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On the relationship between motor performance and executive functioning in children with intellectual disabilities

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Abstract

Background It has been suggested that children with intellectual disabilities (ID) have motor problems and higher-order cognitive deficits. The aim of this study was to examine the motor skills and executive functions in school-age children with borderline and mild ID. The second aim was to investigate the relationship between the two performance domains.
Methods Sixty-one children aged between 7 and 12 years diagnosed with borderline ID (33 boys and 28 girls; $71 < IQ < 79$) and 36 age peers with mild ID (24 boys and 12 girls; $54 < IQ < 70$) were assessed. Their abilities were compared with those of 97 age- and gender-matched typically developing children. Qualitative motor skills, i.e. locomotor ability and object control, were evaluated with the Test of Gross Motor Development (TGMD-2). Executive functioning (EF), in terms of planning ability, strategic decision-making and problem solving, was gauged with the Tower of London (TOL) task.
Results Compared with the reference group, the full ID cohort scored significantly lower on all assessments. For the locomotor skills, the children with mild ID scored significantly lower than the children with borderline ID, but for the object control skills and the TOL score, no significant differences between the two groups were found. Motor performance and EF correlated positively. At the most complex level, the TOL showed decision time to be a mediator between motor performance and EF: the children with the lower motor scores had significantly shorter decision times and lower EF scores. Analogously, the children with the lower object control scores had longer execution times and lower EF scores.
Conclusions The current results support the notion that besides being impaired in qualitative motor skills intellectually challenged children are also impaired in higher-order executive functions. The deficits in the two domains are interrelated, so early interventions boosting their motor and cognitive development are recommended.

Keywords borderline and mild intellectual disability, children, motor profile, planning, problem solving, strategic decision-making

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Introduction

In the Netherlands, the prevalence of intellectual disabilities (ID) is estimated at 0.7% (Wullink *et al.*

2007). Children with ID are classified in borderline (70 < IQ < 80) or mild ID (49 < IQ < 71) (American Psychiatric Association 1994). ID can be characterised by substantial limitations in intellectual functioning, e.g. learning, reasoning and problem solving, and adaptive behaviour, such as conceptual, social and practical adaptive skills (American Association on Intellectual and Developmental Disabilities 2007). Besides the aforementioned limitations, their motor skills may also be compromised (Frey & Chow 2006; Simons *et al.* 2008). Using the Test of Gross Motor Development-2 (TGMD-2; Ulrich 2000), Frey & Chow (2006) showed that in the ages between 6 and 18 years children with mild ID scored lower on the locomotor and object control subtests than their typically developing peers, as did Simons *et al.* (2008).

The poor motor performance observed in children with borderline and mild ID has been suggested to be related to their impaired intellectual functioning. Piaget & Inhelder (1966) argued that cognitive development relies on motor functioning and recent findings also suggest that motor performance and higher-order cognitive functions, e.g. executive functioning (EF), are linked (Diamond 2000; Wassenberg *et al.* 2005; Ridler *et al.* 2006). Executive functions include the abilities of goal formation and planning, and the effective execution of goal-directed plans (Jurado & Rosselli 2007). These processes are dependent on prefrontal cortex and cerebellum activation (Schall *et al.* 2003; Wagner *et al.* 2006). Evidence for a relationship between motor performance and EF has been found in neurobiological studies based on spatial similarities and temporal similarities between the development of motor skills and EF. Spatial similarity indicates that motor and cognitive processes use the same brain structures. Temporal similarity signifies a parallel development of motor and cognitive processes, i.e. they develop in the same time span. With regard to the spatial similarities, several neuroimaging studies support the so-called cerebellum hypothesis, which states that the relationship between motor performance and EF is mediated by co-activation of the cerebellum (Diamond 2000; Ridler *et al.* 2006). Indeed, there is evidence to suggest that the neocerebellum is involved in motor learning as well as in cognitive learning, especially when a task is novel or when conditions change, in which case executive functions are heavily relied upon. Moreover, Ridler *et al.* (2006) concluded that the better the development of the primary, premotor and supplementary motor areas, the better the development of executive functions. With regard to the temporal similarities, motor functioning as well as EF showed an accelerated development between 5 and 10 years with a continued development into adolescence (Anderson *et al.* 2001; Anderson 2002).

There is also evidence from behavioural studies for a relationship between motor performance and EF. Studies in typically developing children proposed that motor performance and EF have several underlying processes in common that are related to planning, monitoring, and the detection and correction of errors. These processes all involve forward planning, response inhibition and working memory (Sergeant 2000; Piek *et al.* 2004; Wassenberg *et al.* 2005; Livesey *et al.* 2006; Roebers & Kauer 2009). To date, however, few studies have specifically investigated the potential interrelations between the motor performance and EF in children with atypical development. These studies showed that children with developmental coordination disorder were impaired on working memory (Alloway & Temple 2007; Piek *et al.* 2007), processing speed and set-shifting (Piek *et al.* 2007). Extremely preterm children were impaired on planning and inhibition (Marlow *et al.* 2007). As far as we know, motor performance, executive functions and the relationship between the two, have, to date, not been examined in children with ID. Furthermore, if a relationship can be established in this population, motor interventions may be developed to help reduce their cognitive deficit, as has been observed in several aging studies (Kramer *et al.* 1999; Scherder *et al.* 2005), and in studies with children who were overweight (Tomporowski *et al.* 2008) and typically developing adolescents (Budde *et al.* 2008).

Accordingly, the primary aim of the present study was to examine the motor skills and executive functions in school-age children with borderline and mild ID. The second aim was to investigate the relationship between the two performance domains. We adopted a qualitative approach i.e. a process-oriented test, the TGMD-2, to the assessment of motor skills (locomotor and object control skills). Earlier studies have shown that disadvantaged children have more problems with object control skills than with locomotor skills (e.g. Hartman *et al.* 2005). Therefore, we hypothesised that the children with ID score higher on the locomotor skills relative to the object control skills. In our evaluation of the children's executive abilities, we focused on planning ability, strategic decision-making and problem solving, because these skills are known to be important when learning or perfecting motor skills (Seyhan & Kayhan 1993; Smyth & Mason 1997).

Method

Participants

The children were recruited from three primary special-needs schools located in the northern regions of the Netherlands and included based on the details in their school files. Of all potential 6- to 12-year-olds, 111 children had an IQ below 80 and were thus eligible for participation. IQ was determined on the basis of results of individual intelligence testing obtained from school records. It has been measured by school psychologists as part of the regular diagnosis process. They used standardised tests such as the WISC-III (Kort *et al.* 2002), RAKIT (Bleichrodt *et al.* 1987) and Snijders-Oomen Niet-verbale intelligentie Test – Revisie) (SON-R) (Snijders *et al.* 2003). Fourteen children were subsequently excluded as they were diagnosed with Attention Deficit Hyperactivity Disorder or Autism Spectrum Disorders. The final study population included 97 children: 57 boys, 40 girls with a mean age of 9.76 years (age range = 7–12 years, SD = 1.50). Sixty-one children were classified as borderline ID (33 boys and 28 girls; mean age = 9.82, SD = 1.57; age range = 7–12 years; mean IQ = 75.23, SD = 2.72; IQ range = 71–79) and 36 children with mild ID (24 boys and 12 girls; mean age = 9.67, SD = 1.39; age range = 7–12 years; mean IQ = 62.25, SD = 3.55; IQ range = 54–70). The two groups did not differ significantly with regard to age ($t = 0.484$, $P = 0.630$), but there were significantly more boys in the mild ID group ($\chi^2 = 2.979$, $P = 0.011$). None of the children had a general medical condition which created deviations in motor competence.

From a mainstream primary school in the northern Netherlands 97 age- and gender-matched children were selected for participation. There were 57 boys and 40 girls. The children ranged in age from 7 to 12 years (mean age = 9.76, SD = 1.50) and their age was appropriate to their grade level.

Informed consent for the children's participation was obtained from the parent(s) and all procedures were in accordance with the ethical standards of the Faculty of Medical Sciences of the University Medical Centre Groningen, University of Groningen.

Materials

Motor assessment

To evaluate motor performance we used the TGMD-2, which assesses 12 gross motor skills in children, subdivided into two skill areas: locomotor (run, gallop, hop, leap, jump and slide) and object control (two-hand strike, stationary bounce, catch, kick, throw and underhand roll). Performance is rated by scoring the presence (1) or absence (0) of three to five qualitative criteria per skill, with each skill being executed twice. Thus, if a skill is tested on three performance criteria, its raw score can vary from 0 to 6. The highest total subtest score for the locomotor as well as object control skills is 48. Evidence of the reliability and validity of the TGMD-2 has been reported for typically developing children (Ulrich 2000; Evaggelinou *et al.* 2002) and children with ID (Simons *et al.* 2008).

Executive functioning (EF) assessment

To gauge the children's executive capacity we opted for the widely used Tower of London task (TOL; Shallice 1982), which specifically tests planning ability, strategic decision-making and problem solving (Shallice 1982; Lezak 1995; Anderson *et al.* 1996). The task is brief and easy to administer and readily comprehended by young children (Anderson *et al.* 1996). Using a board with three pegs of varying lengths and three differently coloured beads with holes (red, yellow and blue), participants have to solve 12 problems by transforming a certain start state into a depicted goal state by applying three rules: (1) only one bead can be moved at a time; (2) a bead cannot be moved while another is lying on top of it; and (3) the tallest peg can carry three beads, the middle peg two and the shortest peg only one bead. Participants are instructed to try and solve each problem in the minimum number of moves (as indicated by the experimenter), while a maximum of three trials is allowed to solve each problem. The 12 problems vary in difficulty with the goal state in level-1 problems having to be reached in two or three moves, in level-2 problems in two to four moves, and in five moves in level-3 problems. A problem is solved correctly when the goal state is achieved within the maximum number of moves allowed.

The TOL is rated by assigning 3, 2 or 1 point(s) per problem depending on the number of trials required to reach the goal state, with 3 reflecting one trial, 2 two trials and 1 three trials. The TOL total score is the sum of the scores for all 12 problems, with a maximum of 36. For planning ability, strategic decision-making and problem solving, the duration of the performance is also important. Therefore, two temporal measures were obtained: decision time, defined as the time elapsed between the presentation of a problem and the initiation of the first move on a trial (bead leaves peg), and execution time, i.e. the interval between the initiation of the first move to the completion of the final move on a trial [regardless of the (in)correctness of the move] (Oosterlaan *et al.* 2005). The variables decision and execution time were assumed to give additional information on underlying mechanisms of executive (dys)functioning: relatively short decision times and relative long execution times may be indicative of poor planning and may lead to poor performance on the TOL (Oosterlaan *et al.* 2005).

Results

Performance outcomes

The scores on the TGMD-2 and TOL of the two groups of children with ID (borderline and mild) were compared with those of the typically developing children by means of ANCOVA, with gender as covariate. The Bonferroni test was used for *post hoc* comparisons. The effect sizes were calculated according to Rosenthal & Rubin (2003) for the comparisons: (1) between the children with borderline ID and the matched sample of typically developing children; (2) between the children with mild ID and the matched sample of typically developing children; and (3) between the children with mild and borderline ID. The effect size can be considered small, $r = 0.1$, medium, $r = 0.3$ and large, $r = 0.5$ (Cohen 1988; Field 2005).

Table 1 lists the TGMD-2 sub-scale and the TOL total scores for the two ID groups and those of the typically developing children. Relative to the performance of typically developing children, the performance of the children with borderline and mild ID was poor as was reflected by their significantly lower scores on both TGMD-2 sub-scales and the TOL. Bonferroni *post hoc* comparisons showed significant differences between both ID groups and the typically developing children on both TGMD-2 subtests and the TOL. Relative to the performance of typically developing children, the differences were small in children with borderline ID and medium in the children with mild ID. For the locomotor skills, the children with mild ID scored significantly lower than the children with borderline ID, but for the object control skills and the TOL, no significant differences between the two groups were found. The TGMD-2 effect sizes revealed that the scores of both ID groups were relatively lower for the object control items than they were for the locomotor tests.

TGMD-2 subtest outcomes and the TOL total score

To look for associations between motor performance and EF, we ran a regression analysis with the total TOL score as the dependent and the locomotor score as the independent variable. The model was adjusted for age, gender and IQ. Analogously, we performed regression analyses with object control scores as the independent variable.

Table 2 shows the relationship between the TGMD-2 sub-scale scores and the TOL total scores for the two ID groups combined. Both the locomotor and the object control scores were positively and significantly related with the TOL scores. The analysis with the locomotor scores revealed a significant effect of age ($P = 0.014$), favouring the older children. There were no significant effects of gender and IQ.

Table 1 Estimated mean TGMD-2 sub-scale and TOL total scores for the two subgroups of children with intellectual disabilities (ID) and the typically developing children

	Mild ID	Borderline ID	Typically developing children			ES (r)		
	(n = 36)	(n = 61)	(n = 97)					
	M (SE)	M (SE)	M (SE)	F	P*	Mild ID – Typically developing children	Borderline ID – Typically developing children	Mild ID – Borderline ID
TGMD-2								
Locomotor skills	36.00^{ac} (0.79)	38.09^{bc} (0.61)	40.08^{ab} (0.48)	10.426	0.000	0.37	0.19	0.21
Object control skills	34.73^{a} (0.72)	35.53^{b} (0.55)	39.09^{ab} (0.44)	19.64	0.000	0.47	0.25	0.04
Total TOL score	25.20^{a} (0.62)	26.45^{b} (0.48)	28.15^{ab} (0.38)	9.518	0.000	0.36	0.19	0.14

* Statistically adjusted for gender.
^{a,b,c} Groups with the same letter were significantly different.
TGMD-2, Test of Gross Motor Development; TOL, Tower of London.

TGMD-2 performance and the TOL temporal outcomes per difficulty level

To investigate whether motor performance was related to shorter or longer decision times, we ran regression analyses with the decision time per difficulty level as the dependent and the locomotor score or the object control score as the independent variable. The model was adjusted for age, gender and IQ. We replicated these analyses with execution time per difficulty level as the dependent variables.

Table 3 illustrates the associations between the TGMD-2 sub-scale scores and the decision and execution times for the TOL per difficulty level.

Decision time

The locomotor scores were positively and significantly related with decision time at TOL level 3, reflecting shorter decision times for children with lower (poorer) locomotor scores. There was a significant effect of age ($P = 0.014$), reflecting shorter decision times for younger children. At the lower two levels no significant relationships emerged. The object control scores were also positively and significantly related with decision time, but now at levels 2 and 3, though not at level 1. At level 3, there was a significant effect of IQ ($P = 0.030$): the children with lower IQ scores had shorter decision times. There was no significant effect of gender.

Execution time

The locomotor scores were not significantly related to execution time, but, at level 3, there was a significant effect of age ($P = 0.042$) reflecting longer execution times for younger children. The object control scores were inversely and significantly related at difficulty level 3, reflecting longer execution times for children with lower (poorer) object control scores. Younger children had significantly longer execution times than older children ($P = 0.033$). There were no significant effects of gender and IQ.

Time as mediator in the motor performance–EF relationship

When motor performance correlated significantly with the TOL score and the two temporal mea-

Table 2 Relationship between the TGMD-2 sub-scale scores and the TOL total score for the full ID sample ($n = 97$)

	F	*B*	Beta	t	Δ R^2	*P*
Locomotor skills	6.879	0.250	0.304	3.131	0.230	0.002
Object control skills	5.480	0.224	0.266	2.245	0.192	0.027

Both models were adjusted for age, gender and IQ.
TGMD-2, Test of Gross Motor Development; TOL, Tower of London.

sures, we performed a regression analysis to determine whether decision or execution time were mediators in the motor–TOL relationship. First, motor performance was regressed on decision or execution time per difficulty level. Second, we examined the change in the parameter estimate for motor performance when decision or execution time was added to the model with TOL score as the dependent variable. We finally conducted the Sobel test for mediation to determine whether the change was in effect significant.

Decision time

For both TGMD-2 sub-scales, the Sobel test for mediation showed that decision time was a significant mediator of the effects of the locomotor and object control scores on TOL performance at difficulty level 3 only ($z = 1.862$, $P = 0.03$ and $z = 1.992$, $P = 0.02$, respectively): the children with lower TGMD-2 sub-scale scores had the shorter decision times and the lower TOL scores.

Execution time

Due to the absence of a statistically significant relationship with execution time, we did not conduct a Sobel test for the locomotor sub-scale. Execution time was found to be a significant mediator of the effect of the object control scores on TOL performance at difficulty level 3 ($z = 1.882$, $P = 0.03$): the children with lower object control scores had longer execution times and lower TOL scores.

Discussion

With our study, we showed that the locomotor and object control skills of primary school-age children with borderline and mild ID were less well developed than the skills of their typically developing peers. For the locomotor skills, the children with mild ID obtained significantly lower scores than the children with borderline ID, but for the object control skills, no significant difference between the two groups was found. In the two ID groups, the scores for object control were relatively lower than those for locomotor skills. Earlier studies of disadvantaged, deaf and visually impaired children also found the problems with object control to be more pronounced than the problems with locomotion (Goodway & Branta 2003; Hartman *et al.* 2005; Houwen *et al.* 2007). The complexity of object control skills and the way they are generally mastered may possibly account for the relatively poor experimental performance in these differently challenged populations. In contrast to locomotor skills, object control is generally practiced during play and sports, situations that require swift adaptation to changing environmental circumstances (Houwen *et al.* 2007) where successful execution also relies more heavily on executive functions. Furthermore, children with ID and motor problems will more often avoid participation in culturally normative activities like sports (Bouffard *et al.* 1996; Wall 2004; Frey *et al.* 2008), while other factors such as social and communication problems will inhibit their engagement in these activities even further (Townsend & Hassall 2007; Visscher *et al.* 2007; Siperstein *et al.* 2009).

Our finding that qualitative motor performance and EF are associated is in line with Wassenberg *et al.* (2005) who reported relationships in typically developing children between balance and ball skills and specific aspects of EF like working memory. Several factors may account for the observed relationship. First of all, motor activity and EF are closely coupled in terms of neural substrates (prefrontal cortex, cerebellum; Diamond 2000; Bonifacci 2004). Second, qualitative motor activity and

Table 3 Relationship between TGMD-2 sub-scale scores and the two temporal measures of the TOL per difficulty level in the full ID sample (*n* = 97)

	Difficulty level 1						Difficulty level 2						Difficulty level 3					
	F	**B**	**Beta**	**t**	**Δ R^2**	**P**	**F**	**B**	**Beta**	**t**	**Δ R^2**	**P**	**F**	**B**	**Beta**	**t**	**Δ R^2**	**P**
Decision time																		
Locomotor skills	1.032	0.279	0.122	1.124	0.043	0.264	0.885	0.314	0.138	1.268	0.037	0.208	4.532	0.464	0.229	2.327	0.088	0.022
Object control skills	1.201	0.419	0.178	1.385	0.05	0.169	1.83	0.685	0.292	2.305	0.074	0.023	3.865	0.559	0.269	2.208	0.144	0.03
Execution time																		
Locomotor skills	0.629	0.076	0.026	0.238	0.037	0.812	1.552	−0.514	−0.097	−0.905	0.064	0.368	3.564	−0.745	−0.147	−1.427	0.134	0.157
Object control skills	0.628	−0.09	−0.029	−0.226	0.027	0.822	2.11	−1.18	−0.218	−1.711	0.085	0.09	4.659	−1.538	−0.295	−2.457	0.17	0.016

All models were adjusted for age, gender and IQ.
TGMD-2, Test of Gross Motor Development; TOL, Tower of London.

EF are assumed to share certain underlying *skills*, in particular skill sequencing. The TGMD-2 appeals to skill sequence rather than the product of performance (Wiart & Darrah 2001), and skill sequence is also an important aspect of TOL performance (Levin *et al.* 1994). It has been assumed that for sequence production in general, individuals construct a mental plan prior to performance that specifies the content and ordering of sequence events. More specifically, motor sequencing is the serial order and integration of individual components to form smooth and efficient movement (Keele & Summers 1976; Lazarus 1990; Delevoye-Turrell *et al.* 2007). It is exactly in this mental sequence preparation that children with learning disabilities tend to have deficits (Kowalski & Sherrill 1992).

When their EF was stretched most, the children with the lower qualitative motor scores used shorter decision times, resulting in lower (poorer) EF scores. This suggests that the children with lower motor scores took less time to devise a mental plan prior to their performance. These results are conflicting with those from Piek *et al.* (2007) who found slower reaction times on a visual inspection task in children with developmental coordination disorder compared with typically developing children. A factor that may account for the different results in our study may be the difference in time pressure within the task. The visual inspection time task required the children to react to a stimulus as quickly as possible, while there is less time pressure during the execution of the TOL. The results of the present study suggest another underlying mechanism motor deficits and executive dysfunctioning share: failure to adequately inhibit responses in planning tasks, as poor inhibition leading to premature responding expresses itself in reduced decision times (Oosterlaan *et al.* 2005; Young *et al.* 2007). This phenomenon has also been observed in studies investigating differences in skill acquisition between novices and experts. Thus, expert chess players demonstrated *longer* planning times than non-expert chess players (Unterrainer *et al.* 2006), while skilled music performance is typically characterised by increased anticipatory behaviour and hence superior planning abilities (Drake & Palmer 2000). Studying sports performance in an experiment in which the participants could take as much time as needed to perform a novel task, Beilock *et al.* (2008) demonstrated that in both novice and skilled golf players longer planning times led to better performance. Our results accordingly add to the evidence that skilled performance differs from less skilled performance with regard to anticipatory behaviour in complex situations.

Our finding that the children with poorer object control skills and lower EF (TOL) scores needed more time executing the most complex EF tasks also supports earlier findings: Unterrainer *et al.* (2004) suggested that poor planning leads to a longer execution time due to planning activities while moving the beads.

Unfortunately, the cross-sectional nature of our study did not allow us to draw firm conclusions about the causality of the relationships we found. Diamond (2000) stated that both complex cognitive and motor development, in terms of fine motor control, bimanual coordination and visuomotor skills, continues into early adulthood, and that both cerebellum and prefrontal cortex reach maturity late (Luna & Sweeney 2001; Rubia *et al.* 2006). This consequently implies that motor performance affects cognitive functioning in children, and vice versa. Our study was, however, restricted to gross motor skills, but in a longitudinal study Murray *et al.* (2005) did find early gross motor development to be related to superior adult EF. Furthermore, Piek *et al.* (2008) found a relationship between early gross motor and later school aged cognitive development. Therefore, to learn more about the causality of the associations we observed in our cohorts of children with ID, we need longitudinal results.

However preliminary, the results of the present study do suggest that children with ID might benefit from a motor intervention that addresses their qualitative motor skills, especially those involving object control. An intervention directed at improving their motor sequencing abilities and anticipatory behaviour may further help to reduce the children's motor impairments by enhancing EF in terms of improving mental preparation and thus motor response in more complex situations.

Conclusion

The current study supports the notion that primary school-age children with ID experience problems with qualitative motor performance, especially object control skills, and executive functions. Furthermore, the motor and executive deficits seem to be related: poorer motor control results in poorer EF and vice versa. The results underscore the importance of timely motor interventions fostering the motor and cognitive development in this vulnerable population.

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