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The interrelationships between motor, cognitive, and language development in children with and without intellectual and developmental disabilities

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ABSTRACT

It is generally agreed that cognitive and language development are dependent on the emergence of motor skills. As the literature on this issue concerning children with developmental disabilities is scarce, we examined the interrelationships between motor, cognitive, and language development in children with intellectual and developmental disabilities (IDD) and compared them to those in children without IDD. In addition, we investigated whether these relationships differ between children with different levels of cognitive delay. Seventy-seven children with IDD (calendar age between 1;0 and 9;10 years; mean developmental age: 1;8 years) and 130 typically developing children (calendar age between 0;3 and 3;6 years; mean developmental age: 1;10 years) were tested with the Dutch Bayley Scales of Infant and Toddler Development, Third Edition, which assesses development across three domains using five subscales: fine motor development, gross motor development (motor), cognition (cognitive), receptive communication, and expressive communication (language). Results showed that correlations between the motor, cognitive, and language domains were strong, namely .61 to .94 in children with IDD and weak to strong, namely .24 to .56 in children without IDD. Furthermore, the correlations showed a tendency to increase with the severity of IDD. It can be concluded that both fine and gross motor development are more strongly associated with cognition, and consequently language, in children with IDD than in children without IDD. The findings of this study emphasize the importance of early interventions that boost both motor and cognitive development, and suggest that such interventions will also enhance language development.

1. Introduction

Early in life, children go through a period of incredible growth and learning. The emergence of motor milestones is an important part of typical development in infants (Adolph & Joh, 2007; Leonard & Hill, 2014). However, the importance of motor development goes beyond the attainment of new motor skills. The development (and thus improvement) of motor skills provides infants with new opportunities for learning about their environment (Adolph & Joh, 2007; Von Hofsten, 2009).

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Being able to act upon their environment allows children to gain knowledge about their surroundings, which leads to changes in various perception-action systems (Von Hofsten, 2009). These changes bring about advances in cognition and language[1], which in turn will affect how children examine and manipulate their environment (Campos et al., 2000; Iverson, 2010). The idea that there is a relationship between motor and cognitive development, and consequently between motor and language development[2], stems in part from the embodied cognition perspective, in which cognition, and language as a subdomain of cognition, are considered to occur in the context of the individual's bodily interaction with the physical and social environment (Barsalou, 1999; Gibbs, 2005; Oudgenoeg-Paz, Volman, & Leseman, 2012; Smith & Gasser, 2005).

There is a growing body of neurophysiological and neuroimaging evidence that is consistent with this perspective. Neuroimaging techniques have shown that regions important to motor performance and cognition such as the cerebellum, dorsolateral prefrontal cortex, and the connecting structures (including the basal ganglia) are co-activated in certain motor and cognitive tasks. This confirms the mutual association between these two domains (Abe & Hanakawa, 2009; Diamond, 2000; Hanakawa, 2011). Furthermore, areas of the brain implicated in language functions (e.g., Broca's area) are also activated during motor tasks (i.e., action planning, action observation, action understanding, and imitation; Nishitani, Schürmann, Amunts, & Hari, 2005) and the activation of motor areas has been observed during language tasks (e.g., Hauk, Johnsrude, & Pulvermüller, 2004; Pulvermüller, 2005; Willems & Hagoort, 2007).

Evidence for the relationship between motor and cognitive development and between motor and language development can also be found in behavioural studies. Recent developmental work has revealed associations between motor maturity in infancy and changes in cognition (Woodward, 2009) and language (Oudgenoeg-Paz et al., 2012). Moreover, embodied effects on cognition and language are prevalent throughout childhood and into adulthood as well (Kontra, Goldin-Meadow, & Beilock, 2012). Both normative studies and those examining children with atypical development have shown a link between motor performance and cognition (Estil, Whiting, Sigmundsson, & Ingvaldsen, 2003; Marlow, Hennessy, Bracewell, & Wolke, 2007; Piek et al., 2004; Piek, Dawson, Smith, & Gasson, 2008; Rigoli et al., 2013; Wassenberg et al., 2005) and between motor performance and language (Alcock & Krawczyk, 2010; Cheng, Chen, Tsai, Chen, & Cherng, 2009; Wang, Lekhal, Aarø, & Schjølberg, 2014b). Similar results have been found in healthy adults and adult patients (e.g., Camicioli, Wang, Powell, Mitnitski, & Rockwood, 2007; García & Ibáñez, 2014). This evidence highlights the enduring nature of the relationship between the motor domain and the cognitive and language domains, although studies vary in sample characteristics and the particular skills that were examined.

Although motor, cognitive, and language development may share several underlying processes in both typical and atypical populations, the correlation between these developmental domains might be stronger in children with atypical development than in typically developing children (Dyck, Piek, Hay, Smith, & Hallmayer, 2006; Roebers & Kauer, 2009). It has been suggested that the stronger correlations between developmental domains in children with atypical development reflect abnormal dependences between neurocognitive processes (Dyck et al., 2006; Martin, Tigera, Denckla, & Mahone, 2010). More specifically, Martin et al. (2010) argued that a relationship between novel and complex movements and cognitive processes can be found in typically developing and atypically developing samples due to shared neural substrates and neurological integrity in general, whereas a relationship between simple movements and cognitive processes will only be found in clinical samples, based on underlying neurodevelopmental weakness. It would be interesting to measure and compare the strength of such relationships in typically developing children and specific populations (e.g., children scoring higher/lower on cognitive skills and/or motor skills; Van der Fels et al., 2015).

In addition, there are discrepancies concerning whether or not there is a global-to-global relationship between the motor domain and the cognitive and language domains. Some studies have found that certain cognitive skills are only associated with gross (relatively 'big' movements such as throwing and jumping) and not fine motor skills (relatively delicate movements, such as grasping and putting beads on a rod) (Piek et al., 2008; Rigoli, Piek, Kane, & Oosterlaan, 2012), while other studies found results to the contrary (Livesey, Keen, Rouse, & White, 2006; Rigoli et al., 2013). A recent review showed that there is little evidence to support a global relationship between the motor and cognitive domain in typically developing children aged 4–16 years (Van der Fels et al., 2015). More support has been found for specific associations: results from studies using cross-sectional designs have shown associations between specific aspects of motor performance and cognition. Specifically, fine motor skills showed the strongest relationship with higher order cognitive skills (Van der Fels et al., 2015). Whether these findings also hold true for younger children or children with disabilities is not yet clear. It has been suggested that whether or not a relationship is found between certain motor and cognitive skills may depend on the assumed direction of the relationship, the presence of movement difficulties, and the developmental level of the child (Rigoli et al., 2013). With regard to language, the question of whether there are specific relationships between different sub-areas of motor development (i.e., fine and gross) and different domains of language (i.e., expressive or receptive language skills) remains to be answered.

[1] Cognition and language are broad concepts that have been defined in a number of different ways. In the current article, 'cognition' is defined as the mental acts or processes for acquiring knowledge and understanding through thought, experience, and the senses. 'Language' is seen as a systematic means of communicating ideas or feelings through the use of conventionalized signs, sounds, gestures, or marks which have understood meanings. In broad terms, language can be divided into two categories: receptive language (understanding what is said or written) and expressive language (use of words, sentences, gestures and writing to convey meaning and messages to others).

[2] Cognition and language are interrelated, both practically and conceptually, although there is considerable disagreement among experts about the precise nature of this relationship. This discussion is, however, beyond the scope of this article, and therefore will not be dealt with here.

Despite the apparent coupling of motor development with cognitive and language development and atypicalities reported in motor skills (e.g., Rintala & Loovis, 2013; Van der Putten, Houwen, & Vlaskamp, 2015; Westendorp, Houwen, Hartman, & Visscher, 2011; Wuang, Wang, Huang, & Su, 2008) and language (e.g., Roberts, Price, & Malkin, 2007; Van der Schuit, Segers, van Balkom, & Verhoeven, 2011) in children with intellectual and developmental disabilities (IDD), relatively few studies have considered the relationships between these developmental domains in this specific group. Hartman, Houwen, Scherder, and Visscher (2010) showed significant relationships between gross motor skills and planning (higher-order cognitive skill) in a study of 61 school-age children with borderline intellectual disability and 36 age-matched peers with mild intellectual disability. Wuang et al. (2008) found strong relationships between overall motor performance and total IQ in 7- to 8-year-old children with mild intellectual disability. Furthermore, they showed that specific cognitive predictors (processing speed and verbal comprehension) explained almost twice as much variance in fine motor skills compared to gross motor skills. To the best of our knowledge, no data are yet available on the relationships between motor and cognitive development in children, including young children, with more severe IDD, or the influence of severity of IDD on this relationship. Furthermore, at this point little is known about the relationship between motor and language development in children with IDD. This points to the need to investigate whether similar relationships exist along a developmental continuum, extending to young children and severely developmentally delayed children.

Therefore, the primary aim of this study was to explore and compare the relationships between motor, cognitive, and language development in samples of children with and without IDD and a developmental age below 3;6 years. This is imperative, given the changes that occur in the motor, cognitive, and language domains during the early years. The identification of areas of cognitive deficit with reference to compromised motor function will allow specific recommendations for intervention strategies to be made.

The second aim of the study was to extend previous research by examining the strength of possible relationships between motor, cognitive, and language development in subgroups of children with IDD, defined on the basis of the level of cognitive delay (mild/moderate versus severe/profound). Previous research has shown that more severe cognitive problems are related to an increased range and severity of co-morbid problems such as poor motor coordination (e.g., Beckung, Steffenburg, & Uvebrant, 1997). We therefore expect the relations between motor, cognitive, and language development to be stronger in children with severe or profound cognitive delay than in children with mild or moderate cognitive delay. Thus, we formulated the following research questions: (i) How are motor, cognitive, and language developmental levels related in children with and without IDD, and with a developmental age below 3;6 years? (ii) Is there a difference between children with different levels of IDD in terms of the relationships between motor, cognitive, and language developmental levels?

2. Method

2.1. Participants

The test results from a developmental assessment of two groups of children were analysed: 'children with IDD' and 'children without IDD'. Both samples were taken from a larger sample of children who took part in a large-scale study (Visser, 2014) on the Special Needs Addition to the Dutch Bayley Scales of Infant and Toddler Development, Third Edition (Bayley-III-NL; Bayley, 2006; Van Baar, Steenis, & Verhoeven, 2014a). We included all children who were tested with the standard Bayley-III-NL, without the Special Needs Addition. Ethical permission was provided by the Medical Ethical Committee of the University Medical Center Groningen, the Netherlands.

2.1.1. Children with IDD

This group consisted of 77 children with IDD. The eligibility criteria were: (1) the child was receiving early intervention services because he/she was diagnosed with or 'at risk' of IDD, (2) the child had a maximum estimated developmental age of 3;6 years and a maximum calendar age of 10;0 years, and (3) the child had a cognitive developmental quotient of 70 points or lower on the Bayley-III-NL. The referring specialist decided which children to refer on the basis of inclusion criteria 1 and 2 above and thus determined whether or not a child was diagnosed with or at risk of IDD. In the current study, we added the third inclusion criterion. The cut-off point of 70 was chosen because it is the usual score used for the classification of an intellectual disability (Cooper, 2014; Edwards & Sarwark, 2005; Schalock et al., 2010). We chose to include the cognitive level as a selection criterion because cognitive deficits are the hallmark characteristic of IDD. Although cognition and intelligence (and thus intellectual disability) are two different constructs, they are very much related (Blair, 2006).

The sample included young children as well as school-age children with severe or profound cognitive delay. Furthermore, the sample included children with specific syndromes associated with IDD (e.g., Down syndrome) as well as undifferentiated developmental delays. The mean calendar age was 4;9 years (sd 2;3 years, range 1;0 to 9;10 years) and the mean developmental age was 1;8 years (sd 0;9 years, range 0;4 to 3;6 years). There were 36 boys and 41 girls. Table 1 presents information about the diagnoses and functional impairments of the children.

2.1.2. Children without IDD

This group consisted of 130 children without IDD, as defined by the inclusion criteria: (1) no known developmental disabilities and (2) a cognitive developmental quotient of 70 points or higher on the Bayley-III-NL. The mean calendar age

Table 1
Diagnosis and functional impairment(s) of the children with intellectual and developmental disabilities.

Functional impairment	None	Motor	Visual	Hearing/ language	Motor & visual	Motor & hearing/ language	Motor & visual & hearing/ language	No information	Total
Diagnosis									
Unspecified	16	1	1	4	0	1	1	3	27 (35%)
Down syndrome	7	0	0	5	0	2	0	0	14 (18%)
Phelan-McDermid Syndrome	1	0	1	0	0	0	0	10	12 (16%)
PDD	1	0	0	3	1	2	0	0	7 (9%)
Hydrocephalus	6	0	0	0	0	0	0	0	6 (8%)
Other genetic disorder	1	0	0	0	0	2	1	0	4 (5%)
PDD & Other	0	0	1	0	0	0	0	0	1 (1%)
Other	2	0	0	2	1	1	0	0	6 (8%)
Total	34 (44%)	1 (1%)	3 (4%)	14 (18%)	2 (3%)	8 (10%)	2 (3%)	13 (17%)	77 (100%)

Note: PDD = pervasive developmental disorder.

was 1;10 years (sd 1;1 years, range 0;3 to 3;6 years). These numbers were identical for the mean cognitive developmental age. There were 56 boys and 74 girls. The children were mainly from the north of the Netherlands and had the following nationalities: 122 Dutch, four from another European country, one from a non-western country, and three unknown. The educational level of the mother was: 52 low, 40 medium, 34 high, and four unknown.

2.2. Instruments

Data regarding the development of the children were gathered in the earlier study (Visser, 2014) using the Bayley-III-NL, which assesses the developmental level of children with a calendar age between 0;1 and 3;6 years. It is also used to assess children who are older but who have an expected developmental age within this range (Van Baar et al., 2014a, p. 8). The instrument consists of three main scales–Cognitive, Language and Motor–tested on five subscales: Cognition (91 items), Receptive Communication (49 items), Expressive Communication (46 items), Fine Motor Development (66 items), and Gross Motor Development (72 items). The instrument was chosen because it clearly provides information about the three different domains of development relevant to this study (cognition, language, and motor development) and it is the instrument most widely used to assess the development of young children (Johnson, Moore, & Marlow, 2014).

The administration of the instrument consists of playing with a child using various test materials and scoring the responses of the child to the instructions. Scoring is done dichotomously (pass/fail). The first item administered is decided on the basis of the child's calendar age. The basal rule is that the first three items should be scored positively, and the ceiling rule is that the administration of the subscale should be stopped when five consecutive items have been scored negatively. In other words, the administration of a subscale is stopped when a child fails five items in a row. The basal and ceiling rules are the same for each of the five subscales.

The items in each subscale are ordered on the basis of difficulty level. Consequently, by using the basal and ceiling rules, items are administered that fit the child's level of development. On average, about 15 items per child per subscale are administered. The Cognition subscale assesses abilities such as sensorimotor development, exploration and manipulation, object relatedness, concept formation, memory, and simple problem-solving. Items in the Cognition subscale include tasks such as completing puzzles and distinguishing colours and sizes. The Language Scale consists of subscales for Receptive Communication (word comprehension and the ability to respond appropriately to words and requests) and Expressive Communication (preverbal communication, vocabulary and syntactic development). Items in these two Language subscales include tasks such as responding to one's own name (for very young children) and naming objects and pictures. The Motor Scale consists of subscales for Fine Motor skills (grasping, perceptual-motor integration, motor planning, and speed) and Gross Motor skills (sitting, standing, locomotion, and balance). Items in these two Motor subscales include tasks such as sitting, crawling, walking (up and down stairs), building blocks and using a pencil. Some, but not all, items include a time limit, which means that the tester keeps track of the time and records it. The child is not aware of these time limits.

The items in the Dutch version are translations of the items in the United States version. Two items in the Expressive Communication subscale were deleted. At the time of data collection, Dutch norms for the Bayley-III were still under construction. The Dutch standardization was published at the end of 2014. It is based on a sample of 1953 children. The validity is supported by moderate correlations with test scores on other instruments. The inter-item relationships range from .53 to .98, depending on age groups and subscales, with the subscale average ranging from .81 to .90. Test-retest reliability coefficients range from .38 to .86, depending on age groups and subscales, and increase with age (Van Baar, Steenis, Verhoeven, & Hessen, 2014b).

2.3. Procedure

2.3.1. Recruitment of children with IDD

In the earlier study (Visser, 2014), the children were referred by a developmental psychologist from an organization in the Netherlands supporting young children with IDD. Informed consent was requested from the parents of the children through this psychologist, who also provided information about each child in advance. This information was required to prepare the administration of the test, and included age, diagnosis, and any special needs that had to be taken into account. The test administrator then planned and subsequently administered the test (standard Bayley-III-NL).

2.3.2. Recruitment of children without IDD

The earlier study (Visser, 2014) recruited the children without IDD in three different ways: through the local government, convenience sampling, and a study concerning a system that tracks the development of children in regular daycare (Smoorenburg, 2013). In this latter study, the children were tested with the standard Bayley-III-NL by test administrators also taking part in the study on the Special Needs Addition, and the results were used for the two studies simultaneously. The test results of all 130 children without IDD were also used in the standardization study of the Bayley-III-NL.

2.3.3. Procedure during test administration

The majority of the tests were administered by advanced students of psychology or special needs education, who had also received intensive training in administering the test. In addition, a minority of children were tested by one of the researchers or, in the case of the children with IDD, the developmental psychologist or test assistant of the referring organization.

Most test administrations on children with IDD took place at the referring organization which the child attended regularly. It was therefore a familiar place to them. A small number of tests took place at the university or the child's home. The children without IDD were tested at their daycare centre, at home, or in a testing room at the university. For all tests, the circumstances were kept the same as much as possible: a quiet room with a table to work on. If possible, a person who was familiar to the child (e.g., one of the parents) was present. If the child did not cooperate (e.g., refused or was distracted), the item was reported as non-scored and it was counted as a failed item (0 score) in the analyses.

2.4. Data analysis

We analysed the results using IBM SPSS Statistics 21. To answer the research questions, we needed data files with the children's test scores on the cognitive, language, and motor domains. To construct these files, we formed datasets on the item level containing the test results of children who were assessed with all five subscales of the Bayley-III-NL and we removed unreliable test administrations. We defined unreliable as having more than three non-scored items (in which the child did not cooperate, for example) on at least one of the subscales. We then calculated a developmental quotient (DQ) for each child. Because about half of the children in the IDD group were older than 42 months of age and the Bayley-III-NL was standardized for children with a calendar age of up to 42 months, we could not calculate standardized scores for all of the children. Therefore, we took the raw score and looked up the developmental age that is equivalent to it in the Bayley-III (Bayley, 2006). The developmental age equivalents were established on the basis of the American norms because Dutch norms were not yet available during the execution of this study. We did this for each of the subscales for all children. Subsequently, we used the function '(developmental age/calendar age) $\times$ 100' (Milne, McDonald, & Comino, 2012) to calculate a quotient score for each subscale. This quotient score (DQ) has an average of 100 and should be interpreted as the level of development as a percentage of the calendar age. This is fundamentally different from the index score of the Bayley-III-NL, which also has an average of 100, but has a standard deviation of 15. Generally, a DQ above 70 is considered within normal limits (Edwards & Sarwark, 2005). The IDD group was divided into a subgroup of children with mild to moderate cognitive delay (DQ 35–70) and a subgroup of children with severe to profound cognitive delay (DQ $<$ 35) on the basis of the DQ for the Cognition subscale (Batshaw, Roizen, & Lotrecchiano, 2013, p. 295).

Our research questions were focused on the relationships between motor, cognitive, and language development and difference therein between children with different levels of IDD. To answer these questions, we first of all expressed the children's developmental level by calculating descriptive statistics (mean, standard deviation, and range) of the raw test score, developmental age equivalent, and DQ on each of the five subscales for the children without IDD, the group of children with IDD as a whole, and separately for the two subgroups of children with IDD. We applied independent t-tests (with equal or unequal variances as appropriate) to test whether the differences observed between the scores described for each groups (i.e. with versus without IDD, and mild to moderate cognitive delay versus severe to profound cognitive delay) were significant. Unbiased effect sizes for t-tests are reported after applying Hedges correction to Cohen d_s (Hedges g_s) using the spreadsheet provided by Lakens (2013). To increase the interpretability of the results, we report the common language (CL) effect indicator (Lakens, 2013) that expresses the probability that a randomly sampled individual from one group in the current study has a higher value on one measurement than a randomly sampled individual from the other group.

The research question focused on the strength of relationships between motor, cognitive, and language developmental levels and on differences therein between the subgroups. Pearson correlation is the prescribed method for studying the strength of relationships between variables. We therefore calculated Pearson correlation coefficients for the group of children without IDD and the group of children with IDD as a whole, and scatterplots were used to facilitate the interpretation of the correlations. In addition, to explore whether correlations differed between the two IDD subgroups, correlation coefficients were calculated within the two subgroups. We used the Fisher z tests (2 tailed) between correlations (http://vassarstats.net/rdiff.html) to test whether the differences observed between the resulting correlation coefficients were significant. We used the categorization by Cohen (1988) to interpret the strength of the correlation coefficients: $r < .3$ = weak, $.3 \leq r < .5$ = moderate, and $r \geq .5$ = strong. Statistical significance was set at $p < .05$. The sample sizes of 77 and 130 are sufficient to detect medium and large effect sizes (Olejnik, 1984).

3. Results

3.1. Descriptive statistics

The results of the group comparisons (without IDD vs with IDD) on the raw scores, developmental age equivalents, and DQ per subscale of the Bayley-III are presented in Table 2. Means, standard deviations, ranges, t-test results, and effect sizes are reported. The differences between the groups in terms of raw scores and developmental age equivalents result from differences in developmental level as well as calendar age. The differences between the groups in terms of DQs result from differences in developmental level. The average DQ of the children in the control group was around 100 for all subscales, with the exception of the average Gross Motor DQ (M = 90). The average DQ of the children with IDD ranged from 35 to 44 for all of the subscales. Table 2 shows that differences in DQ between groups were significant for all subscales, with the group of children with IDD obtaining lower values. The effect size estimates of these between-group differences are situated in the large range. The CL effect sizes indicate that the chance that for a randomly selected pair of individuals the score of the individual from the group of children without IDD is higher than the score of the individual from the group of children with IDD is 98–99%.

Table 3 presents the means, standard deviations, ranges, t-test results, and effect sizes for the IDD subgroups. In all comparisons with regard to DQ, the means were higher for the children with mild to moderate cognitive delay. The effect size estimates of these between-subgroup differences are situated in the large range. The CL effect sizes indicate that the chance that for a randomly selected pair of individuals the score of the individual from the group of children with mild to moderate cognitive delay is higher than the score of the individual from the group of children with severe to profound cognitive delay is 90–99%.

For the Cognition subscale, the significant differences between groups is a logical consequence of the fact that the children were divided into the different groups on the basis of their DQ score on that subscale.

3.2. Associations between motor, cognitive, and language scores

Fig. 1 presents the scatterplots and corresponding correlation coefficients for DQ scores between the Motor, Cognitive, and Language Scales. Within the total group of children with IDD, correlations were moderate to strong, namely between

Table 2
Descriptive statistics for the Bayley-III-NL test scores for the children without IDD (n = 130) and the children with IDD (n = 77).

Scale	Score type	Without IDD	IDD	t-values	Hedges's g_s	CL effect size (%)
Cognition	Raw score: m (sd) range	56 (21) 10–86	55.5 (15.5) 22–80			
	DAE: m (sd) range	1;10 (1;1) 0;3–3;6	1;8 (0;9) 0;4–3;6			
	DQ: m (sd) range	103 (15) 73–145	39.8 (18.0) 5.5–69.1	26.23*	3.89	99
Fine motor	Raw score: m (sd) range	37 (14) 5–65	36.9 (9.3) 15–52			
	DAE: m (sd) range	1;11 (1;2) 0;3–3;6	1;11 (0;11) 0;4–3;5			
	DQ: m (sd) range	102 (15) 63–138	44.2 (21.6) 8.2–95.5	20.64*	3.25	99
Gross motor	Raw score: m (sd) range	47 (16) 13–69	51.0 (10.2) 26–68			
	DAE: m (sd) range	1;8 (1;1) 0;3–3;6	1;8 (0;10) 0;6–3;6			
	DQ: m (sd) range	90 (14) 59–130	39.8 (18.8) 8–85	20.58*	3.14	98
Receptive Comm.	Raw score: m (sd) range	24 (13) 6–46	20.6 (10.0) 4–39			
	DAE: m (sd) range	1;9 (1;2) 0;2–3;6	1;6 (0;11) 0;1–3;5			
	DQ: m (sd) range	95 (20) 48–139	35.4 (22.4) 1–87	19.59*	2.84	98
Expressive Comm.	Raw score: m (sd) range	26 (14) 4–46	20.9 (11.1) 3–43			
	DAE: m (sd) range	1;10 (1;2) 0;2–3;6	1;5 (0;10) 0;1–3;5			
	DQ: m (sd) range	101 (20) 45–161	34.7 (21.1) 1–98	22.78*	3.24	99

Note: DAE = developmental age equivalent in years; months; DQ = developmental quotient.
Comm. = communication; IDD = intellectual and developmental disabilities; CL = common language.
* $p < .001$.

Table 3
Descriptive statistics for the Bayley-III-NL test scores for the IDD subgroups.

Scale	Score type	Mild to moderate (n = 45)	Severe to profound (n = 32)	t-values	Hedges's g_s	CL effect size (%)
Cognition	Raw score: m (sd) range	60.9 (11.3) 29–80	47.9 (17.6) 22–79			
	DAE: m (sd) range	1;11 (0;7) 0;7–3;6	1;4 (0;10) 0;4–3;5			
	DQ: m (sd) range	52.7 (10.5) 35.5–69.1	21.6 (7.7) 5.5–34.5	14.97*	3.26	99
Fine motor	Raw score: m (sd) range	40.1 (6.9) 25–52	32.5 (10.5) 15–51			
	DAE: m (sd) range	2;2 (0;8) 0;9–3;5	1;6 (1;0) 0;4–3;5			
	DQ: m (sd) range	59.0 (14.6) 23.0–95.5	23.4 (8.9) 8.2–41.5	13.28*	2.81	98
Gross motor	Raw score: m (sd) range	53.2 (9.1) 26–68	47.8 (10.9) 26–67			
	DAE: m (sd) range	1;10 (0;9) 0;6–3;6	1;6 (0;10) 0;6–3;6			
	DQ: m (sd) range	50.2 (16.4) 22.9–85.1	25.3 (10.4) 8.3–53.9	8.16*	1.73	90
Receptive Comm.	Raw score: m (sd) range	23.9 (9.1) 8–39	15.8 (9.3) 4–38			
	DAE: m (sd) range	1;10 (0;10) 0;4–3;5	1;0 (0;10) 0;1–3;5			
	DQ: m (sd) range	48.9 (18.6) 8.5–86.5	16.5 (10.1) 0.6–38.2	9.85*	2.05	94
Expressive Comm.	Raw score: m (sd) range	24.6 (10.4) 7–43	15.7 (10.0) 3–40			
	DAE: m (sd) range	1;9 (0;10) 0;5–3;5	1;0 (0;9) 0;1–3;2			
	DQ: m (sd) range	46.7 (18.6) 12.0–97.7	17.8 (9.6) 1.2–35.9	8.92*	1.84	92

Note: DAE = developmental age equivalent in years; months; DQ = developmental quotient; Comm. = communication; Cl = common language.
* $p < .001$.

.61 and .94, and significant (all $p < .001$). The correlations between the Fine Motor subscale and the Cognition (.94) and Expressive and Receptive Communication subscales (.74 and .76) were stronger than the correlations between the Gross Motor subscale and the Cognition (.76) and Expressive and Receptive Communication subscales (.63 and .61). A similar pattern was seen for the children without IDD, albeit with lower correlations, namely between .24 and .56. The z tests revealed significant differences in relationships between subscales, with the exception of the relationship between Gross Motor DQ and Receptive Communication DQ ($z = -1.87$, $p = .062$). Specifically, the pair-wise comparison of correlation coefficients proved significant for the Gross Motor DQ correlation to the Cognition DQ ($z = -5.14$, $p < .001$) and the Expressive Communication DQ ($z = -3.18$, $p < .001$), and for the Fine Motor DQ correlation to the Cognition DQ ($z = -7.56$, $p < .001$), the Expressive Communication DQ ($z = -3.35$, $p < .001$), and the Receptive Communication DQ ($z = -3.41$, $p < .001$), showing stronger correlations for the children with IDD compared to children without IDD.

Partial correlations between the Fine and Gross Motor and the Expressive and Receptive Communication subscales were also conducted with the Cognition DQ as a covariate because cognitive level varied so widely and was significantly correlated with the Expressive and Receptive Communication subscales for both the children with IDD (Cognition DQ-Expressive Communication DQ: $r = .76$, $p < .001$; Cognition DQ-Receptive Communication DQ: $r = .77$, $p < .001$) and the children without IDD (Cognition DQ-Expressive Communication DQ: $r = .39$, $p < .001$; Cognition DQ-Receptive Communication DQ: $r = .47$, $p < .001$). The partial correlations showed that when cognitive level was taken into account, the correlations between the Fine and Gross Motor subscales and the Receptive and Expressive Communication subscales no longer reached significance in the group of children with IDD (Gross Motor DQ-Expressive Communication DQ: $r = .13$, $p = .256$; Gross Motor DQ-Receptive Communication DQ: $r = .05$, $p = .654$; Fine Motor DQ-Expressive Communication DQ: $r = .13$, $p = .276$; Fine Motor DQ-Receptive Communication DQ: $r = .17$, $p = .134$), meaning that the relationships found between the Receptive and Expressive Communication subscales and the Fine and Gross Motor subscales are largely the result of the fact that they are all correlated with cognition. In the group of children without IDD, the correlations were somewhat lower, but remained significant (Gross Motor DQ-Receptive Communication DQ: $r = .35$, $p < .001$; Fine Motor DQ-Expressive Communication DQ: $r = .28$, $p = .001$; Fine Motor DQ-Receptive Communication DQ: $r = .26$, $p = .003$), with the exception of the correlation between the Gross Motor DQ and the Expressive Communication DQ ($r = .13$, $p = .141$).

For the IDD subgroups, correlations varied from .25 to .82 (see Table 4). The correlations showed a tendency to increase with the severity of IDD, with the exception of the correlation between the Fine Motor DQ and the Cognition DQ and the Gross Motor DQ and the Receptive Communication DQ. However, when comparing the correlation coefficients, a significant difference was only found for the correlation between the Gross Motor DQ and the Expressive Communication DQ ($z = -1.79$, $p = .037$).

Partial correlations with the Cognition DQ as covariate showed that the correlations between the Fine and Gross Motor and the Receptive and Expressive Communication subscales no longer reached significance in the subgroups of children with IDD (all $r < .34$, all $p > .05$).

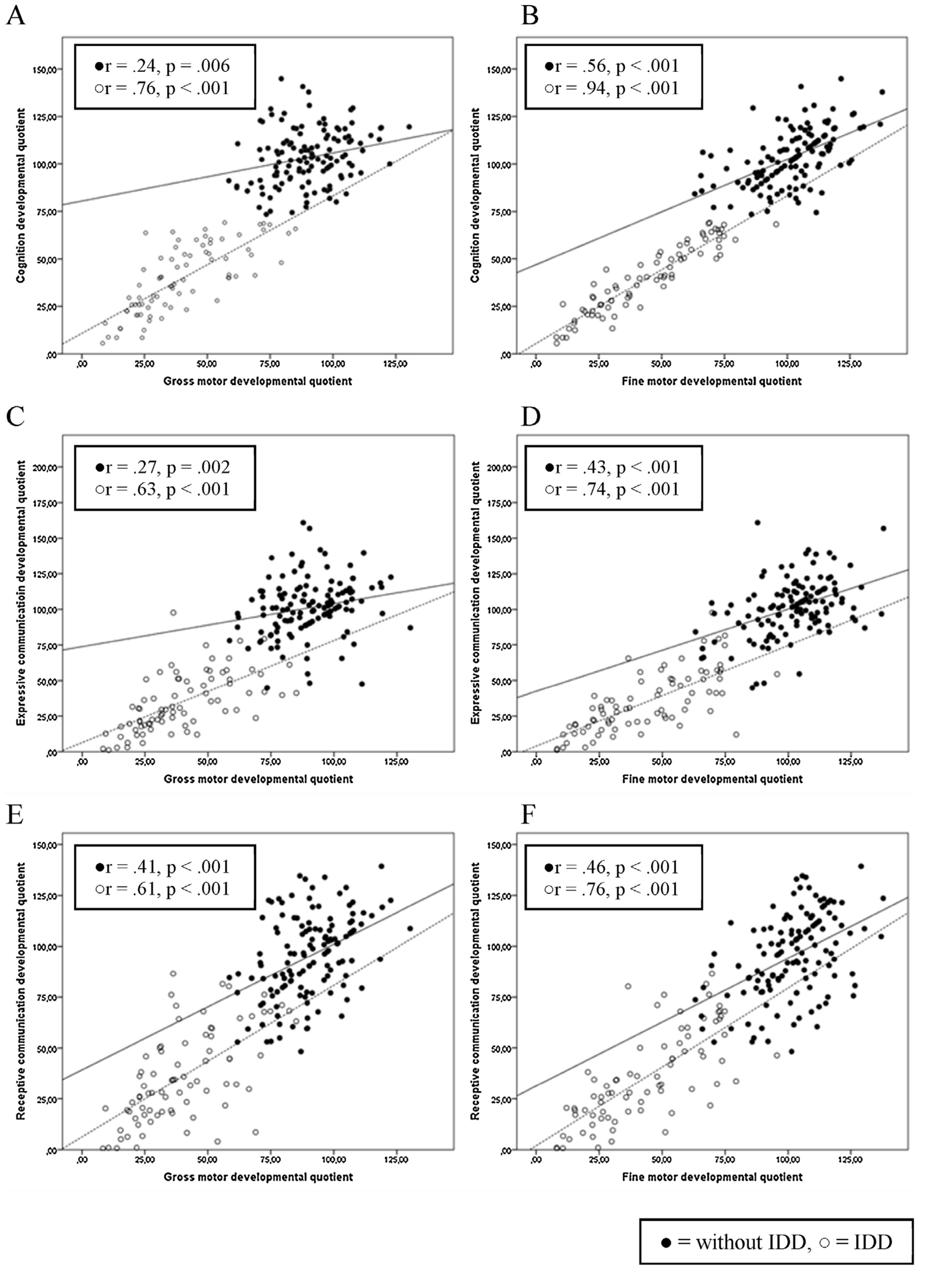

Fig. 1. Scatterplots of (A) Gross motor DQ versus Cognition DQ, (B) Fine motor DQ versus Cognition DQ, (C) Gross motor DQ versus Expressive communication DQ, (D) Fine motor DQ versus Expressive communication DQ, (E) Gross motor DQ versus Receptive communication DQ, and (F) Fine motor DQ versus Receptive communication DQ.

Table 4
Correlations between DQs for IDD subgroups.

	Mild to moderate ($n = 45$)	Severe to profound ($n = 32$)	Fisher z
Fine motor DQ–Cognition DQ	.82***	.69***	1.28
Gross motor DQ–Cognition DQ	.47***	.63***	−.96
Fine motor DQ–Receptive Comm. DQ	.42**	.47**	−.26
Gross motor DQ–Receptive Comm. DQ	.26	.25	.04
Fine motor DQ–Expressive Comm. DQ	.39**	.57***	−.98
Gross motor DQ–Expressive Comm. DQ	.27	.61***	−1.79*

Note: DQ = developmental quotient; Comm. = communication.
* $p < .05$.
** $p < .01$.
*** $p < .001$.

4. Discussion

4.1. Main findings

The current study considered the relationship between motor, cognitive, and language development in both children with IDD and children without IDD. The results highlight the strong relationships between these developmental domains in children with IDD. For the subgroups of IDD, correlations between the three domains ranged from weak to strong, with correlations showing a tendency to increase with the severity of IDD. This result suggests that the severity of the IDD might play a moderating, albeit small role in the relationship between developmental domains. Furthermore, our results also highlight the critical role of cognitive development in mediating between motor and language development in children with IDD: the correlations between the scores on the Fine and Gross Motor and Expressive and Receptive Communication subscales were no longer significant when controlling for the score on the Cognition subscale.

Research examining the motor performance of children with IDD has been limited, but results have consistently associated IDD with poor motor skills compared to peers without IDD (e.g., Westendorp et al., 2011; Wuang et al., 2008). Our study moved beyond typical age comparisons and included a comparison group based on developmental age (mental age). A comparison group based on mental age permits the exploration of potential deviances in development by considering the extent of delays relative to developmental level (Burack, Iarocci, Bowler, & Mottron, 2002). The current results showed that despite being closely matched on mental age, children with IDD had significantly lower fine and gross motor skills and these differences cannot merely be attributed to cognitive level.

The present study revealed substantial correlations between developmental domains in both children with IDD and without IDD. An important finding in our study was that skills in the various domains are more strongly interrelated in children with IDD compared to children without IDD, supporting the notion that the relationship between developmental domains is stronger in atypical populations (Dyck et al., 2006; Martin et al., 2010; Roebers & Kauer, 2009). In addition, the correlations found between developmental domains in the children without IDD in the present study are comparable to or slightly higher than those found in previous studies involving older typically developing children (Van der Fels et al., 2015; Wang, Lekhal, Aarø, Holte, & Schjolberg, 2014a). It is plausible that the nature of the relationship at this young age (developmental age < 3;6 years) is different from that of older children: movement acts as a control parameter for the development of cognitive functions in young children, but the relationship is more reciprocal in later childhood (Rigoli et al., 2013). In addition, Wang et al. (2014a) indicated that the relationship between the motor and language domains before the age of three is different from development after this age.

That children with IDD often exhibit motor problems is not a novel finding, but the mechanisms underlying the coexistence of motor and cognitive impairments are still unclear. There are several theoretical accounts addressing the link between motor and cognitive development, including language, in the literature. One contributing factor to the correlation between children's motor and cognitive skills may be biological maturation (Dyck, Piek, Kane, & Patrick, 2009; Roebers et al., 2014). The relationship between motor and cognitive development may be due to variations in neurological maturation or neurological abnormalities. Support for this idea comes from research on children with neurodevelopmental disorders such as developmental coordination disorder, autism, and speech/language impairment, which shows a substantial comorbidity between poor motor skills and several aspects of cognitive dysfunction (Diamond, 2000; Hill, 2001). According to the embodied cognition perspective, there is a reciprocal relationship between sensory-motor systems and higher-order cognitive functions. On a neuroanatomical basis, the co-activation of brain areas such as the cerebellum, the dorsolateral prefrontal cortex, and the connecting structures (including the basal ganglia) explains the relationship between motor and cognitive development. Magnetic resonance imaging research on children with IDD has shown that in comparison with controls, children with IDD have a higher incidence of brain anomalies (Baglio et al., 2014; Decobert et al., 2005; Van Karnebeek, Jansweijer, Leenders, Offringa, & Hennekam, 2005). Baglio et al. (2014) found increased regional grey matter volume in the bilateral sensorimotor and right posterior temporal cortices and decreased grey matter volume in the right parahippocampal gyrus in children with borderline intellectual functioning compared to an age-matched control group. In addition, Carducci et al. (2013) found decreased grey matter volume in the cerebellum, frontal lobes, and the hippocampus, as well as a decrease of white matter volume in the left cerebellum, frontal and parietal lobes in children and adolescents with Down Syndrome compared to an age-matched control group. These findings may help us understand why weak results on cognitive and language tasks are associated with poorer results on motor tasks and vice versa. In addition, Van Karnebeek et al. (2005) noted in their systematic review of the literature that more brain abnormalities were found in children with moderate to profound IDD versus those with borderline to mild IDD.

An alternative account is provided by Luo, Jose, Huntsinger, and Pigott (2007). They argued that environmental factors such as family characteristics and parenting practices similarly affect motor and cognitive development. For example, children with lower IQs need more time to learn a motor skill. Hence, early recognition and the influence of environmental factors need to be taken into account when examining motor and cognitive development (Smits-Engelsman & Hill, 2012). Thus, it is also important to acknowledge the role of individual experiences in the relationship between motor, cognitive, and language development. The present study cannot provide an explanation for the relationships between the different developmental domains. In order to answer this question, future research should examine biological maturation, the effects of practice on motor skills, and consider multiple measures of motor, cognitive, and language development over the period of early childhood.

Another interesting result was that the Fine Motor subscale had higher correlations with the Cognitive and Expressive and Receptive Communication subscales than the Gross Motor subscale. In addition, the children with severe to profound cognitive delay had lower scores on the Fine Motor subscale than the Gross Motor subscale compared to the children with mild to moderate cognitive delay. These results are consistent with studies in typically developing children (Van der Fels et al., 2015) as well as in school-age children with IDD (Vuijk, Hartman, Scherder, & Visscher, 2010; Wuang et al., 2008). Wuang et al. (2008) suggested that the difference between scores on gross motor skills and fine motor skills is due to the fact that fine motor skills place greater demand on the maturity and integrity of the cortical nervous system, in particular, the frontoparietal network (see also Davare, Andres, Cosnard, Thonnard, and Olivier, 2006).

4.2. Study limitations

This study has some limitations. First, the sample of children with IDD from which the data were collected was quite heterogeneous with regard to problems experienced. In the present sample, we did not have sufficient data to conduct separate analyses for different subsamples of IDD, but this would be an interesting future study. However, this group is representative of the children generally found in Dutch special education centres and may therefore be regarded as an ecologically valid sample. Nevertheless, the generalizability of our results is, thus far, limited to the kinds of participants included in the sample, that is, clinically referred children. The children without IDD were selected to be part of that group if they had no known developmental disabilities and their developmental quotient score on the Bayley-III-NL was 70 or higher. There was no screening in addition to this, but we would argue that the above-mentioned criteria were sufficient to ensure that the children in this group did not have IDD. Second, the data are cross-sectional, which limits causal inferences. More research is needed on how the relationships between motor, cognitive, and language development unfold. Few longitudinal studies have provided evidence on the direction of the relationship between the motor, cognitive and language domains, although there is initial evidence that early motor development predicts later performance on complex cognitive tasks, including working memory (Murray, Jones, Kuh, & Richards, 2007; Piek et al., 2008; Ridler et al., 2006). Third, by using data from a previous study, we could not include additional measures. It would have been useful, for example, to obtain information about more specific motor, cognitive, and language skills of the children and see how they relate to each other in the different study groups. Fourth, the use of the Bayley-III with children who are older than 42 months of age has limitations. The Bayley-III was standardized for children with a calendar age of up to 42 months. This means that the suitability of the Bayley-III items for children who are older is not known. It also means that a standardized score cannot be calculated for older children. While a standardized score is well studied and the reliability and validity known, the age-equivalent score on which we based the DQ is less reliable and does not have a reliability interval. This means that the results of the current study must be interpreted with caution. The consequences of using the DQ for the results of a large-scale study the current one are, however, not as significant as would be the case when using the Bayley-III for testing individual children, even more so because it is not the DQ in itself that we were interested in, but the relationships between different DQs. Despite these limitations, this study contributes to the sparse literature available on the relationships between motor, cognitive, and language development in children with IDD.

4.3. Practical implications and future research

Our findings support the idea that motor development is not an independent process but has rich and complex relationships with the development of other, cognitive and language, domains. Based on these findings, it is suggested that any therapeutic strategy for young children with IDD, as well as school-age children with severe or profound cognitive delay, should focus not only on cognitive functions but also on motor skills. Research has shown that motor interventions are effective in improving motor skills in children with borderline to mild IDD (Westendorp et al., 2014) and children with severe to profound IDD (Houwen, Van der Putten, & Vlaskamp, 2014). Despite theoretical and practical links between motor and cognitive development in children with IDD, very little research has been done into the effects of motor interventions on cognitive and language outcomes in children with IDD (Houwen et al., 2014). Therefore, we should also be realistic, pointing out that neither practical nor theoretical links between motor, cognitive, and language development are sufficient to predict the efficacy of a motor-related intervention for children with IDD. However, a review of motor-related interventions designed to increase speech/language and social-communication skills in young non-verbal and minimally verbal children with autism has shown promising results (McCleery, Elliott, Sampanis, & Stefanidou, 2013). In addition, early motor-related interventions have been effective in advancing both motor and cognitive abilities in children with or at risk of disabilities (Lobo, Harbourne, Dusing, & McCoy, 2013). Nevertheless, it is important to examine whether motor-related interventions can also lead to improvements in cognitive and language abilities in young children with IDD as well as school-age children with severe to profound cognitive delay (Houwen et al., 2014).

It has been suggested that there may be sensitive periods in the relationship between different developmental domains, meaning that motor-related interventions focusing on other developmental domains may be most effective during an ideal time-window (McCleery et al., 2013). Depending upon the particular relationship being targeted, this time-window may be a sensitive chronological age or developmental age period (McCleery et al., 2013). In contrast, it has also been suggested that the influence of (sensori)motor experiences on other developmental domains does not stop or change fundamentally throughout development and that development is a multifaceted embodied process that is significantly influenced by the interaction of the child with its environment (Wellsby & Pexman, 2014). Indeed, from the perspective of situated action, the social environment plays a central role in shaping cognitive mechanisms, reflecting the idea that cognitive processing is experience-dependent (Barsalou, 2008). Finally, it is important to keep in mind that the difficulty children with IDD may have in performing developmental tasks does not solely reside with them. Significant others in the child's life might be able to alter the environmental context and/or modify the task in such a way that is highly stimulating to motor and all forms of cognitive development, including language, so as to maximize learning potential. Further studies must explore the significant role of parents, direct support professionals, child rearing and educational practices in stimulating motor, cognitive, and language development in children with IDD.

5. Conclusions

It can be concluded that both fine and gross motor development have stronger associations with cognition, and consequently language, in children with IDD than in children without IDD. In terms of the support that children with IDD receive, the current data emphasize the importance of early interventions that boost both motor and cognitive development, and suggest that such interventions will also enhance language development. Future research using subgroups of children with IDD, as well as more fine-grained assessments of motor, cognitive, and language skills, will allow more complex modelling of the relationships between all three developmental domains. This will be necessary to clarify the relative importance of different motor skills for cognitive and language development and to provide clear strategies for practitioners in terms of screening and intervention.

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