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The Early Motor Repertoire in Preterm Infancy and Cognition in Young Adulthood: Preliminary Findings

Sahar Salavati[1,*], Anne E. den Heijer[1], Maraike A. Coenen[2], Janneke L.M. Bruggink[1], Christa Einspieler[3], Arend F. Bos[1] and Jacoba M. Spikman[2]

[1]Division of Neonatology, Department of Pediatrics, Beatrix Children's Hospital, Groningen, the Netherlands
[2]Department of Clinical Neuropsychology, University of Groningen, University Medical Center Groningen, Groningen, the Netherlands
[3]Research Unit iDN, Division of Phoniatrics, Medical University of Graz, Graz, Austria

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Abstract

Objective: Preterm birth poses a risk to cognition during childhood. The resulting cognitive problems may persist into young adulthood. The early motor repertoire in infancy is predictive of neurocognitive development in childhood. Our present aim was to investigate whether it also predicts neurocognitive status in young adulthood. **Method:** We conducted an explorative observational follow-up study in 37 young adults born at a gestational age of less than 35 weeks and/or with a birth weight below 1200 g. Between 1992 and 1997, these individuals were videotaped up until 3 months' corrected age to assess the quality of their early motor repertoire according to Prechtl. The assessment includes general movements, fidgety movements (FMs), and a motor optimality score (MOS). In young adulthood, the following cognitive domains were assessed: memory, speed of information processing, language, attention, and executive function. **Results:** Participants in whom FMs were absent in infancy obtained lower scores on memory, speed of information processing, and attention than those with normal FMs. Participants with aberrant FMs, that is, absent or abnormal, obtained poorer scores on memory, speed of information processing speed, attention, and executive function compared to peers who had normal FMs. A higher MOS was associated with better executive function. **Conclusions:** The quality of the early motor repertoire is associated with performance in various cognitive domains in young adulthood. This knowledge may be applied to enable the timely recognition of preterm-born individuals at risk of cognitive dysfunctions.

Keywords: General movements, Fidgety movements, Neurocognitive development, Preterm-born young adults

INTRODUCTION

Preterm birth poses a risk to cognitive performance that becomes manifest during childhood. The resulting problems can be diagnosed as a lower level of intelligence compared to that of term-born peers, as reflected by low verbal and performance IQ scores (Twilhaar et al., 2018). Developmental delays in general and academic difficulties are also often observed (Twilhaar et al., 2018). Specific cognitive domains, such as attention and working memory, are known to be affected in preterm-born children (Aarnoudse-Moens, Weisglas-Kuperus, Van Goudoever, & Oosterlaan, 2009; Allotey et al., 2018; Anderson & Doyle, 2003; Saigal & Doyle, 2008). On average, the scores obtained in these domains are 0.5 *SD* lower compared to those of term-born peers (Aarnoudse-Moens et al., 2009; Allotey et al., 2018). Cognitive performance is known to be related to infants' gestational ages at birth (Bhutta, Cleves, Casey, Cradock, & Anand, 2002; Johnson, 2007). As they grow up, the development of preterm-born individuals continues to lag behind that of their term-born peers (Aarnoudse-Moens et al., 2009; Anderson & Doyle, 2003; Saigal & Doyle, 2008). The transition from childhood to adulthood is accompanied by increasingly complex daily life tasks and requires cognitive skills, such as memory and attention. More importantly, the transition demands higher-order executive skills, such as planning and organization. Not only are lower educational levels more common in preterm-born young adults compared to term-born peers, but unemployment and the need for social benefits also occur more often (Bilgin, Mendonca, & Wolke, 2018). These two problems may be the result of difficulty with carrying out complex daily life tasks that require various cognitive skills (Aylward, 2014). To enable timely

*Correspondence and reprint requests to: Sahar Salavati, Hanzeplein 1, HPC CA51, Groningen, 9713 GZ, the Netherlands. E-mail: s.salavati@umcg.nl

interventions that may improve outcome, early recognition of the risks of unfavourable cognitive development and negative outcomes is necessary. Hence, identifying early predictors is imperative.

To identify significant predictors of neurodevelopmental outcome of preterm-born individuals is challenging (Spittle et al., 2013). A promising method is the qualitative assessment an infant's early motor repertoire. Motor behaviour can be measured objectively and is believed to provide an indication of unfavourable brain development (Einspieler, Bos, Libertus, & Marschik, 2016). Deviations from the normal early motor repertoire may predict neurocognitive problems. The early motor repertoire consists of general movements (GMs) and various other spontaneous movements and postures, such as wiggling-oscillating arm and leg movements, swipes, and kicks. General movements are endogenously generated movement patterns and form part of the infant's spontaneous motor repertoire. From preterm birth until 8 weeks' corrected age (CA), GMs are characterized by complexity, fluency, and variability. If an infant's movements are lacking in these qualities, that is, the movements appear monotonous and jerky, the GMs are considered abnormal. Three types of abnormal GMs have been defined: poor repertoire, cramped-synchronized, and chaotic GMs (Einspieler, Prechtl, Bos, Ferrari, & Cioni, 2004). From 6 to 9 weeks' CA, GMs gradually change into fidgety movements (FMs). These are movements of small amplitude and moderate speed in all joints, in all directions, and of variable accelarations (Einspieler & Prechtl, 2005). They are continuously present in typically developing infants during active wakefulness. FMs are aberrant if they appear exaggerated regarding speed, amplitude, and jerkiness, that is, abnormal FMs, or if they cannot be observed between 9 and 20 weeks' CA, that is, absent FMs. The sensitivity of the early motor repertoire and more specifically that of the quality of the FMs for predicting the development of cerebral palsy (CP) is 98% (Einspieler et al., 2019; Novak et al., 2017). Moreover, there is accumulating evidence that it may also be relevant for predicting neurocognitive outcomes. Various associations between aspects of the early motor repertoire and cognitive function in preterm-born children up to school age have been reported (Einspieler et al., 2016). Spittle et al. found that the presence of normal FMs was associated with better cognitive performance at 2 years (Bayley Scales of Infant and Toddler Development) and better verbal and nonverbal reasoning at 4 years in very preterm-born children. (Spittle et al., 2013). Previously, in the cohort investigated for the present study, our colleagues found that GMs that were consistently abnormal beyond term-equivalent age were predictive of lower IQ scores at school age (Bruggink, Van Braeckel, & Bos, 2010). To date, however, it is unknown whether deviations of the normal early motor repertoire are also associated with poorer cognitive outcomes in young adulthood. We hypothesize that these associations are present in preterm-born young adults. Our current explorative study aims to improve early recognition of infants at risk of poor neurocognitive development, followed by early interventions, with the ultimate aim to improve neurocognitive outcome later in life.

METHOD

Participants

Thirty-seven young adults, aged 21 to 27 years, participated in this explorative, observational follow-up study. They were admitted to the neonatal intensive care unit (NICU) of University Medical Center Groningen, shortly after birth. Practically all the infants were born in our hospital. They were part of a longitudinal cohort study ($n = 93$) on the associations between the early motor repertoire and development up to school age (Bos, Martijn, Okken, & Prechtl, 1998; Bos, Martijn, Van Asperen, et al., 1998; Bos, Van Asperen, De Leeuw, & Prechtl, 1997; Bos, Van Loon, et al., 1997; Bruggink et al., 2010). The inclusion criteria were a GA of less than 35 weeks or a birth weight below 1200 g. General movements, FMs, other spontaneous movements and postures, were videotaped from the first week after birth up until 17 weeks' CA age. Neurodevelopmental follow-up was performed in toddlerhood, at school age (7–11 years), and in young adulthood, when we administered a range of neurocognitive tests (duration approximately 3 h) and questionnaires. The current study focuses on the assessment of the early motor repertoire in infancy and cognitive outcomes in young adulthood.

In Figure 1 we describe the individuals who had dropped out of the initial cohort of 93 individuals, that is, the remaining samples in infancy and childhood. The final sample can still be considered representative of the NICU population of our centre in the 1990s. From 1983 onwards, under the auspices of the Dutch Ministry of Health, the intensive care of newborn infants in our country was centralized by region resulting in ten perinatal centres. The annual, obligatory registration of perinatal and neonatal data indicates that the remaining sample can be considered representative regarding gestational age, morbidities, and treatment of preterm children admitted to a tertiary NICU in the Netherlands. The present follow-up study in young adulthood examined part of the sample that participated in a previous study of this cohort (24 out of 60), in whom associations between the early motor repertoire and intelligence in childhood were determined (Bruggink et al., 2010). Differences between the two samples arose because four individuals with CP who had been excluded in childhood, were included in adulthood, and nine individuals who had not participated in the study by Bruggink (Bruggink et al., 2010), did agree to participate in young adulthood. The study was approved by the Medical Ethical Committee of UMCG and written informed consent was obtained from all participants.

Our study data were compared to the data on the cognitive test results of a matched sample selected from a large reference database comprised of healthy controls of 19 to 90 years of age. These data had been collected at the Department of Clinical Neuropsychology, University Medical Center

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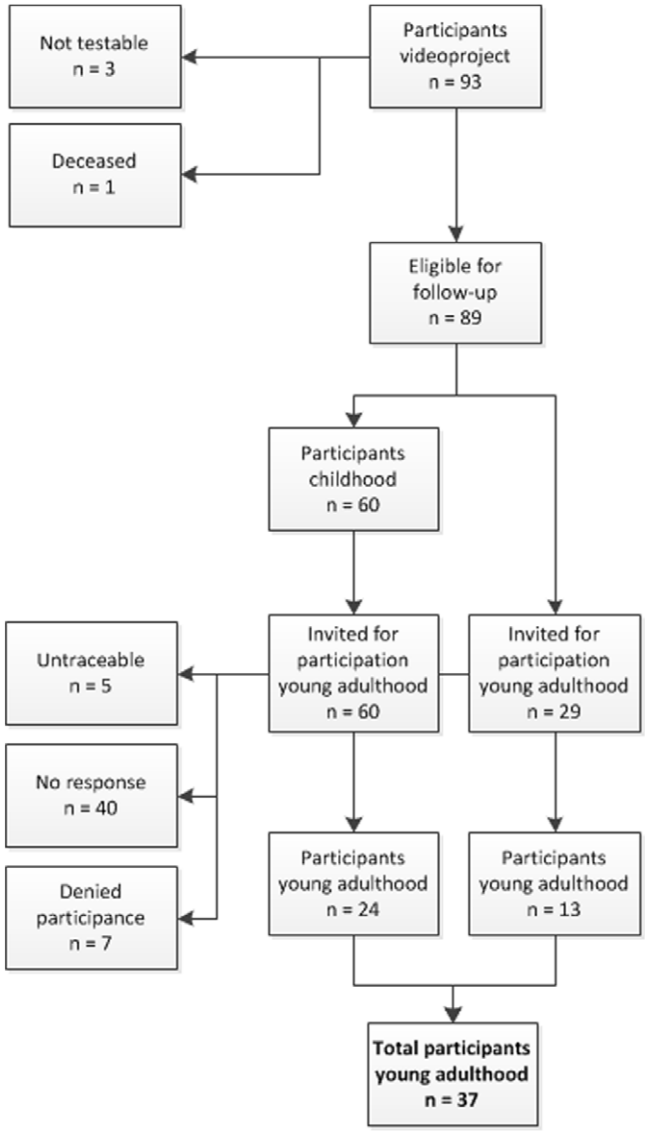

Fig. 1. Inclusion flowchart.

Groningen, for various research projects investigating neuropsychological impairments in different neurological patient groups, including participants with traumatic brain injury, stroke/subarachnoid haemorrhage, cerebral tumours, Alzheimer's disease and frontotemporal dementia, and movement disorders, such as Huntington's and Parkinson's disease.

Recordings of Early Motor Repertoire

The participants were videotaped for 10 to 60 min up to 17 weeks' CA. We made weekly recordings from the first week after birth up until 36 weeks' postmenstrual age. Subsequently, at least one recording was made at 38 to 42 weeks' postmenstrual age, 2 to 8 weeks' CA, and 11 to 17 weeks' CA. Two certified scorers, JLMB and AFB, who were unfamiliar with the children's medical history except for the fact that the infants were preterm-born, assessed the recordings according to Prechtl's method of GM assessment (Einspieler et al., 2004). In case the scorers disagreed, the recording was re-assessed together with a third scorer, CE. The final scores were decided by consensus. For all analyses in the present study we used the scores obtained for the purpose of the previous studies of this cohort (Bruggink et al., 2010).

General movements up until 8 weeks' CA

Up until 8 weeks' CA, the GMs were scored as normal, poor repertoire, or cramped-synchronized. Subsequently, we converted the longitudinal GMs scores into a variable based on the normalization of GMs up until 8 weeks' CA. It consisted of two categories: (1) consistently normal, or normalized before 8 weeks' CA; and (2) consistently abnormal, that is, poor repertoire or cramped-synchronized, up until 8 weeks' CA. Previously, this timing of normalization was

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demonstrated as being predictive of IQ in childhood (Bruggink et al., 2010).

FMs and the motor optimality score at 11 to 17 weeks' CA

At 11 to 17 weeks' CA, FMs were identified as normal or aberrant, that is, absent or abnormal (Einspieler et al., 2004; Einspieler & Prechtl, 2005). Additionally, the infant's motor optimality score (MOS) was determined (Bruggink et al., 2009; Einspieler et al., 2004). The MOS comprises five subscales: FMs, observed movement patterns, age-adequate movement repertoire, observed postural patterns, and movement character (Bruggink et al., 2009; Einspieler et al., 2004; Yuge et al., 2011). Motor optimality scores range from 5 to 28 (best possible performance). In case of multiple recordings at 11 to 16 weeks' CA, the one closest to a CA of 12 weeks was selected. If FMs were absent at a CA of more than16 weeks, this case was excluded from further analyses because the mandatory age for FMs had passed and inclusion could bias the interpretation of the data (Ferrari et al., 2016).

Assessment of Cognition in Young Adulthood

Twenty-five years (range 21–27) after the assessment of the early motor repertoire, we tested performance in various cognitive domains using neuropsychological validated tests with good reliability (Barelds, 2004; Benton & Hamsher, 1976; Bouma, Mulder, & Lindeboom, 1996; Burgess & Shallice, 1996; Reitan & Wolfson, 1985; Stroop, 1935; Wilson, Alderman, Burgess, Emslie, & Evans, 1996).

Memory

Verbal memory was assessed using the 15-Words Test (15WT, the Dutch version of the Auditory Verbal Learning Test). Participants were asked to memorize a list of fifteen non-associated words presented verbally. This task was repeated five times (immediate recall variable name is 15WT-IR) and followed by a delayed recall task (named 15WT-DR) 20 to 30 min later (Bouma et al., 1996). The number of words remembered, both during the immediate recall and delayed recall rounds, was counted. Higher scores represent better performance. To create a measure representing the extent to which delayed recall was proportional to the immediate recall, we calculated a ratio score, that is, ratio score = word count delayed recall/(total word count immediate recall/5, named 15WT-Ratio).

Speed of information processing

We assessed psychomotor speed using the Trail Making Test, Part A (TMT-A), in which the time needed to draw a line between a range of ascending numbers was measured (Reitan & Wolfson, 1985). The Stroop Color and Word Test measured the time needed to read the names of colours in black (Part I, Stroop-I) and naming colours (Part II, Stroop-II) (Stroop, 1935). For both tests higher scores indicate poorer performance.

Language

The Letter Fluency Test (a part of the Groninger Intelligence Test, that is, the Dutch version of the Controlled Oral Word Association Test), was used to measure phonological fluency and divergent thinking. Additionally, the Semantic Fluency Test was administered to measure semantic memory (Barelds, 2004; Benton & Hamsher, 1976). For both tests the number of words produced by the participant was counted (variable names are Letter Fluency and Semantic Fluency, respectively). For both tests higher scores represent better performance.

Attention

We tested flexibility (shifting attention) using Part B of the Trail Making Test (TMT-B), in which a line needed to be drawn by alternating between ascending numbers and letters, that is, 1-A-2-B-3 . . . , (Reitan & Wolfson, 1985). Part III of the Stroop Color and Word Test was administered to assess selective attention and susceptibility to interference (Stroop, 1935). The reading time of names of colours printed in incongruent colours was used. For both variables higher scores indicate poorer performance.

Executive function

Planning and organizational skills were assessed using the Zoo Map Test (Zoo-1), a subscale of the Behavioural Assessment of the Dysexecutive Syndrome (Wilson et al., 1996). We asked participants to draw a route on a zoo map while following a set of rules. We used the score of the first attempt. The Hayling Test was used to assess inhibition (Burgess & Shallice, 1996). Participants were first asked to complete a series of sentences presented verbally with appropriate words and subsequently, to complete sentences with non-related words. Scores were based on the number of correctly complemented sentences (Hayling-total). Higher scores for both Zoo-1 and Hayling-total indicate better executive function.

Statistical Analyses

We performed the statistical analyses using SPSS Statistics for Windows, Version 23 (IBM Corp., Armonk, NY). Baseline characteristics of the participants were compared to those of the remaining samples in infancy and childhood, using the independent samples *t*, Mann–Whitney *U*, chi square, or Fisher's exact tests. Participants' cognitive test results were compared to those of healthy controls matched for gender, age at assessment, and educational level using the independent sample *t*, Mann–Whitney *U* tests, or

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ANCOVA, with the aforementioned variables as covariates. Furthermore, for a measure of effect size Cohen's *d*'s were calculated for comparisons of cognitive test results of participants and healthy controls.

Associations between the GMs up until 8 weeks' CA, FMs, MOS, and the raw scores on cognitive tests were determined using the Mann–Whitney *U*, Kruskal–Wallis, and Spearman's rank-order correlation tests, depending on the variable type. Cohen's *d*'s were calculated for comparisons of cognitive test results based on the type of GMs or FMs in infancy.

RESULTS

Participants

The mean age of the 37 young adults who participated in the present follow-up study was 24.9 ± 1.5 years. We present the participants' patient characteristics in Table 1. One participant had cognitive developmental delay (not specified). Four were diagnosed with CP (11%; Gross Motor Function Classification System, GMFCS, I-II ($n = 2$), III, and IV). One of these participants (GMFCS I-II) had visual problems as a result of unilateral retinopathy of prematurity that were partly corrected with prescription glasses. Another participant (GMFCS III) had cerebral visual impairment. Possible consequences of these impairments for their participating in cognitive tests are discussed below (see "Cognition in young adulthood").

We compared the participants' patient characteristics with individuals who had dropped out from the study after infancy ($n = 52$) or at school age ($n = 36$). The group that had dropped out after infancy comprised significantly fewer boys and had a significantly lower birth weight (Table 1). Of the group that had dropped out after school age, significantly fewer individuals had received postnatal steroids and fewer were diagnosed with CP (Table 1).

Early Motor Repertoire in Infancy

We present the scores on the early motor repertoire in Table 1. No appropriate recordings were available of five young adults for GM analysis ($n = 4$) or FMs ($n = 1$). Out of five infants with abnormal FMs in infancy, three were diagnosed with developmental coordination disorder in childhood, in one motor development was normal, and the information on motor development was lacking in one other. Four of the participants in whom FMs were absent were diagnosed with CP, while one was diagnosed with developmental coordination disorder in childhood.

Cognition in Young Adulthood

We present the scores on all cognitive tests compared to those of healthy controls in Table 2. Because of significant group differences in baseline characteristics between preterm participants and specific subgroups of controls, the comparisons of the Semantic Fluency, Letter Fluency, and Hayling tests were corrected for educational level and/or age at assessment. We also present the scores of preterm-born young adults, excluding four cases with CP, in Table 2.

One participant was incapable of completing the 15-Words and Stroop Color and Word tests on account of a poor comprehension of their contents. This participant had a full-scale IQ of 79, was not diagnosed with any developmental disorder, and had normal FMs in infancy (MOS 28 points). Another participant failed to complete the Hayling Test, also on account of poor comprehension. She was diagnosed with a cognitive developmental delay and had abnormal FMs in infancy (MOS 13 points). Lastly, one participant was too tired to complete the last two tests of the battery, that is, the Semantic Fluency and Letter Fluency tests,. Furthermore, her scores on the Stroop Color and Word, Trail Making and Zoo Map tests were excluded from analyses because of her presumed cerebral visual impairment. This participant was also diagnosed with CP (GMFCS IV), with FSIQ 48 and in infancy, FMs had been absent (MOS 10 points).

Early Motor Repertoire Scores and Cognition: Differences and Associations

We present all the results on differences and associations between aspects of the early motor repertoire in infancy and cognition in young adulthood in Table 3.

General movements up until 8 weeks' CA

No differences were found between individuals with normal or abnormal GMs at 8 weeks' CA regarding their cognitive performance.

Fidgety movements

If FMs had been absent in infancy, young adults performed significantly poorer on the memory measures (15WT-IR and 15WT-Ratio) compared to their peers with normal FMs in infancy. Additionally, participants in whom FMs had been absent also had a significantly lower memory score (15WT-IR) compared to those who had abnormal FMs. Furthermore, the absence of FMs corresponded with poorer speed of information processing, that is, for Stroop-I, while a trend was found for TMT-A. Lastly, the absence of FMs corresponded with poorer attention, that is, on Stroop-III, while a trend was found for TMT-B. For other cognitive outcomes we found no evidence for differences based on the type of FMs in infancy.

After dichotomizing the quality of FMs into normal versus aberrant, we found evidence that participants with aberrant FMs obtained significantly poorer scores on measures of memory (15WT-IR), speed of information processing (TMT-A), attention (TMT-B), and executive function (Zoo-1 and Hayling-total).

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Table 1. Patient characteristics according to participation in follow-up in young adulthood note: patient characteristics of the remaining samples in infancy ($n = 52$) and childhood ($n = 36$) (Bruggink et al., 2010) are compared to participants in young adulthood ($n = 37$)

	Participants in young adulthood	Remaining sample in infancy	Remaining sample in childhood
n	37	52	36
Maternal educational level, *n* (%)			
Low	15 (43)	29 (56)	22 (61)
Middle	5 (14)	7 (13)	3 (8)
High	15 (43)	16 (31)	11 (31)
Gestational age, mean ± *SD*, weeks	29.3 ± 2.1	30.0 ± 1.9	30.1 ± 1.8
Birth weight, mean ± *SD*, g	1085 ± 279	1222 ± 289*	1203 ± 289
IUGR, *n* (%)	8 (22)	12 (23)	9 (25)
Male participants, *n* (%)	17 (46)	36 (69)*	23 (64)
Prenatal corticosteroid treatment, *n* (%)	23 (62)	37 (71)	27 (75)
Apgar score 5 min, mean ± *SD*	7.5 ± 2.1	7.6 ± 1.8	7.9 ± 1.7
Umbilical pH, mean ± *SD*	7.28 ± 0.06	7.26 ± 0.09	7.26 ± 0.08
Ventilatory support (IPPV or HFOV), *n* (%)	21 (57)	31 (60)	18 (50)
Septicaemia, *n* (%)	15 (41)	16 (31)	12 (33)
ICH grade, *n* (%)			
No	28 (76)	38 (73)	26 (72)
I	6 (16)	11 (21)	10 (28)
II	1 (3)	0 (0)	0 (0)
III	0 (0)	1 (2)	0 (0)
IV	2 (5)	2 (4)	0 (0)
PVL grade, *n* (%)			
No	14 (38)	27 (52)	21 (58)
I	20 (54)	22 (42)	15 (42)
II	2 (5)	3 (6)	0 (0)
III	1 (3)	0 (0)	0 (0)
Bronchopulmonary dysplasia, *n* (%)	12 (32)	14 (27)	10 (28)
Postnatal corticosteroid treatment, *n* (%)	10 (27)	7 (14)	2 (6)*
GMs writhing normalization *n* (%)			
Normal before or at 8 weeks' CA	15 (46)	27 (54)	22 (65)
Abnormal throughout, including 8 weeks' CA	18 (54)	23 (46)	12 (35)
Poor repertoire	30 (91)		
Cramped-synchronized	3 (9)		
Fidgety movements, *n* (%)			
Normal	26 (72)	37 (72)	29 (81)
Abnormal	5 (14)	7 (14)	7 (19)
Absent	5 (14)	7 (14)	0 (0)
MOS, median (interquartile range)	24 (13)	23 (12)	23 (12)
Cerebral palsy, *n* (%)	4 (13)	9 (19)	0 (0)
Developmental coordination disorder,*n* (%)	9 (28)	9 (19)	9 (25)
Socioeconomic status young adulthood			
Low	2 (5)	–	–
Middle	24 (65)	–	–
High	11 (30)	–	–
Full-scale IQ young adulthood	84.8 ± 14.5	–	–

Abbreviations: CA, corrected age; HFOV, high frequency oscillatory ventilation; ICH, intracranial hemorrhage; IPPV, intermittent positive pressure ventilation; IUGR, intrauterine growth restriction; PVL, periventricular leukomalacia; MOS, motor optimality score.*$p \leq .05$, which is significantly different from participants in young adulthood. Inconsistencies in numbers are the result of missing data (maternal educational level, general movements, fidgety movements, and developmental coordination disorder). Socioeconomic status categories are defined as low (primary and pre-vocational secondary education), middle (secondary vocational education), and high (senior general secondary, pre-university, higher professional, and university education). Differences between the samples in adulthood and childhood arose because individuals with CP had been excluded in childhood but not in adulthood ($n = 4$), individuals who did not participate in the study by Bruggink et al., but who did agree to participate in young adulthood ($n = 9$).

A dichotomous comparison of participants with normal and aberrant FMs enabled us to repeat the analysis after excluding the four participants with CP, in all of whom FMs had been absent in infancy. In doing so, we found that the presence of aberrant FMs in infancy corresponded significantly with poorer executive function (Zoo-1 and

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Table 2. Cognitive test results in young adulthood ($n = 37$)

Test	Variable	Preterm young adults $n = 37$	Controls[a]	Cohen's d[a]	Preterm young adults without CP $n = 33$
Memory					
15-Words Test	15WT-IR (word count)	46 ± 9; 27–59	50 ± 9; 24–65*	0.44	48 ± 8; 28–59
	15WT-DR (word count)	9 ± 3; 5–14	11 ± 3; 3–15*	0.67	10 ± 5–14
	15WT-Ratio	1.01 ± 0.23; 0.68–1.32	1.06 ± 0.17; 0.60–2.29	0.25	1.02 ± 0.68–1.32
Speed of information processing					
Trail Making Test	TMT-A (time in seconds)	33 ± 12; 16–72	25 ± 8; 13–52***	0.78	33 ± 13; 16–72
Stroop Color and Word Test	Stroop-I (time in seconds)	48 ± 10; 35–83	41 ± 6; 30–73***	0.85	47 ± 10; 35–83
	Stroop-II (time in seconds)	64 ± 14; 43–100	53 ± 8; 38–75***	0.96	62 ± 12; 43–91
Language					
Semantic Fluency Test	Semantic Fluency (word count part I + II)	41 ± 9; 25–64	46 ± 9; 30–66	0.56	41 ± 9; 25–64
Letter Fluency Test	Letter-fluency (word count)	34 ± 12; 10–62	40 ± 11; 22–80	0.52	34 ± 12; 10–62
Attention					
Trail Making Test	TMT-B (time in seconds)	74 ± 30; 38–191	55 ± 20; 28–157***	0.75	70 ± 22; 38–119
Stroop Test	Stroop-III (time in seconds)	95 ± 24; 62–154	80 ± 15; 50–119***	0.75	93 ± 23; 62–154
Executive function					
Zoo Map Test	Zoo-I (raw score)	4.5 ± 4.7; −7.0–8.0	6.1 ± 2.7; 0.0–8.0	0.47	4.7 ± 4.6; −7.0–8.0
Hayling Test	Hayling-total (total scaled score)	14 ± 4; 7–20	18 ± 2; 11–22***	1.26	14 ± 4; 7–20

15WT-DR, delayed recall 15-Words Test; 15WT-IR, immediate recall 15-Words Test; 15WT-Ratio, ratio 15-Words Test; Stroop-I, Part I Stroop Color and Word Test; Stroop-II, Part II Stroop Color and Word Test; Stroop-III, Part III Stroop Color and Word Test; TMT-A, Part A Trail Making Test; TMT-B, Part B Trail Making Test; Zoo-I, Part I Zoo Map Test.

All results are presented as mean scores ± *SD*; minimum–maximum unless indicated otherwise. Significant differences between preterm young adults ($n = 37$) and healthy controls have been tested for.*Signifies $p \leq .05$ and

*** Signifies $p \leq .001$.

[a] Controls were compared to all participating young adults ($n = 37$); the number of participating controls varied per test, ranging from $n = 33$ to $n = 113$.

Table 3. Early motor repertoire scores and cognition: differences for cognition based on types of GMs and FMs; associations between cognition and MOS

	Memory		Speed of information processing		Language		Attention		Executive function	
	15-Words Test		Trail Making Test	Stroop Color Test	Semantic Fluency Test	Letter Fluency Test	Trail Making Test	Stroop Color Word Test	Zoo Map Test	Hayling Test
Early motor repertoire	15WT-IR Word count	15W T-Ratio	TMT-A Time, s	Stroop-I Time, s	I + II Word count	Word count	TMT-B Time, s	Stroop-III Time, s	Zoo-I Raw score	Hayling-total Scaled score
Preterm young adults ($n = 37$)										
GMs at 8 weeks' CA										
Normal, $n = 15$ (46)	47 ± 9	1.01 ± 0.16	30 ± 9	45 ± 8	43 ± 8	35 ± 10	79 ± 21	90 ± 25	5.2 ± 4.3	15 ± 4
Abnormal, $n = 18$ (54)	44 ± 10	1.01 ± 0.18	38 ± 17	56 ± 24$^{\Delta}$	39 ± 9	32 ± 13	75 ± 37	101 ± 24	2.5 ± 5.2	13 ± 4
Cohen's *d*	0.32	0.00	0.59	0.61	0.47	0.26	0.14	0.45	0.57	0.50
FMs										
Normal, $n = 26$ (72)	48 ± 8	1.04 ± 0.16	31 ± 10	47 ± 10	42 ± 10	34 ± 13	67 ± 23	92 ± 23	5.7 ± 3.8	15 ± 3
Aberrant, $n = 10$ (28)	41 ± 11*	0.94 ± 0.18	42 ± 15*	52 ± 11$^{\Delta}$	38 ± 6	33 ± 9	94 ± 40*	106 ± 24$^{\Delta}$	2.1 ± 4.6*	11 ± 4*
Cohen's *d*	0.73	0.59	0.86	0.48	0.49	0.09	0.83	0.60	0.85	1.13
FMs										
Normal, $n = 26$ (72)	48 ± 8***	1.04 ± 0.16*	31 ± 10$^{\Delta}$	47 ± 10*	42 ± 10	34 ± 13	67 ± 23$^{\Delta}$	92 ± 23*	5.7 ± 3.8$^{\Delta}$	15 ± 3$^{\Delta,\Delta}$
Abnormal, $n = 5$ (14)	49 ± 7*	1.01 ± 0.20	44 ± 2	49 ± 12	39 ± 2	32 ± 9	83 ± 17	97 ± 21	1.8 ± 5.4$^{\Delta}$	11 ± 5$^{\Delta}$
Absent, $n = 5$ (14)	33 ± 7***,*	0.87 ± 0.16*	39 ± 5$^{\Delta}$	57 ± 8*	36 ± 10	34 ± 11	109 ± 59$^{\Delta}$	118 ± 25*	2.5 ± 4.2	11 ± 5$^{\Delta}$
Cohen's *d* (normal vs. abnormal)	0.13	0.17	0.79	0.18	0.41	0.18	0.79	0.23	0.84	0.97
Cohen's *d* (normal vs. absent)	2.0	1.06	1.01	1.10	0.60	0.00	0.94	1.08	0.80	0.97
Cohen's *d* (abnormal vs. absent)	2.3	0.77	0.33	0.78	0.42	0.20	0.60	0.91	0.14	0.00
MOS, rho	0.15	0.22	-0.089	-0.20	0.32$^{\Delta}$	0.21	-0.004	-0.19	0.14	0.45**,[a]

(*Continued*)

Table 3. (*Continued*)

	Memory		Speed of information processing		Language		Attention		Executive function	
	15-Words Test		Trail Making Test	Stroop Color Test	Semantic Fluency Test	Letter Fluency Test	Trail Making Test	Stroop Color Word Test	Zoo Map Test	Hayling Test
Early motor repertoire	15WT-IR Word count	15W T-Ratio	TMT-A Time, s	Stroop-I Time, s	I + II Word count	Word count	TMT-B Time, s	Stroop-III Time, s	Zoo-I Raw score	Hayling-total Scaled score
Preterm young adults without CP ($n = 33$)										
GMs at 8 weeks' CA										
Normal, $n = 15$ (52)	47 ± 9	1.01 ± 0.16	30 ± 10	45 ± 8	43 ± 8	35 ± 10	78 ± 21	90 ± 25	5.2 ± 4.3	15 ± 4
Abnormal, $n = 14$ (48	47 ± 9	1.04 ± 0.18	35 ± 16	50 ± 13	39 ± 9	31 ± 14	65 ± 20	97 ± 22	3.1 ± 5.2	13 ± 4
Cohen's *d*	0.00	0.18	0.38	0.46	0.47	0.33	0.63	0.30	0.44	0.50
FMs										
Normal $n = 26$ (81	48 ± 8	1.04 ± 0.16	31 ± 10	47 ± 10	42 ± 10	34 ± 13	67 ± 23	92 ± 23	5.7 ± 3.8	15 ± 3
Aberrant, $n = 6$ (19)	47 ± 9	0.97 ± 0.21	42 ± 19	49 ± 11	38 ± 5	32 ± 8	81 ± 16$^{\Delta}$	101 ± 21	2.0 ± 4.9*	10 ± 4*
Cohen's *d*	0.12	0.37	0.72	0.19	0.51	0.19	0.71	0.41	0.84	1.41
MOS, rho	-0.14	0.088	0.062	-0.008	0.34$^{\Delta}$	0.29	0.15	-0.061	0.057	0.44^{*,b}

Abbreviations: (. . .), percentage; 15WT-DR, delayed recall 15-Words Test; 15WT-IR, immediate recall 15-Words Test; 15WT-Ratio, ratio 15-Words Test; CA, corrected age; FMs, fidgety movements; GMs, general movements; MOS, Motor Optimality Score; Stroop-I, Part I Stroop Color and Word test; Stroop-II, Part II Stroop Color and Word test; Stroop-III, Part III Stroop Color and Word Test; TMT-A, Part A Trail Making Test; TMT-B, Part B Trail Making Test; Zoo-I, Part I Zoo Map Test.

All scores are presented as mean ± *SD* unless indicated otherwise.

The statistical tests used were the Mann–Whitney, Kruskal–Wallis, and Spearman rank correlation tests.$^{\Delta}$ Signifies $p \leq .1$.

*Signifies $p \leq .05$.

** Signifies $p \leq .01$.

*** Signifies $p \leq .001$.

[a] Excluding FMs points, that is, maximum MOS = 16): rho = 0.46 **.

[b] Excluding FMs points: rho = 0.44 **.

Hayling-total). Differences in performance on memory, speed of information processing, and attention tests lost their significance after excluding participants with CP.

Motor optimality score

We found evidence for positive associations between a higher MOS and better executive function (Hayling-total). In a repeat analysis, using the MOS minus the subscale FMs (maximum MOS = 16 points) to determine the role of the aforementioned association, the evidence remained strong. After excluding participants with CP, the evidence also remained. No other significant associations between the MOS and cognitive outcomes were present.

DISCUSSION

This study demonstrates that there are several associations between the early motor repertoire and cognitive functioning in preterm-born young adults. To the best of our knowledge ours is the first study to address this issue. As hypothesized, we found evidence that poorer qualitative aspects of the early motor repertoire are associated with poorer cognitive outcomes in young adulthood. Absence of FMs was associated with poorer memory, speed of information processing, and attention. The MOS corresponded positively with executive function.

First, we found evidence for the association between the absence of FMs and poorer performance on memory, speed of information processing, and attention tests. Participants in whom FMs were absent in infancy also had lower memory scores when compared to peers with abnormal FMs. The quality of FMs was not associated with language performance. When we examined absent and abnormal FMs together (aberrant FMs), young adults with aberrant FMs in infancy not only obtained lower scores on memory, speed of information processing, and attention tests, but also on executive function. Previously, the quality of FMs has been related to verbal and nonverbal cognitive performance in 4-year-old, very preterm-born children (Spittle et al., 2013). To date, however, FMs have not been studied in relation to memory, speed of information processing, and attention.

Second, apart from the fact that the quality of FMs was associated with executive function, we found that a higher MOS also corresponded with better executive function, inhibition in particular. This was irrespective of the quality of the FMs. Moreover, the association remained strong after we excluded the young adults with CP. We found no other associations between the MOS and cognitive domains in young adulthood. In a previous study of healthy term-born infants, we found that a higher MOS is associated with better expressive language in childhood (Salavati et al., 2017). We could not confirm this finding in our current study. It has been reported that infants with extremely low birth weights with an abnormal movement character, a subscale of the MOS, had lower scores on working memory and speed of information processing at school age (Grunewaldt et al., 2014). Given the relatively small sample size of our current study, we chose not to perform separate analyses of the MOS subscales.

The cognitive functioning of young adults who consistently had abnormal GMs up until 8 week's CA was not significantly different from that of young adults who had normal GMs. It should be noted that FMs were normal in most infants, which indicates that FMs may be more relevant for predicting outcome than GMs. Previously in our cohort, Bruggink and colleagues found that at school age, children whose GMs were consistently abnormal up until 8 weeks' CA, were 4.9 times more likely to have a total IQ below 85 compared to peers who had normal GMs (Bruggink et al., 2010). The samples tested in childhood and in young adulthood differed regarding their baseline characteristics and the cognitive domains tested. In childhood no other cognitive domains were tested and the characteristics of the participants differed, amongst others, in that our study included a number of individuals with CP. Hence, comparison with our study is difficult.

Our findings may be explained in several ways. We propose that the early motor repertoire portrays the integrity of the developing central nervous system. We know that white matter injury in very preterm infants can be reflected by abnormalities in GMs and FMs (Peyton et al., 2017; Spittle et al., 2008). We also know that cognitive development depends on the integrity of diffuse neural networks (Sporns, Tononi, & Edelman, 2000). Consequently, any disruption of the integrity of areas of the brain – both motor-related and cognition-related – may be reflected by aberrations in the infant's early motor repertoire. We do not believe, however, that the assessment of an infant's early motor repertoire should be used to identify problems in specific domains of cognition. Rather, we advocate its use to obtain an overall impression of how susceptible an infant is to poor cognitive development. Moreover, we think that early spontaneous movements and postures, which are characterized by variability and complexity, may promote motor and cognitive development in early life. The first few months after birth are known to be critical for neurodevelopment (Hensch, 2005). Various studies reported that sensory deprivation during this critical period increases the risk of poor development of the functions related to the sense deprived, for example, vision (Lewis & Maurer, 2005; Mowery, Kotak, & Sanes, 2016; Neville & Bavelier, 2002). Hampered to explore the environment on account of abnormalities in the early motor repertoire may have similar consequences.

There are several strengths and limitations to our study. We consider our study design, that is, long-term follow-up into young adulthood and the wide range of cognitive tests we administered, as strengths. In addition, our sample can be considered representative of the NICU populations in the nineties in the Netherlands. A limitation is the relatively small sample that participated in young adulthood and may have limited the power to detect significant results. The inability of a few participants to complete certain tests on account of not fully comprehending the contents, may also have influenced our detecting all possible results.

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Nevertheless, practically all the findings in our sample of 37 young adults showed trends consistent with our hypothesis, that is, that a favourable early motor repertoire is associated with better cognition later on. As a result of the small size of our sample, however, we were unable to account for possible factors that influenced neurocognitive functioning in young adulthood, such as socioeconomic status. Furthermore, given the explorative nature of our study, we refrained from correcting for multiple testing to not incur the risk of Type II errors (Rothman, 1990). Because mostly nonparametric tests were indicated, we refrained from using omnibus tests for the parametric analyses as this would complicate the comparisons of parametric and nonparametric test results. We interpret our findings with caution. Another limitation is the possible interference of motor skills of participants with CP in the Trail Making and Zoo Map tests. For the Zoo Map Test, however, the time needed to complete the task did not influence participants' scores. Furthermore, the administration of different sets of tests at different time points in the control group may have led to some heterogeneity. However, for each tests exact the same version was used throughout time, so we believe this possible heterogeneity not to be significant. A final limitation is that some individuals were too impaired to participate in several cognitive tests, as occurs frequently in populations of preterm-born individuals. This may have resulted in a shift of average group scores to the better end of the spectrum. As a consequence, we are aware that we may have overestimated the young adults' cognitive performance.

Our study should be regarded as explorative. It is the first to describe associations between early motor repertoire and cognitive performance in young adulthood. We consider it of utmost interest that these associations exist, given the long duration between infancy until follow-up in young adulthood. Our findings could initiate further research into the predictive value of the early motor repertoire for cognitive outcome in preterm-born young adults. In our opinion the relevance of such research is evident because challenging themes, such as participation in society and employment, become important in young adulthood. Especially so in preterm-born individuals who are known to be at risk of problems in daily life functioning (Bilgin et al., 2018). We trust that recognising the individuals at risk of poor neurocognitive development will lead to early interventions during the critical period and thus to improved outcome.

The quality of the FMs of preterm-born young adults rather than their MOS or GMs up until 8 weeks' CA, indicates their level of cognitive performance. Most importantly, the absence of FMs in infancy is associated with poorer performance on various cognitive domains. These findings should be further explored in a larger sample.

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CONFLICTS OF INTEREST

The authors state that they had no interests that might be perceived as posing conflict or bias.

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