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Infant motor behaviour and functional and cognitive outcome at school-age: A follow-up study in very high-risk children

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ABSTRACT

Background: The Infant Motor Profile (IMP) is an appropriate tool to assess and monitor infant motor behaviour over time. Infants at very high risk (VHR) due to a lesion of the brain generally show impaired motor development. They may grow into or out of their neurodevelopmental deficit.
Aims: Evaluate associations between IMP-trajectories, summarised by IMP-scores in early infancy and rates of change, and functional and cognitive outcome at school-age in VHR-children.
Study design: Longitudinal study.
Subjects: 31 VHR-children, mainly due to a brain lesion, who had multiple IMP-assessments during infancy, were re-assessed at 7–10 years (school-age).
Outcome measures: Functional outcome was assessed with the Vineland-II, cognition with RAKIT 2. Associations between IMP-trajectories and outcome were tested by multivariable linear regression analyses.
Results: When corrected for sex, maternal education and follow-up age, initial scores of total IMP, variation and performance domains, as well as their rates of change were associated with better functional outcome (unstandardised coefficients [95% CI]): 36.44 [19.60–53.28], 33.46 [17.43–49.49], 16.52 [7.58–25.46], and 513.15 [262.51–763.79], 356.70 [148.24–565.15], and 269 [130.57–407.43], respectively. Positive rates of change in variation scores were associated with better cognition at school-age: 34.81 [16.58–53.03].
Conclusion: Our study indicated that in VHR-children IMP-trajectories were associated with functional outcome at school-age, and to a minor extent also with cognition. Initial IMP-scores presumably reflect the effect of an early brain lesion on brain functioning, whereas IMP rate of change reflects whether infants are able to grow into or out of their initial neurodevelopmental deficit.

1. Introduction

Motor behaviour undergoes impressive developmental changes during infancy [1]. Its assessment always has been an essential part in the evaluation of infant development. Traditionally, much emphasis was on quantitative aspects of motor behaviour, i.e., attainment of motor milestones. Gradually, it has become clear that assessment of qualitative aspects is also an important tool in the prediction of neurodevelopmental outcomes, such as cerebral palsy (CP) and intellectual disability [2]. The Infant Motor Profile (IMP), a video-based assessment of motor behaviour that finds its theoretical background in the Neuronal Group Selection Theory (NGST), covers both quantitative and qualitative aspects [3]. The IMP evaluates motor behaviour in five domains: variation, adaptability, performance, symmetry and fluency. The IMP is

Abbreviations: CI, confidence interval; COPCA, COPing with and CAring for infants with special needs; CP, cerebral palsy; (c)PVL, (cystic) periventricular leukomalacia; GMFCS, Gross Motor Functioning Classification System; IMP, Infant Motor Profile; L2M, LEARN2MOVE; MND, minor neurological dysfunction; MRI, magnetic resonance imaging; NGST, Neuronal Group Selection Theory; RAKIT, Revisie Amsterdamse Kinder Intelligentie Test; TIP, typical infant physiotherapy; UMCG, University Medical Center Groningen; VABS, Vineland Adaptive Behaviour Scales.

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an excellent tool to monitor the infant's motor developmental progress, i.e., it allows for longitudinal assessment of early motor behaviour and is responsive to change [3]. Longitudinal studies evaluating motor development in infancy are important to disentangle relationships between early motor development and later functional and cognitive skills, and to improve early identification and therewith possibilities for intervention in children at high risk of neurodevelopmental disorders [4,5].

Previous studies revealed that low total IMP-scores predict CP in infants at increased risk of neurodevelopmental disorders [6,7]. The domains that contributed most were variation and performance. Other studies in infants at low risk of developmental disorders showed that lower total IMP-scores are associated with lower IQ scores at school-age [8,9]. The domains variation, adaptability and performance contributed most to these associations. The aim of the current study was to evaluate whether IMP-trajectories, summarised by initial IMP-scores and IMP rate of change in children at very high risk of neurodevelopmental disorders, mainly due to an early lesion of the brain, are associated with functional outcome and cognition at school-age. In other words, our study addressed the question whether largely improving IMP-scores are associated with better outcomes at school-age and reflect growing out of a deficit, and whether deteriorating IMP-scores or IMP-scores that show a slower than typical increase in score are associated with worse outcomes as they reflect growing into a deficit.

2. Methods

2.1. Participants

Participants of the current study were children who participated in the LEARN2MOVE 0–2 years trial in infancy (L2M0-2). In L2M0-2, two forms of early intervention were evaluated in infants at very high risk of (CP) [10,11]: the family-centred program COPing with and CAring for infants with special needs (COPCA [12]) and typical infant physiotherapy. Inclusion criteria for L2M0-2 were 0 to 9 months corrected age and being at very high risk of CP based on the presence of an evident brain lesion on neuroimaging, and/or clinical neurological dysfunction suspect for a developing CP. Children were assessed longitudinally throughout infancy with the final assessment around 21 months CA. Detailed descriptions of recruitment and content of the interventions of L2M0-2, and infants' outcome at 21 months have been published previously [10,11]. Caregivers of all 43 children who participated in L2M0-2 were approached to participate in the current study when their children were between 7 and 10 years of age. The study protocol was approved by the Medical Ethics Committee of the University Medical Center Groningen (UMCG) under registration number 2017.321. All caregivers gave written informed consent.

2.2. Procedures

Assessments were carried out by trained assessors and took place at the children's home or at the Institute of Developmental Neurology in the UMCG, depending on caregivers' preferences. All assessments were video-recorded and scored under supervision of a neurodevelopmental expert (MHA). Both at infancy and school-age, neither assessors nor supervisor were aware of details of the clinical background and the type of intervention the children had received in infancy.

2.2.1. Brain imaging

All children underwent brain imaging during the neonatal period as part of standard care (mostly MRI, see Table 1). Brain imaging data were classified by an experienced paediatric neurologist, who was blinded to clinical data, based on the predominant pattern: a) periventricular leukomalacia (PVL; cystic and non-cystic), b) cortical infarction (full-term border-zone infarction or middle cerebral artery infarction), c) posthemorrhagic porencephaly, d) basal ganglia or thalamic lesions, and e) non-specific lesions (e.g., ventriculomegaly) or no lesion [13].

Table 1
Background characteristics.

	n = 31
Boys/girls	18/13
Gestational age in weeks, median (min–max)	30.3 (25.9–41.3)
Birth weight in grams, median (min-max)	1550 (720–4410)
Maternal education[a]: low/middle/high, n (%)	5 (16)/15 (48)/11 (35)
Neonatal brain imaging, n (%)	
MRI/cranial ultrasound	25/6
Type of brain lesion	
Posthemorrhagic porencephaly	7 (23)
PVL: cystic/non-cystic	9 (29)/4 (13)
Basal ganglia/thalamus	3 (10)
Cortical infarction	2 (6)
No/non-specific lesion	6 (19)
IMP-scores <P5, n (%)	
Initial	
Total	15 (48)
Variation	30 (97)
Adaptability[b]	7 (23)
Performance	5 (16)
Final	
Total	28 (90)
Variation	26 (84)
Adaptability[b]	22 (71)
Performance	17 (55)
Intervention during infancy: TIP/COPCA	12/19
Age at follow-up assessment in years, median (min–max)	8.4 (7–10.5)
Neurological condition at school-age, n (%)	
Typical	0
Simple MND	2 (6)
Complex MND	11 (35)
No CP but MND unknown	1 (3)
CP	17 (55)
GMFCS I/II/III/IV/V/unknown	3/4/0/6/2/2
Uni spastic/bi spastic/bi atactic	4/12/1

Legend to the table:
[a] Level of highest completed education. Low: no or only primary education, primary or lower forms of secondary vocational education and training. Middle: higher forms of secondary vocational training, senior general secondary education and university preparatory education. High: vocational college and university.
[b] For the adaptability domain we used P15 for this domain conform the IMP-manual [3].

2.2.2. Infant Motor Profile

Motor development in infancy was assessed by means of the Infant Motor Profile (IMP) [3]. The IMP is a video-based assessment that evaluates motor behaviour of infants between 3 and 18 months corrected age, or until the age at which the infant has mastered the ability to walk independently for a couple of months. Motor behaviour is assessed in supine, prone, sitting and standing and walking position. In addition, reaching, grasping and manipulation are assessed. The IMP comprises 80 items and consists of five domains: variation, adaptability, fluency, symmetry and performance. The first two domains are based on the NGST on motor development [1]. IMP domain scores are calculated as percentages of the maximum score per domain. The total IMP score is the mean of the five domain scores, however in infants aged 6 months or younger the adaptability domain is not taken into account when calculating the total score, as for most motor functions adaptability only starts to develop after the first half year of life. According to norm data from the general Dutch infant population, raw total and domain scores may be converted to percentile scores. A score below the 15th percentile (<P15) is regarded atypical. The IMP has a good construct validity, a good inter-rater and intra-rater reliability and a high predictive ability for neurodevelopmental outcome in both low-risk and high-risk populations [3,7,9]. Lastly, the IMP has a good responsiveness to change [14,15]. Although the IMP has originally been designed for infants aged 3–18 months, we also included assessments of the infants aged 2 months, since in earlier studies it turned out that the IMP could be well applied at this age [16].

2.2.3. Neurological condition at school-age

In order to describe the children's clinical outcome at school-age, neurological condition was evaluated with the assessment of minor neurological dysfunction (MND) [17]. The MND-assessment evaluates eight neurological domains: posture and muscle tone, reflexes, involuntary movements, coordination, fine manipulative ability, associated movements, sensory deficits and cranial nerve dysfunctions. The resulting neurological outcome is classified in four categories: typical, simple MND (sMND), complex MND (cMND), and abnormal, denoting the presence of a clear neurological syndrome, such as CP. sMND represents a non-optimal yet typical function of the nervous system, whereas cMND is considered the clinically relevant form of MND. The MND-assessment has good psychometric properties [17]. In children diagnosed with CP, the subtype, and gross motor function in terms of GMFCS level (Gross Motor Functioning Classification System) were also reported [18,19].

2.2.4. Functional outcome at school-age

Our primary outcome was children's functional performance in daily life in terms of adaptive behaviour at school-age and was assessed with the Dutch translation of the Vineland Adaptive Behavior Scales, second edition (Vineland-II) expanded version [20,21]. We used daily functioning as our primary outcome since it addresses what matters most: how the child functions in daily life. In addition, it reflects multiple aspects of neurodevelopment and is therefore a common outcome measure in populations at high risk of neurodevelopmental disorders [22]. The Vineland-II is a structured parental interview that evaluates children's functional and adaptive behaviour in four domains: communication, daily competences, socialization and motor skills [20]. Each item is scored from 0 (never) to 4 (almost always). Vineland's total score is calculated by adding up the scores of the four domains and has a maximum of 2376. A higher score indicates a better performance. Most of the Vineland interviews were performed face-to-face, but occasionally, due to COVID-induced limitations, by means of telephone interview.

2.2.5. Cognitive outcome at school-age

Cognitive outcome was assessed with the Revisie Amsterdamse Kinder Intelligentietest 2 (RAKIT-2). The RAKIT-2 is a reliable, valid and norm-referenced assessment of cognitive function in children aged 4 to 12.5 years [23]. We used the short version, which is suitable for children with limited attention abilities and motor impairments. It consists of six subtests covering domains of perceptual reasoning, verbal learning, visual orientation, and verbal fluency. Raw total scores were converted to standardised scores with a mean of 100 and standard deviation of 15. We used the total standard score, i.e., the short RAKIT intelligence quotient (IQ) that provides an indication of the child's cognitive development. A total IQ $\geq$ 85 represents a typical cognitive outcome, a total IQ between 70 and 84 a mild cognitive delay, and a total IQ $<$ 70 a definitive delay.

2.3. Statistical analyses

At 21 months CA, there was no significant difference in developmental outcome between infants who received the COPCA intervention and infants who were treated with traditional infant physiotherapy [10,11]. Therefore, in the current study the groups were pooled to evaluate associations between motor behaviour in infancy (assessed with the IMP) and developmental outcome at school-age (assessed with Vineland and RAKIT). Sample size estimation was based on the follow-up study of another group of high-risk infants that also used the Vineland as outcome measure [24]. It revealed that a minimum of 36 (2 $\times$ 18) children would allow for the detection of a statistically significant difference in Vineland scores between children with an initial IMP-score $<$P5 and those with a higher initial IMP-score with a power of 80 % (α = 0.05, SD = 15).

We performed multivariable linear regression analyses, with IMP-trajectories summarised by initial IMP-scores and IMP rate of change (difference between final and initial IMP-score divided by the time interval between final and initial assessment) of total IMP-scores and IMP domain scores of variation, adaptability, and performance, as the independent variables. We a priori adjusted for sex, maternal education level, and age at follow-up. Results are presented as unstandardised coefficients B and their 95 % confidence intervals (95% CI). Analyses were performed with SPSS Statistics, version 28 (Armonk, NY: IBM Corp).

3. Results

3.1. Study group

Thirty-one children with a median age at follow-up assessment of 8.4 years (range 7.0–10.5) participated in the follow-up assessments. Background characteristics of the children are shown in Table 1. Twelve (28 %) of the forty-three children of the original L2M0-2 cohort did not participate in the follow-up. Their background characteristics did not significantly differ from the children that participated in the follow-up (data not shown). Reasons for not participating were high care burden, COVID-pandemic induced restrictions, and time constraints of the caregivers. From the participating children, seventeen (55 %) were diagnosed with CP; thirteen of them were bilaterally and four were unilaterally affected. From the children without CP, the major part (11 out of 14; 79 %) had the complex form of MND (Table 1).

3.2. Infant motor behaviour: IMP-scores

Most children had four (n = 15) or five (n = 15) IMP-assessments during infancy and one child had three assessments, resulting in a total of 138 IMP-assessments. There was a high prevalence of atypical total IMP-scores: 127 assessments (92 %) were below the 15th percentile, of which 106 (76.8 %) below the 5th percentile. At the initial and the final assessment these proportions were 81 % ($<$P15) and 48 % ($<$P5), and 94 % ($<$P15) and 90 % ($<$P5), respectively (Table 1). In Fig. 1, the individual trajectories of IMP-scores are shown. On average, all infants showed an increase of total IMP-scores and IMP performance scores with increasing age. In the domains variation and adaptability, the scores of most infants improved with increasing age, but in some infants scores decreased. The median rates of change for total IMP-score and the three domains (variation, adaptability, and performance) were 0.63 (total), 0.11 (variation), 0.91 (adaptability) and 2.23 (performance).

3.3. IMP-scores and functional outcome at school-age

The Vineland-II was completed in 30 of the 31 children. Median total score was 1632 (range 242–2014) out of a maximum of 2376. Two children had severely outlying Vineland scores (scores 242 and 288) and were excluded from subsequent analyses. Higher initial scores and higher rates of change of total IMP-scores and the IMP domain scores of variation and performance were significantly associated with better Vineland scores when corrected for covariates (Table 2). No effect of adaptability trajectories on the Vineland at school-age was found.

3.4. IMP-scores and cognitive outcome at school-age

The RAKIT was completed in 25 of the 31 children. Median RAKIT score was 79 (range 44–121). A typical cognitive outcome was seen in 10 children (40 %), 8 (32 %) had mild cognitive delay, and 7 (28 %) definitive delay. No effect of trajectories of total IMP-scores on RAKIT scores was found. The same held true for the models on the associations between the IMP domains adaptability and performance and RAKIT scores. However, when corrected for initial IMP variation scores, a higher rate of change of the IMP variation score was significantly

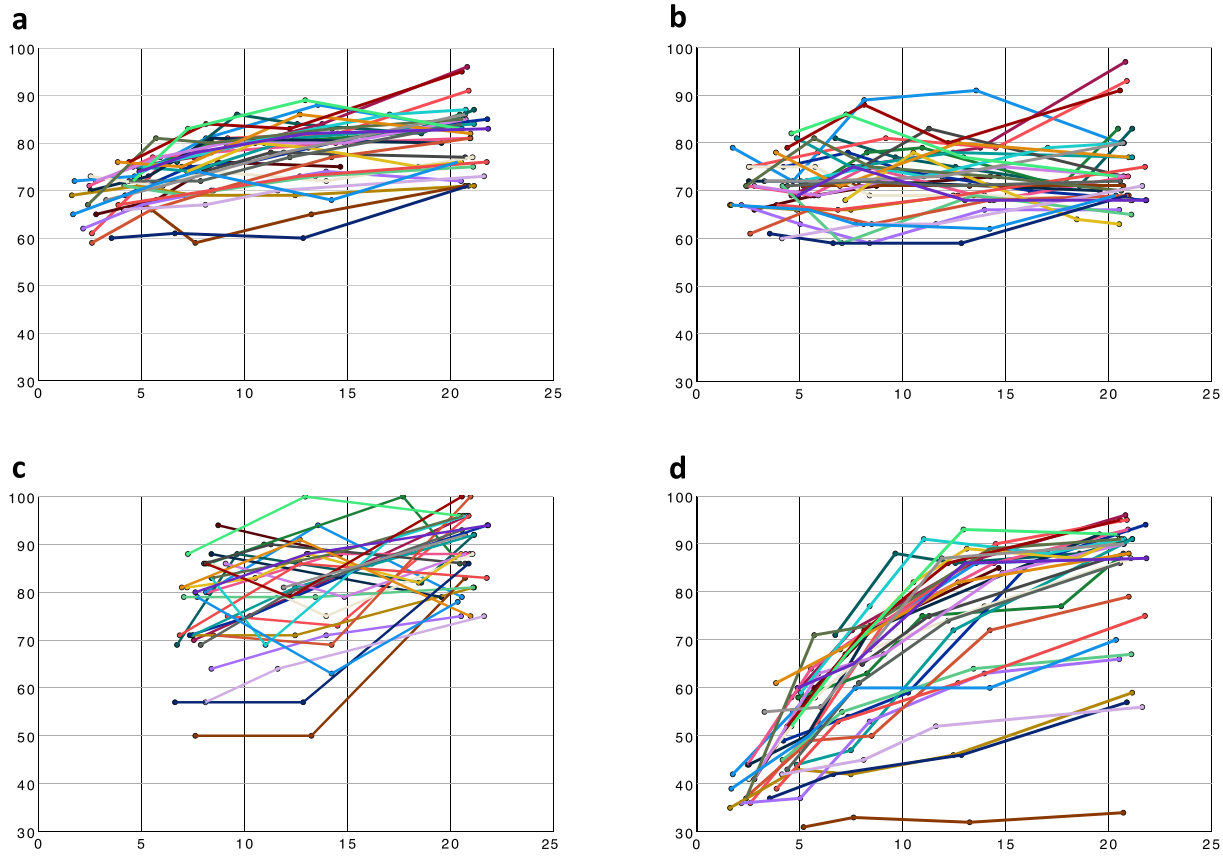

Fig. 1. Individual trajectories of IMP-scores between initial and final assessment in infancy.
Individual trajectories of Infant Motor Profile (IMP) scores: (a) total IMP, (b) variation, (c) adaptability, (d) performance.
The horizontal axes indicate the corrected age (CA) in months; the vertical axes the IMP-scores. Individual lines represent developmental changes in individual infants.

Table 2
Multivariable linear regression analyses of the effect of rate of change in IMP-scores on Vineland scores at school-age.

	Unstandardised coefficient B (95 % CI)		
	Total IMP-score	IMP variation	IMP performance
Constant	−1737.70 (−3202.73 to −272.66)	−1072.83 (−2413.54–267.88)	5.38 (−1054.47–1065.23)
Initial IMP-score	36.44 (19.60–53.28)	**33.46 (17.43–49.49)**	**16.52 (7.58–25.46)**
IMP rate of change	**513.15 (262.51–763.79)**	**356.70 (148.24–565.15)**	**269.00 (130.57–407.43)**
Sex	−158.34 (−330.21–13.54)	−183.57 (−400.26–33.11)	−67.27 (−251.48–116.94)
Maternal education			
Middle	−21.21 (−246.26–203.84)	−106.71 (−343.92–130.51)	−45.69 (−288.57–197.19)
High	76.19 (−168.41–320.78)	5.38 (−268.10–278.85)	61.68 (−192.56–315.92)
Age at follow-up	5.96 (−2.52–14.44)	4.79 (−4.33–13.90)	2.77 (−6.00–11.54)

Sex: male = 1, female = 2. Low maternal education was taken as the reference group in the regression analyses. IMP Rate of change: difference between final and initial IMP-score divided by the time interval between final and initial assessment. 95 % CI = 95 % confidence interval. IMP = Infant Motor Profile. The variables indicated in bold are the IMP-variables of interest.

associated with better RAKIT scores (coefficient B = 34.81, 95 % CI = 16.58–53.03; Table 3).

4. Discussion

In our study group of children at high risk of neurodevelopmental disorders, we found that better motor development in infancy, summarised by higher initial scores and higher rates of change in scores of the total IMP and the domains of variation and performance, was associated with better functional outcome at school-age. IMP-trajectories were hardly associated with cognitive outcome: only positive rates of change in IMP variation scores were associated with better cognition at school-age. The high-risk nature of our group was not only reflected by the finding that at the final IMP assessment the large majority of infants (90 %) had total IMP-scores <P5, but also by the high prevalence of CP (55 %) and complex MND (35 %) at school-age.

Trajectories of total IMP-scores were clearly associated with Vineland scores as measure of functional outcome, but not with cognition at school-age. Total IMP-scores are based on the domain scores. In particular the trajectories of the IMP variation and performance domains were associated with better functional outcome. IMP's variation domain scores reflect the integrity of the nervous system, and specifically the connectivity in cortical-subcortical neural networks [25,26], whereas performance domain scores reflect the net result of what the brain networks are able to accomplish in terms of motor skills. Especially these domains are related to neurodevelopmental outcome in high-risk

Table 3
Multivariable linear regression analyses of the effect of rate of change in IMP-scores on RAKIT scores at school-age.

	Unstandardised coefficient B (95 % CI)
	IMP variation
Constant	−25.84 (−140.64–88.95)
Initial IMP-score	1.67 (0.06–3.27)
IMP rate of change	34.81 (16.58–53.03)
Sex	−7.41 (−25.48–10.67)
Maternal education	
Middle	−11.32 (−31.34–8.70)
High	11.38 (−13.00–35.76)
Age at follow-up	−0.07 (−1.03–0.88)

Sex: male = 1, female = 2. Low maternal education was taken as the reference group in the regression analyses. IMP Rate of change: difference between final and initial IMP-score divided by the time interval between final and initial assessment. 95 % CI = 95 % confidence interval. IMP = Infant Motor Profile. The variables in bold are the IMP-variables of interest.

infants [6,7]. The current results indicate that better initial scores, which conceivably reflect a lesser impact of the brain lesion on brain function, are associated with better functional outcomes. The associations between higher rates of change and better functional outcome suggest that the children's capacity to grow out of a deficit is associated with better outcome. In addition, it reflects that some children grow into a deficit; low positive rates of change, lower than typical for age, and - in particular in the variation domain - negative rates of change contributed to the association between rate of change and functional outcome. IMP-trajectories showed only a minor association with cognition at school-age. In fact, our study was not powered for finding associations between IMP-scores and cognition.

We did not find associations between IMP adaptability trajectories and outcome at school-age. In low-risk infants adaptability scores are associated with cognition at school-age [9]. It is conceivable that the combination of the small group size and the very high-risk nature of our group precluded the finding of associations between adaptability and outcome. It is well known that children with an early lesion of the brain have major problems in the adaptability domain. Therefore, they need more trial-and-error experience to master adaptive behaviour [27–29].

4.1. Strengths and limitations

The major strength of our study is the longitudinal assessment of specific domains of motor behaviour in infancy and functional and cognitive outcome at school-age in a clinically very well-documented group of children at very high risk of neurodevelopmental disorders. The study's main limitation is the small size of the study group, which was aggravated by RAKIT data lacking for some children due to COVID-induced limitations hampering on-site assessment. For the Vineland, we could replace a face-to-face conversation by a telephone interview, therewith preventing further loss of data. The small study group also precluded the use of latent growth modelling, as we did in previous studies on associations between early motor behaviour and later outcome in low-risk children [8,9].

4.2. Concluding remarks

Our study indicated that in children at very high risk of neurodevelopmental disorders developmental trajectories of variation and performance in motor behaviour during infancy are associated with functional outcome at school-age. Developmental changes in variation in motor behaviour were associated with cognition at school-age. Variation and performance are motor domains assessed with the IMP. This means that the IMP is not only an excellent instrument to evaluate the effect of early intervention [15,30,31], but also an adequate tool to monitor developmental progress and to predict neurodevelopmental outcome in high-risk infants.

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Declaration of competing interest

None.

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