Motor development in infancy is related to cognitive function at 4 years of age

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AIM Evidence is accumulating that motor and cognitive development are interrelated. This study investigates associations between motor development in infancy and cognitive function at 4 years of age.

METHOD This study is part of the Groningen prospective cohort study on the development of children born after assisted reproductive techniques such as in vitro fertilization. The study group consisted of 223 children (119 males, 104 females) born to subfertile couples (median gestational age 39.6wks, range 30–43wks). Motor behaviour was assessed with the Infant Motor Profile (IMP) at 4 months, 10 months, and 18 months. IQ was evaluated at 4 years with the Kaufman Assessment Battery for Children, Second Edition. Latent class growth modelling was used to analyse relations between IMP and IQ scores.

RESULTS Infants with low total IMP scores had an IQ that was 8.9 points lower at 4 years than infants with typical IMP scores (95% confidence interval 3.6–14.1). Also, low scores in the domains of variation and performance were associated with a lower IQ at 4 years of age, by 6.1 points and 13.2 points respectively.

INTERPRETATION Motor development in relatively low-risk infants is associated with cognition at 4 years of age. In particular, low motor variation and performance are associated with a lower IQ at 4 years of age.

For a long time it was thought that motor development preceded cognitive development. Piaget described the first of his developmental stages as the ‘sensorimotor’ stage in which infants gain voluntary control of their movements and start to develop the mental representations of these motor actions and their consequences, which he called schemes. In the subsequent developmental stages, the emphasis was on development of cognitive rather than on motor functions. However, evidence is accumulating that indicates motor and cognitive development are not independent phenomena occurring in a fixed sequential order. Motor and cognitive development both start early, have a protracted course into adolescence, and are closely intertwined. Moreover, motor and cognitive function also share the involvement of specific brain structures such as the dorsolateral prefrontal cortex and the neocerebellum.

The interrelation of motor and cognitive development induces the question whether early motor development is associated with later IQ and, if so, which specific motor domains are involved. Traditionally, much emphasis was placed on quantitative aspects of motor development in terms of motor milestones: that is, the ages at which infants reach certain motor skills such as sitting or walking. More recently, it became clear that other aspects of motor behaviour, such as variation (size of the motor repertoire) and adaptability (ability to select out of the repertoire), may also be valid predictors of developmental outcome. Variation is present from early fetal age onwards, and the ability to select situation-specific strategies emerges during the first 18 months postnatally. Variation, adaptability, and motor performance constitute three of the five domains of the Infant Motor Profile (IMP), a video-based assessment of motor behaviour. The two other domains are movement fluency and symmetry.

The Groningen assisted reproductive technologies (ART) cohort study allowed us to study associations between infant motor development measured with the IMP in infancy and IQ at 4 years. This study evaluates the development of children born after ART such as in vitro fertilization and intracytoplasmic sperm injection. The study cohort consists of children born after in vitro fertilization/intracytoplasmic sperm injection with conventional controlled ovarian hyperstimulation, children born after in vitro fertilization/intracytoplasmic sperm injection in the...
modified natural cycle, and children born after natural conception to subfertile couples. Previous studies did not find differences in neurological, cognitive, and behavioural development up to the age of 4 years between these three ART groups. However, severity of subfertility was associated with suboptimal neurological and cognitive development.

The aim of this study was to investigate the relation between motor development in infancy, with special emphasis on variation, adaptability, performance, and later cognitive function of participants in the Groningen ART cohort study. Assessments consisted of the IMP at 4 months, 10 months, and 18 months and the Kaufman Assessment Battery for Children, Second Edition (K-ABC-II) to evaluate cognition at 4 years. We hypothesized that lower total IMP scores, especially lower variation, adaptability, and performance scores, are associated with lower IQ scores at 4 years.

METHOD

Participants

The 249 children of the Groningen ART study were recruited prenatally at the Department of Reproductive Medicine of the University Medical Center Groningen and born between March 2005 and December 2006. Prenatal, perinatal, and demographic information was collected from the parents and medical records with standardized charts during the first follow-up assessment of the ART study at 2 weeks corrected age. The Medical Ethical Committee of the University Medical Center Groningen approved the study design. Parents gave written informed consent.

IMP assessment

Motor behaviour was assessed with the IMP at 4 months, 10 months, and 18 months corrected age. A video recording of 15 minutes of spontaneous and elicited play behaviour was made. Motor behaviour was assessed in several conditions (supine, prone, sitting, standing, walking and reaching, grasping and manipulation), depending on the child’s age and functional capacities.

The 80 items of the IMP are based on the video and constitute five domains: variation, adaptability, fluency, symmetry, and motor performance. Variation denotes the size of the motor repertoire and adaptability is the ability to select efficient strategies from this repertoire. Adaptability can also be considered a variant of the concept of motor planning, the ability to plan and perform the movement on the basis of feedforward organization, and to fine-tune the movement while performing it. The domain motor performance assesses in detail mastered milestones. The IMP results in domain scores and a total score, which is calculated as the mean of the five domain scores. Before the age of 6 months the adaptability domain is not taken into account, as the ability to select motor strategies mainly develops after this age. All scores are expressed as percentages, with 100% as maximum. Reliability and validity of the IMP are good. The videos were analysed by one of two junior examiners with supervision by an experienced assessor (MH-A or KRH). Before the start of the study, intraobserver reliability was tested and found to be satisfactory to good.

Cognitive assessment

At 4 years, cognitive function was evaluated with the K-ABC-II. This was done by two well-trained assessors who were unaware of the IMP scores. The K-ABC-II is a standardized instrument that measures cognitive and processing abilities in children aged 3 to 18 years. It consists of a Total IQ score and four IQ scale scores: (1) sequential processing IQ, which reflects the short-term memory including subtests such as number recall and repeating hand movements; (2) simultaneous processing IQ, which represents the spatial aptitude, with subtests such as face recognition and block counting; (3) learning ability IQ, representing the long-term memory capacity; and (4) knowledge IQ, reflecting general knowledge such as expressive vocabulary and verbal knowledge. All raw scores were normalized into global scores (mean 100, SD 15). Reliability and validity of the K-ABC-II are good. USA norms were applied, as no Dutch norms were available.

Statistical analyses

Demographic characteristics were summarized with various descriptive statistics. The relationship between IMP in infancy and IQ scores at 4 years of age was explored in three steps. First, correlations between IMP and IQ scores were explored with the Pearson correlation coefficient (SPSS statistics version 20; IBM Corp, Armonk, NY, USA). Second, latent class growth modelling was used, to analyse whether specific longitudinal IMP trajectories were associated with IQ. The latent class growth modelling clustered IMP trajectories into several groups using the TRAJ procedure in SAS software, version 9.3 (SAS Institute, Cary, NC, USA). The trajectories were assumed to be quadratic polynomials in age. The number of trajectory groups was determined with the Bayesian information criterion. Subsequently, each child was categorized into one of the trajectory groups. In the third step, this group variable was used to investigate possible differences in intelligence at 4 years using linear regression. Correction was applied for possible confounders: educational level of mother, being small for gestational age, and time to pregnancy. Selection of potential confounders was based on previous studies of the Groningen ART cohort. In addition, we repeated these analyses with two additional potential confounders, namely gestational age and sex. As this did not substantially influence the results, we describe the

What this paper adds

- Motor development in infancy is directly related to cognitive function at 4 years of age.
- This relationship is most pronounced for infant motor variation and performance.
- The size of the differences in IQ is clinically relevant.
results with the original three confounders. These three step analyses were done for the total IMP and the domains of variation, adaptability, and performance. As the latent class growth modelling failed to distinguish more than one group for the domain adaptability, additional linear regression was performed in which scores were dichotomized as atypical (<15th centile of the group, comparable to the cut-off of atypical scores in other developmental tests) and typical (≥15th centile), while adjusting for the confounders. Probability values of 5% or less were considered significant.

RESULTS

Participants

Neonatally, 249 infants were enrolled in the Groningen ART cohort study. Two children were excluded: one female died of congenital heart disease and one male had unilateral fibular aplasia which clearly affected his motor behaviour. Two hundred and forty-one children (97%) had IMP assessment at 4 months, 245 (98%) at 10 months, and 242 (90%) children were assessed with the K-ABC-II. Two children did not complete all IQ scales owing to lack of cooperation. Overall, the attrition rate from baseline to 4 years was 11.3%.

Table I displays the background characteristics of the study group that had follow-up at 4 years. The children who did not have follow-up differed from the actual study group only in terms of prevalence of low birthweight (<2500g) (p=0.046; 26.9% in the group without follow-up vs 12.6% in the actual study group).

Mean IQ at age 4 of the total group was 107 (SD 12; range 63–133). Ten children (4.5%) had IQ scores below 85. Generally, IQ scores for males and females were similar, except for simultaneous processing where females showed some advantage (females 116, males 112; p=0.018).

Exploration: correlations between IMP scores and IQ

Total IMP scores ranged from 70% to 98%; the ranges of the domains were variation 69% to 100%, adaptability 63% to 100%, fluency 58% to 100%, symmetry 83% to 100%, and performance 33% to 95%. Total IMP scores at all ages were correlated with Total IQ score at 4 years (Table II). At 4 months the domains of variation, performance, and symmetry were associated with IQ at 4 years; at 10 months only the IMP performance domain, and at 18 months the domains performance and fluency, were associated (Table II).

IMP total scores and IQ

After fitting the latent growth model with one, two, three, four, and five clusters, the Bayesian information criterion indicated that three average trajectories seemed to fit best to the longitudinal total IMP scores. The quadratic term of the second-order polynomial in age was significant in each of the three groups (all p<0.001). These three average profiles are shown in Figure 1a. The largest group consisted of 199 children and represented the most common trajectory (typically developing group). Twenty-five children had a faster trajectory (‘rapid onset’ group) and 23 a slower development (‘slow’ group).

| Table I: Prenatal, perinatal, and parental characteristics of the study group |
|-----------------------------|-----------------------------|-----------------------------|-----------------------------|
| **Prenatal and perinatal characteristics** | Study group, n | Sub-NC, n (%) | COH-IVF/ICSIA, n (%) | MNC-IVF/ICSIb, n (%) |
| Male sex, n (%) | 119 (53) | 95 (43) | 89 (40) |
| Median gestational age (range), wks | 39.6 (30–43) | 39.6 (30–43) | 39.6 (30–43) |
| Preterm birth (<37wks), n (%) | 36 (16) | 36 (16) | 36 (16) |
| Twins, n (%) | 28 (13) | 28 (13) | 28 (13) |
| Median birthweight (range), g | 3380 (1578–4710) | 3380 (1578–4710) | 3380 (1578–4710) |
| Low birthweight (<2500g), n (%) | 28 (13) | 28 (13) | 28 (13) |
| Small for gestational age, n (%) | 6 (3) | 6 (3) | 6 (3) |
| Caesarean section, n (%) | 59 (27) | 59 (27) | 59 (27) |
| Signs of fetal distress*, n (%) | 75 (34) | 75 (34) | 75 (34) |
| Appgar score at 5min <7, n (%) | 1 (0.5) | 1 (0.5) | 1 (0.5) |
| Neonatal intensive care admission, n (%) | 13 (5.8) | 13 (5.8) | 13 (5.8) |
| Breastfed for >6wks, n (%) | 101 (46.5) | 101 (46.5) | 101 (46.5) |

**Parental characteristics**

<table>
<thead>
<tr>
<th>Study group</th>
<th>Male sex, n (%)</th>
<th>Median maternal age at conception (range), y</th>
<th>Education level mother (high), n (%)</th>
<th>Education level father (high), n (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Study group</td>
<td>Male sex, n (%)</td>
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<td>Education level mother (high), n (%)</td>
<td>Education level father (high), n (%)</td>
</tr>
<tr>
<td>Male sex, n (%)</td>
<td>119 (53)</td>
<td>32.8 (22–41)</td>
<td>93 (42)</td>
<td>84 (39)</td>
</tr>
<tr>
<td>Female sex, n (%)</td>
<td>91 (40)</td>
<td>32.8 (22–41)</td>
<td>93 (42)</td>
<td>84 (39)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Growth characteristics at 4y</th>
<th>Mean head circumference (SD), cm: males/females</th>
<th>Mean height (SD), cm: males/females</th>
<th>Mean weight (SD), kg: males/females</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean head circumference (SD), cm: males/females</td>
<td>50.7 (1.63)/50.3 (1.41)</td>
<td>106.9 (4.15)/108.1 (4.18)</td>
<td>17.6 (2.36)/18.4 (2.61)</td>
</tr>
<tr>
<td>Mean height (SD), cm: males/females</td>
<td>106.9 (4.15)/108.1 (4.18)</td>
<td>17.6 (2.36)/18.4 (2.61)</td>
<td></td>
</tr>
<tr>
<td>Mean weight (SD), kg: males/females</td>
<td>17.6 (2.36)/18.4 (2.61)</td>
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</table>

Sub-NC: children conceived naturally to subfertile couples while they were on the waiting list for assisted reproductive technologies.

COH-IVF/ICSI: conventional controlled ovarian hyperstimulation in vitro fertilization or intracytoplasmic sperm injection.

MNC-IVF/ICSI: modified natural cycle IVF or ICSI.

Birthweight for gestational age is less than −2SD compared with Dutch reference population (Dutch reference tables, Perinatal Registration Netherlands). Signs of fetal distress denoted by meconium-stained amniotic fluid, and/or cardiotocographic signs, and/or acidosis. Data for four children are missing. Main reasons for admission to neonatal intensive care unit were prematurity, asphyxia, and need for ventilator treatment. Data for six children are missing. University education or vocational colleges. No significant relation between head circumference and Total IQ (Pearson correlation 0.13, p=0.075). For three of the four IQ subscales, no significant association was found; only knowledge IQ was weakly related to head circumference (Pearson correlation 0.142, p=0.048).

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**Table II: Correlation between Infant Motor Profile (IMP) scores at 4mo, 10mo, and 18mo and Total IQ scores at 4y of age**

<table>
<thead>
<tr>
<th>IMP score</th>
<th>4mo</th>
<th>10mo</th>
<th>18mo</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total score</td>
<td>0.229 (0.001)</td>
<td>0.209 (0.002)</td>
<td>0.213 (0.002)</td>
</tr>
<tr>
<td>Variation</td>
<td>0.243 (&lt;0.001)</td>
<td>0.122 (0.071)</td>
<td>0.101 (0.137)</td>
</tr>
<tr>
<td>Adaptability</td>
<td>Not applicable</td>
<td>0.121 (0.073)</td>
<td>0.050 (0.462)</td>
</tr>
<tr>
<td>Symmetry</td>
<td>0.140 (0.038)</td>
<td>0.080 (0.238)</td>
<td>−0.002 (0.972)</td>
</tr>
<tr>
<td>Fluency</td>
<td>0.065 (0.341)</td>
<td>0.076 (0.262)</td>
<td>0.161 (0.017)</td>
</tr>
<tr>
<td>Performance</td>
<td>0.205 (0.002)</td>
<td>0.234 (&lt;0.001)</td>
<td>0.252 (&lt;0.001)</td>
</tr>
</tbody>
</table>

Pearson correlation coefficient; p value in brackets; bold type indicates p<0.05.
Comparison of the IQ scores at 4 years showed that the ‘slow’ group had on average 8.9 points lower Total IQ than the typically developing group after adjustment for confounders (Table III). Similar group differences were found for three of the four IQ scale scores (sequential IQ -6.2, simultaneous IQ -8.2, knowledge IQ -7.5). Total IQ scores and IQ scale scores of the typically developing and rapid onset groups did not differ significantly.

**IMP variation and IQ**

For the IMP variation domain, the latent class growth modelling distinguished three groups: a typically developing group of 156 children and two groups with a less varied motor repertoire (a ‘suboptimal’ variation group of 47 children and a ‘reduced’ variation group of 44 children) (Fig. 1b). The reduced variation group had on average 6.1 points lower IQ at 4 years than the typically developing group (Table III). The IQ effect was found in all four IQ domains (sequential -5.0, simultaneous -5.3, learning -4.3, knowledge -4.8). IQ scores of the typically developing group and the ‘suboptimal’ variation group did not differ significantly. Nevertheless, one of the four scale scores differed (in a counterintuitive way): mean learning IQ in the typically developing group was 98.9, 5.1 points lower than in the suboptimal group with mean 104.0 (95% confidence interval [CI] 1.0–9.2).

**IMP adaptability and IQ**

Adaptability data were only available for 10 months and 18 months, as they cannot be computed at 4 months. Latent class growth modelling determined only one cluster using the Bayesian information criterion. Linear regression analysis between IMP adaptability scores at 10 months and 18 months with IQ at 4 years revealed a significant relation between adaptability score at age 10 months and later IQ ($B -5.14$, 95% CI $-9.36$ to $-0.91$, standard error 2.14), but not between adaptability score at 18 months and IQ ($B -0.22$, 95% CI $-3.78$ to $3.34$, standard error 1.81).

**IMP performance and IQ**

For the performance domain, the latent class growth modelling distinguished three trajectory groups: a typically developing group of 132 children, a group of 98 children with a less optimal motor performance (‘suboptimal’ group), and a small group of 17 children with a slow development of performance (‘slow’ group) (Fig. 1c). The slow performance group had on average 13.2 points lower Total IQ at 4 years than the typically developing group (Table III). Similar differences were also present in all IQ scale scores (sequential -9.0, simultaneous -16.7, learning -6.5, knowledge -8.6). Total IQ scores and IQ scale scores of the typically developing and suboptimal performance groups did not differ significantly.

**DISCUSSION**

This study showed a clear relationship between motor development in infancy measured with the IMP and later cognition. Latent class growth modelling showed that low total IMP scores and low scores on motor variation and performance were associated with a lower IQ at 4 years.

Total IMP scores were positively associated with later cognitive function: children with a slow development of total IMP scores had on average 9 points lower IQ at 4 years than the typically developing group. This is a meaningful difference: it is, for example, large enough to determine the educational level in secondary school in the Netherlands.

Children with reduced IMP variation scores had a lower IQ at 4 years of age than those with typical variation. A well-established assessment of movement variation in early...
Infancy is the general movement method. The presence of abnormal general movements at 3 months strongly predicts cerebral palsy. Recently, studies in infants born very preterm have shown that general movement quality is also associated with later IQ. The strongest associations between abnormal general movements and low IQ were found in studies that included children with cerebral palsy. In studies without children with cerebral palsy, similar but less strong associations were found. Our data showed that the established association between movement variation during general movements and later IQ extends to movement variation throughout infancy.

Reduced movement variation is related to diffuse periventricular white matter damage, which is the most prevalent brain abnormality in infants born preterm. This causes a disruption of the cortico-striato-thalamo-cortical and cerebello-thalamo-cortical pathways, which are crucial both for movement variation and for cognitive functions. Also, cerebellar lesions such as cerebellar haemorrhage that occur in infants born preterm are associated with later cognitive impairment. In our ART cohort we did not expect severe brain abnormalities such as white matter damage or cerebellar lesions; however, it is possible that the children in our cohort did have a more subtle, diffuse non-optimal neural connectivity.

Adaptability scores at 10 months were associated with IQ at 4 years, but adaptability scores at 18 months were not. Adaptability is the ability to select efficient motor strategies from the repertoire. This ability starts to bloom from 6 months onwards, peaking for the IMP items between 8 months and 15 months. In previous research, we found a good predictive value of adaptability scores at 10 months and 12 months for cerebral palsy at 18 months. We hypothesize that the function of selecting motor strategies relies in large part on neural networks that are also involved in cognitive tasks, such as executive function, and that this explains the association between adaptability scores and IQ. The absence of such an association between adaptability score at 18 months and later cognitive function most likely reflects a ceiling effect in relatively healthy infants, as most typically developing children have already achieved the maximum adaptability score at 18 months.

The most pronounced associations were found between the IMP performance domain and later IQ: the group with slow performance development had a 13 points lower IQ than the typically developing group. Our results are in line with the majority of existing studies which found that age of attainment of motor milestones in infancy is inversely related to later intellectual function, adult executive functioning, and adult educational level in typically developing individuals. Motor performance may be regarded as the net result of the infant’s motor repertoire (variation) and the ability to select from it. Therefore, we hypothesize that both motor performance and intellectual function reflect the overall integrity of cortico-subcortical circuitries. The IMP has a very detailed way of...
assessing motor performance, which might have contributed to the large difference in IQ we found.

The IMP domains of fluency and symmetry were not consistently associated with later IQ. Movement fluency is very sensitive to slight perturbations of the nervous system, and therefore a certain degree of reduction of movement fluency often occurs and is considered to have little clinical importance. With respect to movement symmetry, in general two types of asymmetry may occur during development: subtle motor asymmetries that are present at a very young age and usually disappear over time, and, on the other hand, profound asymmetries that increase with age and result in serious motor impairments, such as unilateral cerebral palsy. We did find a weak correlation between the symmetry score at 4 months and later IQ, but symmetry scores at older ages were not associated with IQ. The latter presumably reflects the low-risk nature of our study group, without clinically relevant, pathological asymmetries.

The strengths of the study are the relatively large study group and the detailed assessments of motor behaviour and cognitive function with the IMP and K-ABC-II. Another strength is that the assessors were blinded with respect to IMP scores at 4 years of age. A limitation might be that this study was performed in children from the Groningen ART cohort born to subfertile parents with or without the help of ART, and therefore the results cannot be generalized to the general population. It is known that the severity of subfertility is associated with non-optimal neurodevelopment. It is possible that the slightly broader spectrum of neurodevelopmental outcome in the ART population compared with the general population facilitated the detection of the associations between motor development and IQ. Therefore, we suggest that future studies address the associations between motor variation, adaptability and performance, and later IQ in the general, typically developing population, and in high-risk populations such as infants born very preterm. In addition, future research might address the predictive value of IMP scores in infancy for cognitive function at school age.

CONCLUSION

The present study showed a clear relationship between infant motor development and cognitive function at 4 years in children born to subfertile parents. Low total IMP scores and low scores on motor variation and performance were associated with a significantly lower IQ at 4 years. We hypothesize that this is explained by the involvement of extensive cortico-subcortical neural networks and brain structures, such as the frontal cortex and the cerebellum, in both motor and cognitive functions. To elucidate this further, additional research is needed, preferably including functional neuroimaging.

ACKNOWLEDGEMENTS

We thank participating parents and children for their cooperation and enthusiasm during the assessments; Arend F Bos and Karin J Middelburg for their help in initiating the original study and Maaike Haadsma for her help in including the participants; Rosan Aapkes, Elise Bennink, Hanneke Geut, Marjolein Jongbloed-Pereboom, Jorien Sengers, Aisha Sinot, and Bertine de Vries for support in collecting and organizing the data; and Michiel Schrier, Linde Dijkstra, Anneke Kracht-Tilman, and Loes de Weerd for technical assistance. The Groningen ART cohort study was financially supported by the University Medical Center Groningen, grant number 754510, the Junior Scientific Masterclass, the Postgraduate School Behavioural and Cognitive Neurosciences, and the Cornelia Foundation, Groningen, the Netherlands.

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