelligence at school age in preterm born children

**Citation for published version (APA):**

Vermeulen, K., van Beek, P. E., van der Horst, I. E., Pop, V. J. M., van Dam, M., Vugs, B., & Andriessen, P. (2022). Toddler motor performance and intelligence at school age in preterm born children: A longitudinal cohort study. *Early Human Development*, 166, Article 105549. <https://doi.org/10.1016/j.earlhumdev.2022.105549>

**Document license:**

TAVERNE

**DOI:**

[10.1016/j.earlhumdev.2022.105549](https://doi.org/10.1016/j.earlhumdev.2022.105549)

**Document status and date:**

Published: 01/03/2022

**Document Version:**

Publisher's PDF, also known as Version of Record (includes final page, issue and volume numbers)

**Please check the document version of this publication:**

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## Toddler motor performance and intelligence at school age in preterm born children: A longitudinal cohort study

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### ARTICLE INFO

#### Keywords:

Intelligence  
Motor performance  
Prematurity  
Performance IQ  
Longitudinal

### ABSTRACT

**Background:** Current knowledge regarding differences in verbal intelligence scores (VIQ) and performance intelligence scores (PIQ) in preterm born children is limited. As early motor performance may be essential for developing later visual-perceptual and visual-motor skills, early motor performance may be associated with PIQ. **Aims:** To evaluate whether in preterm born children motor performance at two years was associated with PIQ at eight years.

**Methods:** Single-centre cohort study including 88 children born <30 weeks' gestation between 2007 and 2011, who completed the Bayley Scales of Infant and Toddler Development-III (BSID-III) at two years and the Wechsler Intelligence Scale for Children-III-NL (WISC-III-NL) at eight years. Outcome measurements (mean (SD)) were gross and fine motor performance based on the BSID-III, and PIQ and VIQ based on the WISC-III-NL. Linear regression analysis was performed to evaluate the association between motor performance at two years and PIQ at eight years.

**Results:** At two years, mean BSID-III gross motor scaled score was 9.0 (SD 3.0) and fine motor score was 11.5 (SD 2.3). At eight years, mean PIQ was 94.9 (SD 13.5) and mean VIQ 101.8 (SD 13.7). A one-point increase in fine motor scaled score was associated with 1.7 points (95% CI 0.5–2.8) increase in PIQ. Gross motor scaled score was not associated with PIQ.

**Conclusions:** Fine motor performance in toddlerhood was related to PIQ at school age, with lower scores indicating a lower PIQ. Early assessment of fine motor performance may be beneficial in identifying children at risk for lower performance intelligence.

### 1. Introduction

In the past decennia, changes in health care have significantly decreased mortality and morbidity rates in preterm born infants (1–4). However, preterm birth is still associated with a higher risk of adverse outcomes in later life than at term birth (5–8). The risk of having adverse outcomes following preterm birth seems to increase as gestational age (GA) declines (9). Adverse outcomes include physical disabilities as well as a diversity of (long-term) developmental problems such as learning disabilities, neuropsychological and behavioral problems, and lower IQ

scores (5,6,10). Two meta-analyses have shown that both extremely (<28 weeks' GA) and very preterm (28–32 weeks' GA) children have lower cognitive scores on executive functioning, processing speed, and intelligence compared to children born at term during childhood and adolescence (6,7).

Intelligence is commonly divided into two subscales, i.e. verbal intelligence score (VIQ) and performance intelligence score (PIQ) which combine together into a full-scale intelligence score (FSIQ) (11). The verbal intelligence score (VIQ) is a measure of acquired knowledge, verbal reasoning, and attention to verbal materials (12). The

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<https://doi.org/10.1016/j.earlhumdev.2022.105549>

Received 10 November 2021; Received in revised form 15 January 2022; Accepted 24 January 2022

Available online 1 February 2022

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performance intelligence score (PIQ) is a measure of a child's visual spatial intellectual abilities including fluid reasoning, spatial processing, attentiveness to details and visual-motor integration of information (12). Observations from different studies show lower FSIQ in preterm born children (6–8,13,14). Although several studies analysed VIQ and PIQ, research addressing the different intelligence subscales in preterm born children in more detail is still limited. Previous studies indicate that PIQ is lower than VIQ at eight years (15,16).

Low PIQ has been postulated to indicate deficits in visual-motor integration and body movement coordination (17–20). In extremely preterm born children without cerebral palsy, reduced volumes of cortical areas known to be involved in visual-motor integration are observed and this resulted in lower fine motor skills and lower visual-motor integration performance at school age (21). Thus, preterm born children may show deficits in fine motor performance and PIQ. Higher PIQ may result in better motor performance, because the visual perceptual and visual-motor skills embedded in performance intelligence are needed to execute motor tasks (19). On the other hand, early motor performance is important for developing visual-motor integration skills (20). Early assessment of motor performance could be beneficial in identifying preterm children at risk for lower PIQ.

From the hypothesis that early motor performance is essential for later visual-perceptual and visual-motor skills, the aim of this study was to evaluate if motor performance at the age of two was associated with PIQ at the age of eight. Additionally, the difference between PIQ and VIQ in preterm born children at eight years was analysed.

## 2. Methods

### 2.1. Patient population

All children born between July 2007 and May 2011 with a GA below 30 weeks, who were admitted to the neonatal intensive care unit (NICU) of Máxima Medical Centre (MMC, Veldhoven, The Netherlands) and had complete follow-up assessments (see section on follow-up program) at two and eight years of age were eligible for the current study. The NICU of MMC serves a 1.6 million population including antenatal and postnatal transfer from six other hospitals in the region. Children from parents living outside the adherence area of MMC, referrals from other NICUs and children with congenital malformations were excluded. The ethical review board gave approval for the study and waived informed parental consent for participation in this study.

### 2.2. Data collection

Neonatal data were collected from the medical records and included the following patient characteristics: gender; birthweight; GA (days); small-for-gestational age (SGA, defined as birthweight below the 10th percentile (22)); multiplicity (single or multiple birth); parity (primipara or multipara); mode of delivery (vaginal or caesarean section); Apgar score at 5 min postpartum; intubation and artificial ventilation duration >12 h; severe brain injury (defined as intraventricular hemorrhage grade 3 or 4 or cystic periventricular leucomalacia grade 3) (23,24) and total days of NICU admission. Information on maternal education was collected by the psychologist and categorised into three levels (low, middle or high) according to the CBS classification (25). Socioeconomic status was determined using status scores available from the Sociaal en Cultureel Planbureau (SCP) in the Netherlands which are based on education level, employment rate and income in a postal area (26). Status scores have a mean of 0 and a standard deviation (SD) of 1. Scores higher than 1 reflect a higher than average status and scores below 0 a lower than average status.

### 2.3. Follow-up program

Data from the outpatient clinic visits were collected prospectively.

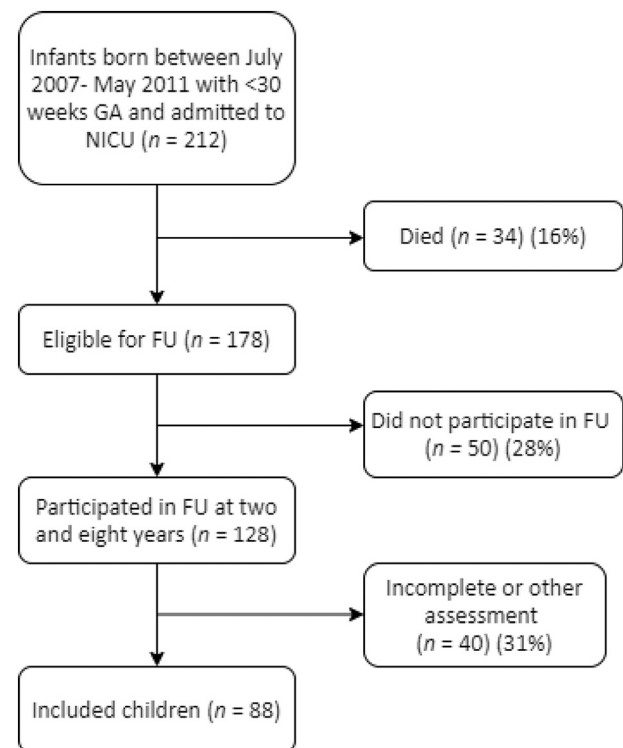


Fig. 1. Inclusion of participants.

The follow-up program included outpatient clinic visits at the corrected age of two and uncorrected age of eight years. The visits included assessments by a trained team consisting of a paediatrician/neonatologist, psychologist and paediatric physiotherapist, and comprised medical history taking, a physical and neurological examination and assessment of mental and psychomotor development with the Bayley Scales of Infant and Toddler Development III (BSID-III) and Wechsler Intelligence Scale for Children-III (WISC-III-NL). The psychologists and paediatric physiotherapists are trained in assessing their scales of the BSID-III and WISC-III-NL. The neonatologist and paediatric physiotherapist evaluated the neurological function. Neurological impairment included cerebral palsy (CP) and non-CP related motor impairments (delayed development in milestones, limited function of balance and tonus dysregulation).

### 2.4. Motor and cognitive outcomes

Motor performance at the age of two was measured using fine motor and gross motor subscales of the BSID-III (27). A correction for prematurity was applied to the motor scores. Subscales of the BSID-III are normally distributed with a mean of 10 (SD of 3) (27).

Cognitive function at the age of eight was assessed using the WISC-III-NL (28). Outcome measures included PIQ and VIQ as continuous variables, uncorrected for prematurity. PIQ and VIQ are normally distributed with a mean of 100 (SD of 15) (28). Intelligence profiles were categorised as disharmonic when a difference of >1 SD between PIQ and VIQ scores was observed (29), which resulted in three groups (PIQ > VIQ, PIQ = VIQ and PIQ < VIQ).

### 2.5. Statistical analysis

Differences in baseline characteristics between included and excluded children were compared using a student-test (normal distribution) or Mann-Whitney *U* test (nonparametric distribution) for continuous variables and a Chi-square test for categorical variables. Maternal education was missing for 11% of the children and imputed

**Table 1**  
Baseline characteristics for included and excluded children.

	Included children (n = 88)	Excluded children (n = 90)	p- Value
<b>Maternal characteristics</b>			
Age	31 [28.3, 32.9]	31 [28.0, 33.0]	0.836
Multipara	35 (40.7%)	30 (33.3%)	0.392
Multiplicity	26 (29.5%)	45 (50.0%)	0.008
Caesarean section	46 (52.3%)	27 (30.0%)	0.004
Socioeconomic status	0.21 (0.89)	0.19 (0.96)	0.879
<b>Neonatal outcomes</b>			
Gender (female)	46 (52.3%)	41 (45.6%)	0.455
GA in weeks+ days	28 + 2 [27 + 2, 29 + 1]	28 + 2 [26 + 6, 29 + 3]	0.945
Birthweight (in grams)	1078 (275)	1123 (263)	0.258
SGA <10th percentile	29 (33.0%)	15 (16.7%)	0.019
Apgar score 5 min	7.9 [7.0, 9.0]	7.6 [7.0, 9.0]	0.068
Ventilation >12 h	42 (47.7%)	46 (51.1%)	0.763
Severe brain injury	1 (1.1%)	5 (5.6%)	0.211
Days hospitalised in the NICU	32 [21, 49]	36 [17, 54]	0.542

Legend: N (%); mean (SD); median [1st quartile, 3rd quartile]; GA, gestational age; SGA, small for gestational age; NICU, neonatal intensive care unit.

**Table 2**  
Motor and cognitive scores.

<b>BSID-III at corrected age of two</b>	
Fine motor scaled score	11.5 (2.3)
Gross motor scaled score	9.0 (3.0)
<b>WISC-III-NL at uncorrected age of eight</b>	
WISC-III-NL Full scale IQ	98.4 (13.5)
WISC-III-NL Verbal IQ	101.8 (13.7)
WISC-III-NL Performance IQ	94.9 (13.5)
Mean difference PIQ – VIQ	6.9 (95% CI 4.1–9.7)
<b>Disharmonic IQ profile</b>	
PIQ < VIQ (>1 SD)	n = 18 (20.5%)
VIQ = PIQ (<1 SD)	n = 68 (77.3%)
PIQ > VIQ (>1 SD)	n = 2 (2.2%)

Legend: N (%); mean (SD); WISC-III-NL, Wechsler Intelligence Scale for Children-III-NL; BSID-III, Bayley Scales of Infant and Toddler Development-III; VIQ, verbal intelligence quotient; PIQ, performance intelligence quotient.

using the R multivariate imputation by chained equation (MICE) package.

The subscales of the BSID-III and WISC-III-NL were expressed as mean  $\pm$  SD. Differences between mean PIQ and mean VIQ was examined using a paired student *t*-test. A disharmonic intelligence profile was defined as a >15 IQ points difference between PIQ and VIQ was present.

To examine associations between (fine and gross) motor performance scales and PIQ, linear regression analyses were performed adjusting for GA (days), gender, SGA (birthweight below the 10th percentile), neurological impairment at age two (dichotomised as either

**Table 3**  
Multiple linear regression analysis of the association between motor performance and PIQ, adjusted for confounders.

Predictors	B (95% CI)	p-Value	B (95% CI)	p-Value
BSID-III Fine motor scaled score (corrected)	1.7 (0.5 to 2.8)	0.007	x	
BSID-III Gross motor scaled score (corrected)	x		0.5 (–0.5 to 1.5)	0.343
GA in days	0.0 (–0.3 to 0.4)	0.802	0.1 (–0.3 to 0.4)	0.750
Gender (0 = female, 1 = male)	–5.3 (–10.8 to 0.2)	0.060	–5.1 (–10.9 to 0.7)	0.081
SGA status	–2.4 (–8.2 to 3.4)	0.416	–3.9 (–9.8 to 2.1)	0.197
Neurological impairment at age two	–11.6 (–23.6 to 0.4)	0.058	–10.9 (–23.9 to 2.2)	0.100
<b>Maternal education</b>				
Low	0.0 (Reference)		0.0 (Reference)	
Middle	7.1 (–0.8 to 15.0)	0.077	7.0 (–1.2 to 15.3)	0.094
High	10.6 (2.8 to 18.4)	0.008	11.6 (3.5 to 19.6)	0.006

Legend: GA, gestational age; SGA, small for gestational age; BSID-III, Bayley Scales of Infant and Toddler Development-III. The left half of the table shows the results of the linear regression using fine motor scaled score, the right half of the table shows the results of the linear regression using gross motor scaled score.

present or absent) and maternal education (categorised as low, middle, high). Analyses were performed using IBM SPSS version 22.0. A *p* value <0.05 was considered significant.

### 3. Results

In the study period, 212 infants were admitted to the NICU with a GA <30 weeks. Of these, 34 (16%) infants died, which resulted in 178 children eligible for follow-up. Fifty children (28%) were lost to follow-up because of various reasons (follow-up elsewhere *n* = 25; no show *n* = 20; moved outside region *n* = 5). As a result, 128 (72%) children were seen at the outpatient follow-up clinic at two and eight years. Of those, 40 children had an incomplete or other assessment at two and/or eight. Finally, 88 children were included in the current study (Fig. 1). In Table 1 baseline characteristics of the included and excluded children are shown.

Table 2 shows the motor scaled scores on the BSID-III, the subscales of the intelligence scores of the WISC-III-NL and the proportion of children with (dis)harmonic intelligence profiles. PIQ was lower than VIQ with a mean difference of 6.9 IQ points (95% CI 4.1–9.7). 20.5% of the children had a disharmonic intelligence profile with PIQ < VIQ.

Table 3 shows the results of the linear regression with PIQ at eight years as dependent variable and motor performance at two years as independent variable after adjustment for confounders (GA, gender, SGA, neurological impairment at age two, maternal education). Every one-point increase in BSID-III fine motor scaled score was associated with a 1.7 point (95% CI 0.5–2.8) increase in PIQ. Gross motor scaled score was not associated with PIQ. High maternal education was associated with a 10.6 point (95% CI 2.8–18.4) increase in PIQ compared to low maternal education.

### 4. Discussion

The aim of this study was to analyse the possible association between early motor performance at age two and PIQ at eight years in preterm born children. Fine motor performance on the BSID-III at two years was significantly associated with PIQ at age eight. Gross motor performance was not associated with PIQ at eight years. The association between fine motor performance and PIQ remained after adjusting for neonatal factors, neurological impairment at age two and maternal education.

This study is one of the first to take into account the developmental association between early motor performance and PIQ in preterm born children in a longitudinal cohort study. An association between motor performance and PIQ at school age has previously been demonstrated in children with autism and children at risk for developmental disorders (19,20). Those studies observed that children with a PIQ < VIQ difference larger than 1 SD had worse motor competence in visual-motor integration, body-movement coordination and fine motor skills, specifically visual-motor coordination (19,20). They postulated that PIQ may be related to motor performance.

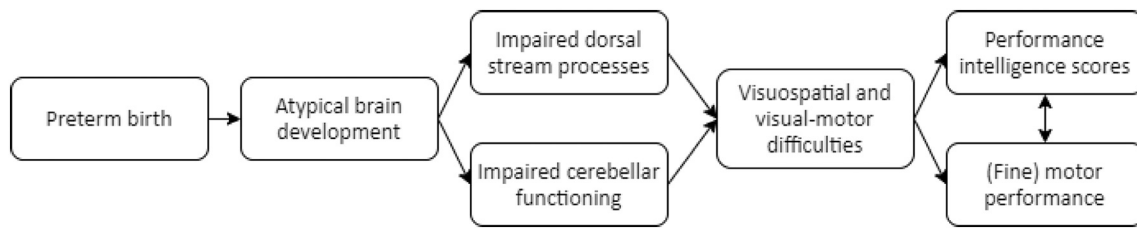


Fig. 2. Conceptual model of the relationship between preterm birth and associated deficits in performance intelligence and motor performance.

It is known that mild to moderate deficits in motor performance more often occur in preterm born children without cerebral palsy than in full-term controls (5,30–33). Preterm born children showed more difficulties on various aspects of motor performance, including visual-motor coordination and fine motor skills (30,31). Problems related to PIQ in preterm born children have also been reported in literature. One study found that PIQ was more strongly affected than VIQ in eight-year-old preterm born children (15). Another study showed very preterm born children to be at higher risk of cognitive impairment in adult life, with particularly their PIQ being affected (16). In the current study we also identified differences between PIQ and VIQ within preterm born children born <30 weeks' GA. Mean PIQ was observed to be 6.9 IQ points lower than mean VIQ, which is in line with studies showing comparable results of a mean PIQ being 7.6 to 9.6 IQ points lower than VIQ (15,16). In our study, 20.5% of the preterm born children showed an intelligence profile with a PIQ < VIQ difference larger than 1 SD, which was higher than the rate of 14.1% found in a normal population (34).

A possible explanation for the associations between early motor performance and PIQ could be that brain alterations as a result of preterm birth underlie difficulties with visuospatial and visual-motor performance, which in turn cause deficits in both fine motor performance and PIQ (Fig. 2). Currently, there is accumulating evidence for the role of impaired dorsal stream processes in deficits with visuospatial and visual-motor function (30,31,35–37). The dorsal stream is a neural network connecting the occipital and posterior parietal cortices with the prefrontal and premotor cortex and hippocampal regions (36). It is suggested impaired cerebellar functioning should also be included in models about altered brain development in preterm born children and deficits in visuospatial and visual-motor performance (35,36). One study found an association between reduced neonatal brain volumes of cortex areas known to be involved in visual-motor integration and fine motor skills with lower scores for these two skills in extremely preterm born children without cerebral palsy (21). As a result, preterm born children could show deficits in fine motor performance and in skills related to performance intelligence scores. An alternative explanation might be that early fine motor performance influences PIQ at eight years, since children need fine motor skills to develop PIQ adequately. Finally, it is also plausible that both explanations are involved. Future research on the underlying mechanisms of the association between early fine motor performance and PIQ is important to further address this issue.

The current findings suggest that it is important to follow-up preterm born children with a reduced motor performance at age two to observe their future PIQ. Early interventions directed at training visuospatial abilities may be useful in supporting the development of performance intelligence. Interventions for the development of fine motor skills could be in turn beneficial for stimulating visuospatial abilities (30). For instance, interventions directed at handwriting skills have shown promising results (38). It is also important to create general awareness about the occurrence of the difference in PIQ < VIQ in preterm born children and keep possible consequences for academic achievements in mind (15). Parents and teachers should be informed about the increased risk of developing difficulties in performance intelligence. In addition, information about possibilities to encourage the development of skills related to performance intelligence in children should be provided. It could also be helpful to stimulate early math skills in young children

(39,40), since lower PIQ is suggested to be related to more difficulties with mathematics (15).

Further research on this topic could explore the association between motor performance and PIQ in more depth. It is yet unclear which preterm born children are specifically at risk for problems with PIQ. More differentiation between different types of motor skills and how they are related to performance intelligence is needed. In addition, examining the neurocognitive functions underlying performance intelligence in more detail could provide more profound information. Moreover, new insights on intelligence have led to the development of the Cattell-Horn-Carroll model (41), which is a different theoretical framework of intelligence than the one used in the WISC-III-NL. It would be intriguing to analyse how the current findings on PIQ < VIQ difference display themselves in this new conceptual framework of intelligence, which is implemented in the WISC-V-NL (42). Another topic for further research could be analysing intelligence subscales in preterm born adults to determine whether a PIQ < VIQ difference continues to persist later in life (16).

#### 4.1. Strengths of the study

The relationship between motor performance and PIQ has been demonstrated in children at risk for developmental disorders (19,20), but not in preterm born children. The longitudinal design of the current study with follow-up at two time points provides new information about possible associations over time. Previous studies did not use a longitudinal follow-up design to investigate the association between motor performance and PIQ.

#### 4.2. Limitations of the study

A limitation concerns the use of the US norms for the Bayley Scales of Infant Development (BSID-III) instead of the Dutch norms (BSID-III-NL), because the BSID-III-NL was not available at the time of assessments (43). Comparison studies show that the use of US norms in Dutch-speaking children could result in over- or underestimation of a child's performance (44,45). In Dutch children, it was observed that US norms caused over-referral regarding gross motor skills, and under-referral regarding fine motor skills (44). When observing the results of the current study, it is possible that mean gross motor scaled score is slightly underestimated (mean score 9.0) and fine motor scaled score somewhat overestimated (mean score 11.5). Moreover, the assessors of the BSID-III and WISC-III-NL were not blinded to medical history, neonatal history and previous testing results of the participants. It is possible that an observer-expectancy effect could have resulted in confirmation bias when administering the test. Finally, there were differences in baseline characteristics between the children included in this study and those who were excluded. Included children were more often SGA and delivered after caesarean section, but were less often part of a twin. This could imply that there were more pre- and perinatal complications in the included children (46,47). However, even though SGA status is related to lower FSIQ scores, it does not appear to have a negative effect on the specific VIQ or PIQ subscales (15,48,49). Perinatal complications leading to worse neonatal outcomes could impact different aspects of IQ (49,50), but other neonatal outcomes showed no differences between



included and excluded children. Therefore, the effect of the differences between included and excluded children on the results of this study is expected to be small.

## 5. Conclusions

In conclusion, fine motor performance at two years was related to PIQ at eight years, with lower motor scores indicating a lower PIQ. Thus, toddler fine motor performance might serve as an early predictor of PIQ in childhood. In general, mean PIQ was lower than mean VIQ in school-aged preterm born children. Early assessment of fine motor performance may be beneficial in identifying children at risk for lower performance intelligence at school age.

## CRedit authorship contribution statement

BV and KV designed the study. KV, PB, IH, MD, BV and PA made substantial contributions to the acquisition of the data. KV analyzed the data and wrote the first draft of the manuscript. PB, IH, VP, MD, BV and PA provided critical feedback and helped to shape the research, analysis and manuscript. All authors approved the final version of the submitted manuscript. BV and PA supervised the project. The corresponding author attests that all listed authors meet authorship criteria and that no others meeting the criteria have been omitted.

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