University of Groningen

# Movement and cognition

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# Movement and Cognition

## The relationship between gross motor skills, executive functioning, and academic achievement in children with learning disorders

Marieke Westendorp

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# Contents

# Chapter 1
# Introduction

**Background of the study**

In the Netherlands, almost forty thousand children attend special-needs primary schools (CBS, 2013). Children in Dutch special-needs primary schools (from now called children with learning disorders) have learning lags in one or more academic skills (i.e. reading, spelling, and mathematics) meaning that a child has not mastered the academic level that would have been expected given the months of formal education they have received[1]. The focus in the education of children with learning disorders (LD), as well as in scientific research about this group of children, is primarily on their cognitive performance. Far less attention is given to the motor development of children with LD, although it is known that motor development is an important factor in child development (Bushnell & Boudreau, 1993; Lubans, Morgan, Cliff, Barnett, & Okely, 2010). Although most attention has been paid to the cognitive profile of children with LD, it has been shown that motor problems are not uncommon in this population (Simons, Daly, Theodorou, Caron, Simons, & Andoniadou, 2008; Vuijk, Hartman, Scherder, & Visscher, 2010; Vuijk, Hartman, Mombarg, Scherder, & Visscher 2011). Less is however known about the developmental trajectory of motor skills and the possible relationship with cognitive performance in this population. Given the importance of sufficient motor development for physical activity, sports participation, healthy lifestyles (Barnett, van Beurden, Morgan, Brooks, & Beard, 2009; Lubans et al., 2010), and cognition (e.g. Haapala, 2013; Rigoli, Piek, Kane, Whillier, Baxter, & Wilson, 2013), research focussing on the motor development of children with LD and the possible relationship with their cognitive development has both scientific and practical relevance. Such research could provide insight into possible relationships between the motor and the cognitive domains of child development in this vulnerable population. Furthermore, this research could provide valuable clues for the development of interventions and may lead to better understanding and support of these children in the educational setting. The aims of this thesis were, therefore, to gain insight into the development of motor skills and the possible relationship between motor skills and cognitive performance in children with LD.

**Theoretical framework**

*Gross motor development*

This thesis focuses specifically on the gross motor skill performance of children with LD. Gross motor skills are motor skills that require the use of large musculature to achieve the goal of the skill (Magill, 2001) and include locomotor skills and object-control skills (also called ball skills in this thesis) (Gabbard, 2008; Ulrich, 2000). Locomotor skills involve moving the body through space from one place to another (e.g. running, hopping, sliding, and jumping) and object-control skills consist of manipulating and projecting objects primarily with hands and feet (e.g. throwing, catching, bouncing, and kicking) (Gabbard, 2008; Ulrich 2000). Gross motor skills are considered as the building blocks for the development of more complex motor skills and sport-specific skills (Stodden et al. 2008; Wall, 2004).

[1] Since 2001 in the Netherlands children with an IQ between 50-79 without a physical disability and children with learning and/or pedagogic problems with an IQ of 80 and above attend the same special-needs primary school.

Competence in gross motor skills does not naturally emerge during childhood, but must be achieved through experience and appropriate practice (Clark & Metcalfe, 2002; Stodden et al. 2008). Sufficient proficiency in gross motor skills enables children to engage successfully in physical activities, sports and games (Stodden et al., 2008; Wall, 2004). In addition, competence in gross motor skills may also have a positive effect on children's cognitive development (e.g. Murray et al., 2006; Piek et al., 2008; Son & Meisels, 2006; Viholainen et al., 2006).

*Motor development and cognitive performance*

Many years ago, Piaget argued that cognitive development relies totally on motor functioning in children (Piaget & Inhelder, 1966). In line with Piaget's argumentation, Busnell and Boudreau (1993) emphasized that the emergence of motor skills determines cognitive and perceptual development. Gibson also reasoned that adequate motor development in (young) children enables them to actively explore their surroundings and to acquire knowledge (Gibson, 1988). For example, when a toddler is crawling through the living room, he detects and observes movements of other objects (parents, animals, other children) and in this way he discovers and gains information about the interrelationship among objects and other people. Object interaction, sitting, and locomotion in infants expand their opportunities to interact and learn, which will have positive effects on the development of cognitive skills (Bornstein, Hahn, & Suwalsky, 2013).

In the last decades, the relationship between motor and cognitive development has been frequently examined in typically developing children. For example, Piek et al. (2008) assessed children at preschool age (ages 4 months to 4 years) and then again at school age which varied from 6 to 12 years old. They found a positive relationship between gross motor skills in the preschool age and cognitive skills (i.e. processing speed and working memory) at school age. Murray et al. (2006) found a significant linear relationship between the age of learning to stand without support and cognitive skills (i.e. categorization with or without working memory load) at age 35; the earlier the attainment of the motor milestone, the better the categorization in adulthood. Son and Meisels (2006) showed that better gross motor skill performance at 4 years of age was positively related to reading and mathematics performance in the first grade. Finally, Viholainen et al. (2006) concluded that children at-risk of familial dyslexia with slow motor development in the first year of life had a smaller vocabulary at 3 and 5 years of age and were also slower in reading speed at 7 years of age compared to children at-risk of familial dyslexia with a fast motor development. To summarize, previous research has shown that the better the development of gross motor skills, the better the cognitive performance. For children with LD, with major problems in academic skills, adequate gross motor skill development may be important to promote the development of their academic skills.

From a neuropsychological perspective, the close association between motor and cognitive development can be explained by the co activation of the cerebellum, important for complex and coordinated movements, and the prefrontal cortex, critical for higher-order cognitive functioning, i.e. executive functioning (Diamond, 2000). Executive functioning (EF) is an umbrella term that includes a number of interrelated higher-order cognitive processes necessary for purposeful and goal-directed behavior (Welsh, Friedman, & Spieker, 2008). Typical EF processes are inhibition, cognitive flexibility, working memory, planning, and problem solving (Diamond, 2013; Miyaka, Emerson, Witzki, Howerter, & Wager, 2000). The neural link between the cerebellum and the prefrontal cortex occurs when tasks are complex and executed in novel, changing and unexpected environments (Diamond, 2000). Through the dynamic, novel, and interactive character of sports and games these settings are ideal situations to effectively acquire and practice EF (Best, 2010). It has been shown that EF plays a critical role in the development of academic skills (e.g. Best, Miller, & Naglieri, 2011; Bull, Epsy, & Wiebe, 2008; Diamond, 2013). Furthermore, it is thought that improvements in EF facilitate improvements in academic skills (Best, Miller, & Jones, 2009), or that adequate EF develops prior to behaviors affecting academic skills (Riggs, Blair, & Greenberg, 2003). It has been suggested that EF serves as common domain-general factor underlying the motor-cognitive performance link (Roebers, Röthlisberger, Neuenschwander, Cimeli, Michel, & Jäger, 2014).

**Research questions and thesis outline**

The aim of this thesis is to examine the development of gross motor skills and the possible relationship between gross motor skills and cognitive performance (i.e. EF and academic skills) in children with LD aged between 7 and 12 years. This thesis attempts to answer the following main research questions: 1) What is the level of gross motor skill performance of children with LD compared to typically developing children and how do gross motor skills develop with age in children with LD? 2) Is there a relationship between gross motor skills and children's cognitive performance? 3) What is the effect of a motor intervention on children's gross motor skills and their cognitive performance?

In Chapter 2, the gross motor skills of children with intellectual disabilities (a subgroup of children with LD) and the relationship with their sport participation are investigated and compared with a large group of typically developing children. To examine whether children with intellectual disabilities have problems with all gross motor skills or specific ones, scores on individual skills are compared with that of their peers. Chapter 3 addresses the question of whether or not specific relationships between different subsets of gross motor skills (i.e. locomotor skills and ball skills) and different domains of academic achievement (i.e. reading, spelling, and mathematics) could be established. In this study, conducted in children with learning disabilities (a subgroup of children with LD), children's performance in locomotor skills and ball skills are related to their performance in reading, spelling and mathematics. Furthermore, the gross motor skill scores are compared with their typically developing peers to gain insight into the motor problems of these children. Chapter 4 presents longitudinal data on the development of gross motor skills in children with LD from 7- to- 11 years old. The aim is to examine developmental changes in gross motor skills during the primary-school period. Additionally, it is explored whether the developmental trajectories of gross motor skills are influenced by sex. The study in Chapter 5 addresses the question of whether gross motor skill performance is related to performance in children with LD on EF one and two years later. Chapter 6 features an intervention study that focused on the effect of a ball skill intervention on children's ball skill performance, EF and academic skills. The theoretical principles, the practical content of the intervention, and the intervention design are described and explained. Finally, Chapter 7 is the general discussion in which the findings of the different studies are combined and discussed. Reflection on the study, practical implications and recommendations for future research as well as recommendations for the educational practice are provided.

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# Chapter 2
# Are gross motor skills and sports participation related in children with intellectual disabilities?

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*Research in Developmental Disabilities, 2011, 32,* 1147–1153

**Abstract**

This study compared the specific gross motor skills of 156 children with intellectual disabilities (ID) (50 ≤ IQ ≥ 79) with that of 255 typically developing children, aged 7-12 years. Additionally, the relationship between the specific gross motor skills and organized sports participation was examined in both groups. The Test of Gross Motor Development-2 and a self-report measure were used to assess children's gross motor skills and sports participation, respectively. The children with ID scored significantly lower on almost all specific motor skill items than the typically developing children. Children with mild ID scored lower on the locomotor skills than children with borderline ID. Furthermore, we found in all groups that children with higher object-control scores participated more in organized sports than children with lower object-control scores. Our results support the importance of attention for well-developed gross motor skills in children with borderline and mild ID, especially to object-control skills, which might contribute positively to their sports participation.

Keywords: Locomotor skills, object-control skills, primary-school-age, mental retardation, organized physical activity

**Introduction**

In the Netherlands, about 44,000 children attend primary special-needs schools (Central Bureau of Statistics, 2010), which include children with borderline (IQ = 71-79) and mild (IQ = 50-70) intellectual disabilities. Intellectual disabilities (ID) are characterized by limitations in cognitive functioning and includes severe deficits or limitations in an individual's skills in several domains: cognitive, language, motor, psychosocial, and specific activities of daily living (American Association on Intellectual and Developmental Disabilities, 2010; Pratt & Greydanus 2007; Salvador & Bertelli, 2008; Shalock, Luckasson, & Shogren, 2007).

Although most attention has been given to the cognitive functioning of children with ID, it has been shown that motor problems are not uncommon in this population (Frey & Chow, 2006; Hartman, Houwen, Scherder, & Visscher, 2010; Simons, Daly, Theodorou, Caron, Simons, & Andoniadou, 2008; Vuijk, Hartman, Scherder, & Visscher, 2010; Zhang, 2001). Well-developed gross motor skills are important, because these skills are thought to facilitate children's cognitive development (Piek, Dawson, Smith, & Gasson, 2008; Son & Meisels, 2006), contribute positively to activities of daily living (Watkinson, Causgrove Dunn, Cavaliere, Calzonetti, Wilhelm, & Dwyer, 2001) and are commonly considered as the building blocks for the development of more complex motor and sport-specific skills (Stodden, Goodway, Langendorfer, Roberton, Rudisill, Garcia, & Garcia, 2008; Wall, 2004). Although a number of studies have examined the gross motor skill (i.e. locomotor skills and object-control skills) of children with borderline and mild ID (Frey & Chow, 2006; Hartman et al., 2010; Simons et al., 2008; Zhang, 2001), none of these studies focused on specific skills like running, jumping, catching, and throwing. The question remains, therefore, whether all gross motor skills are impaired in children with ID or only the relatively more complex skills. More specific information about the gross motor performance of children with ID may provide useful knowledge for physical education teachers and could be utilized in the development of motor interventions for this population.

That some motor tasks may lead to more problems for children with ID may be related to the extend to which cognitive information is necessary for successful execution of the task.  Complex motor tasks are expected to be more strongly related to children's cognitive functioning than simple motor tasks (Planinsěc, 2002; Planinsěc & Pišot, 2006). Complex motor skills can be described as open skills, which are more dependent on factors in the environment for example extern objects and other players, than simple motor skills (Wall, 2004). With regard to gross motor skills, locomotor skills are generally supposed to be more automatized and less dependent on cognitive functioning, while the execution of object-control skills are supposed to require more involvement of cognitive processes (Latash & Turvey, 1996).

Gross motor skills are involved in many physical activities and are prerequisites for the performance of sport-specific skills (Barnett, van Beurden, Morgan, Brooks, & Beard, 2009; Graf et al., 2004; Okely, Booth, & Patterson, 2001; Wrotniak, Epstein, Dorn, Jones, & Kondilles, 2006). Previous studies have shown a positive relationship between gross motor skills and organized sports participation in typically developing children (Barnett et al., 2009; Okely et al., 2001; Ulrich, 1987), in deaf children (Hartman, Houwen, & Visscher, 2011), and in children with visual impairments (Houwen, Hartman, Lemmink, & Visscher, 2007). Childhood motor proficiency may thus be an important factor in organized sports participation. To our knowledge, no studies have examined whether there is a relationship between specific gross motor skills and organized sports participation in children with ID. Gaining insight into the relationship between specific motor items and participation in organized sports in children with ID may provide clues about which gross motor skills (e.g. running, jumping, catching or throwing) are most important in the participation in organized sports in this vulnerable population. Therefore, the present study focused on this relationship in a large sample of children with borderline and mild ID.

Although studies generally found a relationship between gross motor skills and organized sports participation, this relationship is generally weak-to-moderate. Fisher et al. (2005), however, have suggested that the relationship between these parameters might be stronger for children who have the lowest motor skill scores. We, therefore, expect a stronger relationship between gross motor skills and organized sports participation in children with ID compared to their typically developing peers, with the strongest relationship in children with mild ID.

Within the present study, we thus sought to identify differences in the specific gross motor skills in a large sample of children with borderline and mild ID and typically developing children. From the literature, it has been established that children with borderline and mild ID had poor gross motor performance than typically developing children (Frey & Chow, 2006; Hartman et al., 2010; Simons et al., 2008; Zhang, 2001). Therefore, a lower performance on these skills can be expected, however, it would be interesting to know whether all specific gross motor skills are impaired. When children have limited cognitive functioning, like in children with borderline and mild ID, the complexity of the task would affect performance. As object-control skills are generally more complex than locomotor skills (Houwen et al. 2007), we hypothesized a difference in performance on these skills. Additionally, this study also aimed to examine the relationship between the specific gross motor skills and organized sports participation in both groups.

**Material and methods**

*Participants*

The children with ID, aged between 7 and 12 years, were recruited from two primary special-needs schools located in the northern Netherlands. Children who were also diagnosed with Attention Deficit Hyperactivity Disorder (n = 14) or Autism Spectrum Disorders (n = 14) were excluded from the study sample. The definitive study sample consisted of 156 children (104 boys and 52 girls) with a mean age of 9.5 years (SD 1.5). Based on the information provided in their individual school files, the study sample included 88 children with borderline ID (56 boys and 32 girls; mean age 9.5, SD 1.6) and 68 children with mild ID (48 boys and 20 girls; mean age 9.6, SD 1.3). The mean IQ of the children with borderline ID was 75.3 (SD 2.6; range 71-79) and the mean IQ of the children with mild ID was 65.0 (SD 4.5; range 50-70).

We recruited 255 typically developing children (138 boys and 117 girls), aged between 7 and 12 years (mean age 9.7 years; SD 1.3) attending two mainstream schools in the same region as a reference group. The children's age was appropriate to their grade level, indicating that their ability on academic performance was in the normal range (i.e. the expected level in relation to their learning experiences).

The three groups (borderline ID, mild ID, and typically developing children) did not statistically differ from each other on age ($F(2,408) = 1.244$, $p = .289$), but the amount of boys and girls in the three groups differed significantly ($F(2,408) = 3.566$, $p = .029$): there were significantly more boys in the ID groups compared to the group of typically developing children.

The parent(s) provided informed consent for their children's participation 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.

*Test of Gross Motor Development-2 (TGMD-2)*

The TGMD-2 (Ulrich, 2000) is a qualitative measure to assess 12 gross motor skills divided into locomotor skills (run, gallop, hop, leap, jump, and slide) and object-control skills (two-hand strike, stationary bounce, catch, kick, overhand throw, and underhand roll). Each skill is executed twice and evaluated on the basis of the presence (success; score 1) or absence (failure; score 0) of three to five qualitative performance criteria. The highest total raw score for the two subtests is 48 points. The higher the subtest score, the better the performance.

The TGMD-2 has good psychometric qualities to assess the gross motor skill performance of typically developing children (Evaggelinou, Tsigilis, & Papa, 2002; Ulrich, 2000) and children with impairments, among which children with visual impairments (Houwen, Hartman, Jonker, & Visscher, 2010) and children with mild ID (Simons et al., 2008).

*Sports participation*

We used a self-report measure to assess the children's participation in organized sports. Organized sports were defined as those performed under the supervision of a trainer on a regular weekly basis within a sports club setting (Houwen et al., 2007; Okely et al., 2001). The questionnaire included questions about the membership of a sports club and the type of sports in which they were involved. The self-report measurement was administered individually with assistance of the researcher. The reliability and validity of the questionnaire had been tested in a pilot study in a population of children with ID ($n = 44$; aged 6 to 12). The test-retest reliability of the questionnaire for the question 'membership of a sports club' was "very good" (Cohen's Kappa = 1.0).

*Data analysis*

The statistics were performed using SPSS software (version 16.0) and the significance level was set at .05. The TGMD-2 locomotor and object-control subtest raw scores and the specific raw motor skill scores were the dependent variables. The three study groups were: 1) children with borderline ID, 2) children with mild ID, and 3) typically developing children.

To analyse between-group differences, ANCOVAs were conducted on the TGMD-2 locomotor and object-control subtests scores and the specific motor skill scores, controlling for sex.

To identify relationships between gross motor skills and organized sports participation, we tested for differences on the TGMD-2 outcomes between children who participated in organized sports and children who did not, using independent *t-tests.* These analyses were conducted for the three study groups (borderline ID, mild ID, and typically developing children) separately.

To determine the meaningfulness of group effects, correlational effect sizes were calculated for each dependent variable in accordance with Rosnow, Rosenthal, and Rubin (2000). An effect size correlation of r = .10 was defined as small, r = .30 as moderate, and an effect size of r = .50 as large (Field, 2005).

**Results**

*Gross motor skill outcomes*

The TGMD-2 locomotor and object-control subtest scores of the three groups are presented in Tables 2.1 and 2.2. Significant differences were obtained between both ID groups and the typically developing children on both TGMD-2 subtests. The children with mild ID and borderline ID scored significantly lower than the typically developing children, with effect sizes being large for the mild ID group (locomotor skills r = .52, object-control skills r = .56) and moderate-to-large for the borderline ID group (locomotor skills r = .40, object control-skills r = .50). Furthermore, the children with mild ID scored lower on the locomotor subtest (r = .24) in comparison with the children with borderline ID, but not on the object-control subtest (r = .13).

From the analyses per test item it appeared that the children with mild ID scored significantly lower on all test items compared to typically developing children, except the gallop and the throw. The effect sizes were large for the run, the slide, and the roll. The children with borderline ID also scored significantly lower on most test items than their typically developing peers, except on the gallop, the throw, and the jump. The effect sizes were large for the run and the roll. The analyses, further, showed that children with mild ID had significantly lower scores on the leap, the jump, and the slide compared to the borderline ID group. On the run, gallop, and hop and all object-control skills no significant difference were found between both ID groups.

***Table 2.1** Estimated mean TGMD-2 locomotor and object-control subtest scores for the three study groups*

| | Children with mild ID | | Children with borderline ID | | Typically Developing Children | |
|---|---|---|---|---|---|---|
| | n = 68 | | n = 88 | | n = 255 | |
| | M[1] | SE | M[1] | SE | M[1] | SE |
| Locomotor | 34.5[ab] | .61 | 36.9[ac] | .41 | 40.7[bc] | .24 |
| Run | 5.9[b] | .14 | 5.8[c] | .14 | 7.4[bc] | .08 |
| Gallop | 5.9 | .21 | 6.2 | .19 | 6.2 | .11 |
| Hop | 7.4[b] | .20 | 7.7[c] | .17 | 8.3[bc] | .10 |
| Leap | 4.0[ab] | .14 | 4.5[ac] | .12 | 4.9[bc] | .07 |
| Jump | 5.5[ab] | .18 | 6.1[a] | .15 | 6.4[b] | .09 |
| Slide | 5.8[ab] | .14 | 6.6[ac] | .11 | 7.6[bc] | .06 |
| Object-control | 31.8[b] | .56 | 33.2[c] | .51 | 39.5[bc] | .30 |
| Strike | 6.1[b] | .22 | 6.5[c] | .19 | 7.9[bc] | .11 |
| Bounce | 5.9[b] | .19 | 6.2[c] | .18 | 7.1[bc] | .11 |
| Catch | 4.6[b] | .11 | 4.9[c] | .10 | 5.5[bc] | .06 |
| Kick | 5.5[b] | .16 | 5.6[c] | .13 | 6.9[bc] | .08 |
| Throw | 5.1 | .23 | 5.3 | .20 | 5.5 | .12 |
| Roll | 4.7[b] | .17 | 4.7[c] | .15 | 6.7[bc] | .09 |

[1] Statistically adjusted for sex

a, b, c Groups with the same letter were significantly different

***Table 2.2*** *Comparisons of the three study groups on the gross motor skills*

| | Mild ID vs typically developing | | | Borderline ID vs typically developing | | | Mild ID vs borderline ID | | |
|---|---|---|---|---|---|---|---|---|---|
| | *F* | *p* | *r* | *F* | *p* | *r* | *F* | *p* | *r* |
| Locomotor | 119.682 | .000 | .52 | 64.705 | .000 | .40 | 9.248 | .003 | .24 |
| Run | 92.982 | .000 | .48 | 93.548 | .000 | .46 | .079 | .779 | .02 |
| Gallop | 1.287 | .257 | .06 | .110 | .915 | .02 | 1.858 | .175 | .11 |
| Hop | 14.803 | .000 | .21 | 8.451 | .004 | .16 | 1.509 | .221 | .10 |
| Leap | 30.199 | .000 | .29 | 9.421 | .002 | .16 | 6.919 | .009 | .21 |
| Jump | 20.090 | .000 | .24 | 3.498 | .062 | .10 | 7.402 | .007 | .21 |
| Slide | 126.313 | .000 | .53 | 58.768 | .000 | .38 | 8.880 | .003 | .23 |
| Object-control | 149.964 | .000 | .56 | 117.605 | .000 | .50 | 2.325 | .129 | .12 |
| Strike | 52.621 | .000 | .38 | 38.159 | .000 | .32 | 2.742 | .100 | .13 |
| Bounce | 29.828 | .000 | .29 | 19.420 | .000 | .23 | .450 | .503 | .05 |
| Catch | 57.919 | .000 | .39 | 28.046 | .000 | .27 | 3.361 | .069 | .15 |
| Kick | 62.376 | .000 | .41 | 70.034 | .000 | .41 | .293 | .589 | .04 |
| Throw | 3.783 | .053 | .11 | .934 | .335 | .05 | 1.448 | .231 | .09 |
| Roll | 95.397 | .000 | .48 | 129.400 | .000 | .52 | .032 | .858 | .01 |

*Sports participation*

Thirty-nine percent (26 children) of the children with mild ID participated in organized sports at least once a week, 36% (30 children) of the children with borderline ID, and 84% (200 children) of the typically developing children. The children with ID (both borderline and mild) were significantly less likely than their typically developing peers to participate in a organized sports ($F(2,385) = 55.69$, $p = .000$). Eight percent (2 children) of the mild ID group participated at least two different sports, 20% (6 children) of the borderline ID group, and 43% (86 children) of the typically developing peers. The three most mentioned sports reported by children with mild ID were soccer (65.4%), gymnastics (7.7%), and swimming (7.7%). The children with borderline ID participated mostly in soccer (40%), gymnastics (17%), and basketball or judo/karate (10%) and the typically developing children in soccer (41%), gymnastics (16.5%), and volleyball (10%).

*Relationship between gross motor skills and sports participation*

Table 2.3 presents mean scores for the TGMD-2 subtests of the children who participated in sports and those who did not per group (mild ID, borderline ID, typically developing). In the mild ID group, the object-control subtest scores of the children who participated in sports were significantly higher than the scores for those who did not participate in sports, with a moderate-to-large effect size ($r = .45$). The analyses per test item demonstrated that the sports participants scored significantly higher on the bounce (r = .28), the catch (r = .31), and the roll (r = .33). The locomotor skill scores between sports participants and non-participants were not significantly different in the mild ID group.

In the children with borderline ID, significant differences were found for the object-control skill subtest between sports participants and non-participants: children who participated in sports had significant higher scores than those who did not participate, with a small effect size (r = .21). From the analyses per test item it revealed that those who participated in sports had significantly higher scores on the strike (r = .21). The locomotor skills scores between the sports participants and the non-participants were not significantly different.

In the typically developing children, the object-control scores of the children who participated in sports were significantly higher than the scores for those who did not participate in sports, with effect size being small (r = .14). The analyses per test item showed that sports participants scored significantly higher on the kick (r = .30) and the overhand throw (r = .15). No significant differences were found on the locomotor subtest scores.

***Table 2.3*** *Estimated mean TGMD-2 locomotor and object-control subtest scores for the children of the three study groups who participate in sports and those who do not participate in sports*

| | Children with mild ID | | | Children with borderline ID | | | Typically developing children | | |
|---|---|---|---|---|---|---|---|---|---|
| | Sport Yes | Sport No | | Sport Yes | Sport No | | Sport Yes | Sport No | |
| | n = 26 | n = 40 | | n = 30 | n = 53 | | n = 200 | n = 39 | |
| | *M (SD)* | *M (SD)* | *p* | *M (SD)* | *M (SD)* | *p* | *M (SD)* | *M (SD)* | *p* |
| Locomotor | 35.6 (5.5) | 33.2 (5.6) | .088 | 37.3 (4.4) | 36.2 (4.6) | .159 | 40.9 (3.9) | 40.1 (3.9) | .233 |
| Run | 6.3 (1.6) | 5.6 (1.7) | .139 | 5.7 (2.4) | 5.8 (1.8) | .907 | 7.4 (1.0) | 7.5 (.89) | .576 |
| Gallop | 6.0 (1.3) | 5.6 (1.7) | .295 | 6.2 (1.8) | 6.1 (1.6) | .958 | 6.2 (1.9) | 6.0 (1.6) | .456 |
| Hop | 7.6 (1.7) | 7.2 (1.7) | .399 | 7.8 (1.7) | 7.6 (1.2) | .478 | 8.3 (1.6) | 8.3 (1.6) | .895 |
| Leap | 3.8 (1.5) | 3.9 (.83) | .562 | 4.5 (1.0) | 4.4 (1.1) | .720 | 5.0 (1.1) | 4.5 (1.5) | .050 |
| Jump | 5.7 (1.8) | 5.3 (1.3) | .316 | 6.2 (1.6) | 6.0 (1.2) | .553 | 6.4 (1.5) | 6.5 (1.5) | .872 |
| Slide | 6.2 (1.8) | 5.4 (1.9) | .080 | 6.9 (1.2) | 6.3 (1.5) | .068 | 7.6 (.78) | 7.4 (1.3) | .258 |
| Object-control | 35.2 (5.4) | 30.3 (5.6) | .001* | 35.0 (6.4) | 32.2 (5.9) | .044* | 39.9 (4.4) | 38.1 (4.9) | .036* |
| Strike | 6.7 (2.0) | 5.8 (1.9) | .056 | 7.1 (1.9) | 6.2 (1.8) | .043* | 7.8 (1.8) | 8.0 (1.7) | .602 |
| Bounce | 6.7 (1.5) | 5.5 (2.1) | .018* | 6.7 (2.1) | 5.8 (2.2) | .065 | 7.2 (1.4) | 7.1 (1.4) | .670 |
| Catch | 5.0 (1.0) | 4.3 (1.2) | .009* | 5.2 (.90) | 4.8 (1.3) | .056 | 5.6 (.80) | 5.4 (.86) | .362 |
| Kick | 6.1 (1.7) | 5.4 (1.6) | .079 | 5.9 (1.5) | 5.5 (1.3) | .228 | 7.0 (1.3) | 5.9 (1.6) | .000* |
| Throw | 5.5 (1.6) | 5.0 (1.5) | .202 | 5.4 (2.0) | 5.3 (1.6) | .803 | 5.6 (2.0) | 4.8 (2.1) | .020* |
| Roll | 5.2 (1.5) | 4.4 (1.3) | .021* | 4.7 (1.3) | 4.6 (1.4) | .713 | 6.6 (1.4) | 7.0 (1.4) | .154 |

* significant at p < .05

**Discussion**

This study compared the specific gross motor skills of children with ID with those of typically developing peers and examined whether all specific gross motor skills were impaired in children with ID. Additionally, the relationship between the specific gross motor skills and organized sports participation was examined in both groups. Compared to their typically developing counterparts, children with borderline and mild ID scored significantly lower on both the locomotor and object-control skills as assessed with the TGMD-2. That children with ID had lower gross motor skill scores compared to typically developing children is consistent with the studies of Frey and Chow (2006), Hartman et al. (2010), Simons et al. (2008), and Zhang (2001). However, these studies have only focused on the overall performance of locomotor skills and object-control skills without focusing on the specific skill items. Moreover, most of these studies were restricted to children with mild ID.

The present study compared the scores of the children with borderline and mild ID and revealed that the borderline ID group were less impaired on the locomotor skills than the mild ID group, but that their performance on the object-control skills was comparable. This result shows that even a small problem in intellectual functioning leads to poor object-control skills. As stated before, the execution of object-control skills is assumed to be more complex and require more cognitive functioning than locomotor skills (Latash & Turvey, 1996; Planinsěc, 2002; Planinsěc & Pišot, 2006). Object-control skills are generally practised in complex play and sport settings that require adaptation to changing environmental circumstances (Houwen, et al., 2007). Complex and novel situations rely strongly on executive functioning (Diamond, 2000). However, executive functions are less important in simple, automatized skills or in less complex situations. Executive functions are abilities of goal formation and planning, and the effective execution of goal-directed plans (Jurado & Rosselli, 2007) and play a critically role in the overall cognitive functioning (Isquith, Crawford, Espy, & Gioia, 2005). As children with borderline and mild ID show deficits in their executive functioning (Hartman et al. 2010), performance in complex situations is assumed to be difficult for children with ID. It may, therefore, that children with ID had more problems with object-control skills than with locomotor skills.

The analyses per specific motor item showed that children with borderline and mild ID scored lower on most specific items compared to the typically developing children. The effect sizes indicated that some motor skills were more affected than other skills. Looking in more detail into the specific motor items, we found that the children with borderline and mild ID had particular difficulties with some performance criteria. Generally, they had problems with coordinating movements that involved both sides of their body or both upper and lower extremities. For example, during the leap many children showed problems with the forward reach with their arm opposite of their leading foot. During the horizontal jump very few children used their arms during the jump (their arms should swung forcefully forwards and upwards while jumping). Also during the overhand throw and rolling, children did not move their arm opposite to their leg. In addition, children had difficulty to rotating their body, for example during the overhand throw. Taken all together, our results suggest that children with ID had particularly motor problems related to timing and coordination of movement sequences. It seems that children with ID are able to perform simple movements, but when more parts of the body were involved simultaneously, it causes problems for children with borderline and mild ID.

Our sport participation results indicated that children with borderline and mild ID who participated in sports had higher object-control skill scores than children who did not. This relationship was not found for locomotor skill scores. These results are in line with studies in deaf children (Hartman et al., 2011) and in children with visual impairments (Houwen et al., 2007). An explanation for the finding in the present study might be that 50-70% of the children with ID who participated in sports participated in ball sports. This indicates, on the one hand, that higher levels of object-control skills might have positively influenced organized sports participation of these children. On the other hand, participation in ball games may result in higher levels of object-control skills in children (Barnett, Morgan, van Beurden, Ball, & Lubans, 2010). Barnett et al. (2010) showed in their study that object-control skill performance and physical activity were reciprocal related. However, these reciprocal relationship between both parameters would be affected by age (Stodden et al., 2008). During physical activity young children (early childhood) may develop their gross motor skills, but when children grow older (middle and later childhood) the relationship between both components might change: competence in gross motor skills may be an important condition to engage in various physical activities and sports (Stodden et al., 2008).

The present study shows that children who participated in sports had higher object-control scores, but that their scores did not attain the performance level of the typically developing children. Therefore, we argue that extra training, preferably task-specific (Pless & Carlsson, 2000; Revie & Larkin, 1993; Wilson, 2005) is recommended to improve the gross motor skills of children with borderline and mild ID. Furthermore, we suggest that the development of these skills should be an important component of the physical education lessons at all primary-schools to promote long-term physical activity and sports participation (Stodden et al., 2008; Wall, 2004).

In typically developing children, we also found a relationship between object-control skills and organized sports participation. However, the effect sizes in the children with ID, especially in the children with mild ID, were higher than those in the typically developing children, indicating that the relationship between these two parameters in the ID group was stronger than in the typically developing group. This finding is in accordance with Fisher et al. (2005), who suggested that the relationship between gross motor skills and sports participation is stronger in children with the lowest motor skill scores.

A limitation of the present study was that our results give no insight into the causality of the relationship that was found: do higher levels of object-control skills lead to more sports participation or vice versa? We suggest that object-control skills and sports participation are reciprocally associated as Barnett et al. (2010) have found in typically developing children, but this relationship would be affected by age (Stodden et al., 2008). Although we do not provide a causal relationship for this promise, our results support the hypothesis that well-developed object-control skills may lead to more participation in organized sports (Barnett et al., 2009). Intervention studies are recommended to reveal whether there is a real cause-effect relationship between object-control skills and participation in organized sports in children with borderline and mild ID.

**Conclusion**

The present study extends the small body of research on the gross motor skills of children with ID by including a large group of children with borderline and mild ID and by giving more specific information on their performance. This study shows that primary-school-age children with borderline and mild ID perform worse than typically developing children on almost all specific gross motor skills. Furthermore, children with mild ID had lower locomotor scores than children with borderline ID. The positive relationship that was found between object-control skills and organized sports participation in intellectually challenged children and in typically developing children supports the notion that higher levels of these motor skills might contribute positively to children's sports participation. The development of object-control skills should, therefore, be an important component in physical education programs in primary-schools.

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# Chapter 3
# The relationship between gross motor skills and academic achievement in children with learning disabilities

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**Abstract**

The present study compared the gross motor skills of 7- to 12-year-old children with learning disabilities (n = 104) with those of age-matched typically developing children (n = 104) using the Test of Gross Motor Development-2. Additionally, the specific relationships between subsets of gross motor skills and academic performance in reading, spelling, and mathematics were examined in children with learning disabilities. As expected, the children with learning disabilities scored poorer on both the locomotor and object-control subtests than their typically developing peers. Furthermore, in children with learning disabilities a specific relationship was observed between reading and locomotor skills and a trend was found for a relationship between mathematics and object-control skills: the larger children’s learning lag, the poorer their motor skill scores. This study stresses the importance of specific interventions facilitating both motor and academic abilities.

Keywords: Fundamental movement skills, primary-school-age, reading, spelling, mathematics

## Introduction

It is generally agreed that there is a relationship between motor ability and cognitive development. Research has shown that well-developed gross motor capacities facilitate children's cognitive functioning (Burns, O'Callaghan, McDonell, & Rogers, 2004; Bushnell & Boudreau, 1993; Murray et al., 2006; Piek, Dawson, Smith, & Gasson, 2008) and more specifically their academic abilities in reading, language, and mathematics (Son & Meisels, 2006; Viholainen, Ahonen, Lyytinen, Cantell, Tolvanen, & Lyytinen, 2006). From a neuropsychological perspective, there are several explanations for the co-occurrence of motor and cognitive performance. First of all, motor and cognitive functions are coupled through using the same brain structures (Diamond, 2000). For example, the cerebellum is involved in both motor and cognitive functions and the pre-frontal cortex plays an important role in cognitive functioning as well as in motor performance through the strong neural connections between these two brain areas. Dysfunction of these brain structures or the neural pathways may express itself in motor problems as well as in cognitive problems (Diamond, 2000). A second explanation is that motor and cognitive functions seem to follow a similar developmental timetable with an accelerated development between 5 and 10 years of age (Ahnert, Bös, & Schneider, 2003; Anderson, 2002; Gabbard, 2008). A final factor that may account for the co-occurrence of motor and cognitive functions is that both functions have several common underlying processes for example sequences (Hartman, Houwen, Scherder, & Visscher, 2010), monitoring and planning ( (Roebers & Kauer, 2009; Sergeant, 2000).

As gross motor proficiency is assumed to foster academic abilities (Son & Meisels, 2006; Viholainen et al., 2006), it is especially important that children with problems in academic achievement have sufficient proficiency in gross motor skills. Children who have major problems in academic skills are children with learning disabilities (LD). These children have deficits in one or more domains of academic achievement, such as reading disorders, mathematical disorders, and/or disorders of written expression (American Psychiatric Association, 2000). In addition, children with LD generally have poor gross motor skills compared to their typically developing peers (Woodard & Surburg, 2001; Zhang, 2001). Using the Test of Gross Motor Development-2 (TGMD-2; Ulrich, 2000), Woodard and Surburg (2001) found that children with LD (n = 22), aged between 6 and 8 years, obtained lower scores on both TGMD-2 subtests than typically developing children. Furthermore, Zhang (2001) found a small sample of 6-10 year-olds with LD (n = 7) that also scored poorer on the locomotor subtest and average on the object-control subtest relative to the normative TGMD-2 data. Both studies, however, had small sample sizes and focused on a general relation between motor performance and LD, without taking into account that LD is a heterogeneous condition including reading disorders, mathematical disorders, and/or disorders of written expression (American Psychiatric Association, 2000). Vuijk, Hartman, Mombarg, Scherder & Visscher (2011) suggest that the relationship between motor skills and LD may in fact vary depending on the different areas of academic performance (i.e. reading, spelling, and mathematics) and the kind of motor skill. If this is the case then, it is important to investigate the specific relations between the different subsets of gross motor skills (i.e. locomotor skills and object-control skills) and the different domains of academic performance (i.e. reading, spelling, and mathematics) in children with LD rather than a general relation between LD and motor performance.

To date, research examining the relationship between different subsets of gross motor skills and the different domains of academic achievement in children with LD is limited. A study in children with dyslexia (i.e. a specific reading disorder) showed they scored lower on the balance test of the Movement Assessment Battery for Children (Movement ABC; Henderson & Sudgen, 1992) than their typically developing counterparts. No differences were found on the other Movement ABC items and the TGMD-2 (Getchell, Pabreja, Neeld, & Carrio, 2007). Another study on children with reading disorders aged 9-10 years has shown that children who experienced more reading difficulties scored lower on the Movement ABC balance test than children with less reading difficulties (McPhilips & Sheehy, 2004). Furthermore, a recent study of Vuijk et al. (2011) studied the motor skills of 7- to 12-years-old children with LD with co-morbid developmental disorders like Attention Deficit Hyperactivity Disorder or Autism Spectrum Disorders. This study revealed positive correlations (i.e. the lower the motor skill performance, the larger the learning lag) between balance and mathematics and between ball skills and reading, using the Movement ABC.

To summarise, studies examining specific relationships between motor skills and academic performance in children with LD are limited, were mainly restricted to children with reading disorders, and showed inconsistent results. The present study, therefore, will examine in a large sample of children with LD whether there are specific relationships between different subsets of gross motor skills and the different domains of academic performance. Understanding the specific relationship between gross motor skills and academic achievement in children with LD will provide valuable insight for the field of special education. It could be utilized in the development of intervention programs for this population, since evidence suggest that gross motor performance facilitates academic abilities (Son & Meisels, 2006; Viholainen et al., 2006). Successful implementation of such programs could indeed contribute to reducing the gross motor problems and may stimulate the development of academic abilities in children with LD during their primary-school-years.

The aims of present study were twofold. Initially, we sought to identify differences in gross motor performance in a large sample of primary-school-age children with LD and typically developing children. The main goal was to investigate in children with LD whether specific relationships between different subsets of gross motor skills (i.e. locomotor skills and object-control skills) and different domains of academic performance (i.e. reading, spelling, and mathematics) could be established.

## Material and methods

### *Participants*

We recruited 144 children, aged between 7 and 12 years old, all with confirmed learning disabilities from two primary special-needs schools located in the northern Netherlands. Forty children were subsequently excluded because their individual school files stated they were also diagnosed with Attention Deficit Hyperactivity Disorder or Autism Spectrum Disorders. The final study sample comprised 104 children (69 boys and 35 girls) with a mean age of 10.1 years (SD 1.4; range 7-12). Based on the information provided in their individual school files, the children's mean intelligence quotient was 89.9 (SD 7.6; range 80-114). All children were Caucasian.

To collect gross motor skill reference values for the LD group, we recruited 104 aged- matched typically developing peers (61 boys and 43 girls) with a mean age 10.1 years (SD 1.4; range 7-12) attending two mainstream schools in the same region. The children's grade level was appropriate to their age. The two groups (children with LD and typically developing children) did not statistically differ from each other on gender ($F(1,207) = 1.308$, $p = .254$).

The parent(s) provided informed consent for their children's participation 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.

*Instruments*

*Child Academic Monitoring System*

For each child we screened the so-called Child Academic Monitoring System (CAMS), a record each primary school in the Netherlands keeps and which provides an overview of a child's progress in academic skills. First, the CAMS provides the didactical age (DA), expressed as the months of formal education [starting from group 3 (i.e. age 6 to 7)] a child has received with a full school year consisting of 10 didactical months (excl. two months summer vacation) and the entire primary school period of a total of 60 months. When a child stays back a group, 10 months are added to the total DA, but when a child doubles the final group (i.e. age 11 to 12), the total DA will remain 60 months. For example, a child attending group 5 (i.e. age 8 to 9) that has progressed without staying back and is tested early February will have a DA of 25 months based on 20 months in group 3 and 4, and another 5 months (September to February) in group 5.

Second, the CAMS states the child's didactical age equivalent (DAE) on reading, spelling, and mathematics. Every child is tested twice a year on reading, spelling, and mathematics. The raw scores on the academic tests can be converted into norm scores, the DAE. The DAE represents the performance of an average pupil at that time. For example, a DAE of 20 on reading represents an average reading performance at the end of group 4 (i.e. 20 months education). The relation between the DA and the DAE is so-called learning efficiency. The learning efficiency is 100 % when the DA and DAE are equal.

Based on the DA and DAE the learning lag per academic domain could be calculated for each child using the following formula: learning lag = 1 – (DAE/DA). This formula explains the amount of material not mastered per academic domain and is an indication of failures in achievement (Cito, 2004). For example, a child with a learning lag of 0.35 on reading has not mastered 35% of the reading level it should normally have achieved given its DA. The CAMS of the children were not always complete, preventing us from extracting the learning lags for all 104 children. Based on the available learning lags, the mean learning lag for reading was 0.50 (SD .23; range 0.00 - 0.92; n = 96), the mean learning lag for spelling was 0.51 (SD .17; range 0.00 - 0.86; n = 82), and the mean learning lag for mathematics was 0.48 (SD .16; range 0.00 - 0.84; n = 92).

To assess children's reading abilities, the Dutch AVI (Analyse van Individualiserings-vormen or Analysis of Individual Word Forms; Visser van Laarhoven, & ter Beek, 1998) is used. During the test the child is required to read out several short stories whose sentence structures and word complexity gradually increase in difficulty. The amount of mistakes (i.e. reading or spelling a word wrong, skipping, adding or replacing a word) and the time that is needed to read the text are scored. The total score depends on the amount of mistakes, the reading speed and the difficulty of the text. The reliability (r varied from .86-.93), the content validity, and the construct validity of the AVI test were good (Krom, Jongen, Verhelst, Kamphuis, & Kleintjes, 2010). To measure the development in spelling abilities the SVS (Schaal Vorderingen in Spellingvaardigheid or Improvements in Spelling Skills; Van den Bosch, Gillijns, Krom & Moelands, 1997) was used. The SVS is a pencil and paper task requiring the child to write down words of increasing complexity that are read out by the test leader. The raw score is the number of correct written words. The SVS reliability ($r \geq .80$), the content validity, and the construct validity were good (Moelands & Kamphuis, 2001). Mathematical skills are assessed by the WIG (Wereld in Getallen or World in Numbers; Huitema, 2001), requiring children to solve mathematical problems taken from everyday life. The WIG is a common method to teaching mathematics in the Netherlands.

*Test of Gross Motor Development-2*

The Test of Gross Motor Development-2 (TGMD-2) (Ulrich, 2000) is a qualitative measure to assess 12 gross motor skills divided into locomotor skills (run, gallop, hop, leap, jump, and slide) and object-control skills (two-hand strike, stationary bounce, catch, kick, overhand throw, and underhand roll). Each skill is executed twice and evaluated based on the presence (success; score 1) or absence (failure; score 0) of three to five qualitative performance criteria. The highest total raw score for both subtests is 48. The higher the (total) score, the better the performance. The raw scores can be converted into standardized scores per age group. In this study, however, the raw TGMD-2 scores were used, because the normative TGMD-2 data collected on children in the US may not be valid for Dutch children (Houwen, Visscher, Hartman, & Lemmink, 2007) and our data covered the performance of 11- to 12-year-old children, which ages fall outside the range of the TGMD-2 normative data.

The TGMD-2 has good psychometric qualities to assess gross motor skill performance of typically developing children, according to the test manual (Ulrich, 2000). The internal consistency, the test-retest, and the interrater reliability varied between .85 and .98 for both subtests and the total TGMD-2. The construct validity, measured with a confirmatory factor analysis, was good ($\chi^2$= 280.3; GFI = .96; AGFI = .95) (Ulrich, 2000). Reliability and validity studies of the TGMD-2 in children with mild intellectual disabilities and learning disabilities showed similar values as reported by Ulrich (Simons, Daly, Theodorou, Caron, Simons, & Andoniadou, 2008; Zhang, 2001).

*Data analysis*

The statistics were performed using SPSS software (version 18.0) and the significance level was set at .05. To analyze between-group differences in motor performance (children with LD and typically developing children), independent *t*-tests were conducted on the TGMD-2 locomotor and object-control subtests raw scores. To determine the meaningfulness of group effects, correlational effect sizes were calculated for each dependent variable in accordance with Rosnow, Rosenthal, and Rubin (2000). An effect size correlation of $r$ = .10 was defined as small, $r$ = .30 as moderate, and an effect size of $r$ = .50 as large (Field, 2005).

For the children with LD, Pearson's correlations were conducted to examine the relationships between the different subsets of gross motor skills and the performance in reading, spelling, and mathematics (i.e. learning lags in reading, spelling, and mathematics). Following the correlations, hierarchical linear regression analyses were used to identify the relative influence of the independent variables (i.e. age, gender, reading, spelling, and mathematics) on the locomotor and object-control performance in children with LD. As age and gender are related to the object-control skills, and gender to the locomotor skills, they were entered in the regression model on the first step. The variables reading, spelling, and mathematics were entered in the second step in both regression models.

## Results

*Gross motor skill outcomes*

In Table 3.1, the results of the independent *t*-tests for the two TGMD-2 subtests are presented for children with LD and typically developing children. The LD group scored significantly lower (reflecting poorer performance) on both subtests compared to the comparison group, with effect sizes being moderate-to-large.

***Table 3.1*** *TGMD-2 locomotor and object-control subtest scores for the children with LD and the typically developing children*

| | Children with LD n=104 | | Typically developing children n = 104 | | | | |
|---|---|---|---|---|---|---|---|
| | *M* | *SD* | *M* | *SD* | *t* | *p* | *ES* |
| Locomotor | 37.7 | 4.4 | 40.8 | 3.9 | - 5.36 | <.001 | .47 |
| Object-control | 34.7 | 5.6 | 40.2 | 4.5 | - 7.58 | <.001 | .61 |

Note: ES = Effect Size

*Relationship between gross motor skills and academic performance in children with LD*

Table 3.2 lists the correlations between the TGMD-subtests scores, the learning lags in reading, spelling, and mathematics, and age and gender. Significant correlations were obtained between reading and locomotor skills, spelling and locomotor skills, and gender and locomotor skills. Moreover, we found significant correlations between mathematics and object-control skills, gender and object-control skills, and age and object-control skills.

***Table 3.2*** *Bivariate correlations between the TGMD-2 locomotor and object-control subtest scores, the learning lags in reading, spelling and mathematics, and age and gender in children with LD*

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| 1 Locomotor | - | .27** | - .24* | -.22* | -.16 | .14 | .23* |
| 2 Object-control | | - | -.12 | -.12 | -.29** | -.35*** | -.38*** |
| 3 Reading | | | - | .51*** | .43*** | -.11 | -.08 |
| 4 Spelling | | | | - | .38*** | -.25* | -.11 |
| 5 Mathematics | | | | | - | -.27** | .07 |
| 6 Age | | | | | | - | -.00 |
| 7 Gender | | | | | | | - |

* p <.05, ** p <.01, *** p <.001

However, after the hierarchical regression analysis only reading performance was a significant predictor of the locomotor performance (F = 5.881, B = - 4.110, Beta = -.220, t = - 2.058, *p* = .043, 95% CI -8.087 to -.133) once gender was taken into account. The significant predictors explained 13.3% of the variance of locomotor performance, with gender accounting for 8.5% and reading performance for 4.8%. With regard to the object-control skills, none of the variables (i.e. reading p = .522, spelling p = .259, and mathematics p = .052) remained in the final model, when account for age and gender. However, there was a trend for mathematics as a predictor for object-control performance. Age and gender accounted for 20.8% of the variance of the object-control performance.

**Discussion**

This study addressed two main aims: i) to compare the gross motor skills of 104 children with LD with those of 104 age-matched typically developing children and ii) to examine whether specific relationships between different subsets of gross motor skills (i.e. locomotor skills and object-control skills) and the different domains of academic performance (i.e. reading, spelling, and mathematics) in children with LD could be established. Compared to their typically developing counterparts, the children with LD scored significantly lower on both locomotor and object-control skills as assessed with the TGMD-2. Our findings are in line with those of Woodard and Surburg (2001) and partly in line with Zhang (2001). Woodard and Surburg also obtained a poorer performance on both TGMD-2 subtests in 6-8 year old children with LD compared to typically developing children. Using normative TGMD-2 data, Zhang found 6- to 10-year-old children with LD only performed worse on the locomotor subtest. Note, however that the latter study only included 7 children, which may explain the partially incongruent findings. Our large study sample extends the current knowledge on the gross motor performance of primary-school-age children with LD and shows that in addition to having lower gross motor skills than their typically developing peers, children with LD exhibit lower ability in object-control skills than in locomotor skills.

The effect sizes obtained (i.e. large for object-control skills and moderate for locomotor skills) indicate that the gap between the performance of the LD group and the typically developing group was larger for the TGMD-2 object-control items than for the locomotor items. This result is consistent with other studies on the gross motor performance of children with intellectual disabilities (Westendorp, Houwen, Hartman, & Visscher, 2011), deaf children (Hartman, Houwen, & Visscher, 2011), children with visual impairment (Houwen et al., 2007), and disadvantaged children (Goodway & Branta, 2003). A possible explanation for this result is that the execution of object-control skills is assumed to be more complex than the execution of locomotor skills. Object-control skills are generally practised in complex play and sport settings: situations that require fast adaptation to changing conditions (Houwen, et al., 2007). Performance in novel and complex situations relies strongly on executive functioning (Hughes and Graham, 2002), which is dependent on activation of the prefrontal cortex and cerebellum (Diamond, 2000). Executive functions are abilities of goal formation and planning, and the effective execution of goal-directed plans (Jurado & Roselli, 2007). Participation in complex situations is, therefore, considered to be difficult for children with LD, as they show deficits in their executive functioning (Bull & Scerif, 2001; Bull, Espy, & Wiebe, 2008; Van der Sluis, De Jong, & Van der Leij, 2004).

The results regarding the relationship between gross motor skills and academic performance in children with LD showed a clear relation between reading and locomotor skills: the larger the learning lag in reading the poorer the locomotor performance. Although performance in mathematics was not a significant predictor of object-control skills, compared to the p-values of reading and spelling it seems likely to suggest that performance in mathematics is related to object-control performance in children with LD. Probably a larger study sample would have resulted in a significant relationship between both parameters. Future research should give more evidence for the suggest relationship between mathematics and object-control performance.

Several factors may account for the observed relations. The motor and academic skills that were measured may share some underlying processes. Reading is thought to rely particularly on automatization (i.e. the process by which skills become so fluent that they no longer need conscious control [Nicolson, Fawcett, & Dean, 2001]). For example, the AVI reading test used assesses children's reading fluency (Cito, 2008); the child is asked to read out several short stories with increasing difficulty as rapidly as possible without mistakes. Automatization processes play an important role in reading fluency (Hook & Jones, 2002; Landerl & Wimmer, 2008). The test to measure children's mathematics ability, however, extends beyond math fluency (i.e. rapid calculation of single-digit addition, subtraction, and multiplication facts) more complex calculations with the involvement of complex cognitive processes like problem solving, working memory, and procedural processes (Ardilla & Rosselli, 2002; Bull & Scerif, 2001; Bull et al., 2008; Chong & Siegel, 2008). With regard to motor skills, locomotor skills are considered to depend less on cognitive procesess, while the complexity of object-control skills require more involvement of cognitive processes (Latash & Turvey, 1996). Here, we speculate that automaticity plays an important role in the observed relationship between reading and locomotor skills: meanwhile the complexity of skills may be more important for the link between mathematics and object-control skills. Thus, the similarities in the underlying processes may account for the obtained relationships.

A limitation of the present study is that these results do not address into the causality of the relationships that were found: do higher levels of motor skills lead to better academic performance or vice versa? As a growing body of literature states that well-developed motor capacities boost children's academic abilities (Murray et al., 2006; Piek et al., 2008), we suggest based on the present study, that a motor skill intervention aimed at improving object-control skills will stimulate the performance in mathematics, and that a locomotor skill intervention may facilitate children's reading performance. However, as both motor and cognitive skills develop in the same time-span (Anderson, 2002; Gabbard, 2008), these skills may be reciprocally associated (Diamond, 2000). Future intervention studies should focus on whether a cause-and-effect relationship does indeed exist between these performance parameters. Despite these limitations, this study contributes to the sparse literature available about the specific relationships between gross motor skills and academic performance in children with LD.

The present study possesses some practical implications for teachers and educators working with children with LD. First, educators and teachers should note that just as children with LD are a heterogeneous group in academic performance (i.e. different performance levels in reading, spelling, and mathematics), they show also a variety in motor performance. Second, teachers and educators should aware of the specific interrelationship between problems in motor performance and academic abilities. Further, the specific relationships between both parameters may indicate that early assessment of gross motor performance will be useful in the identification of problems with later academic performance. Early detection of both problems is therefore recommended, which would enable timely intervention. Finally, realizing the motor problems of children with LD and the specific relationships with academic abilities, we believe it is important that teachers in physical education emphasize the practice of gross motor skills in their gym lessons in order to facilitating both the motor and the academic domain.

**Conclusion**

This study supports previous findings that primary-school-aged children with LD perform worse than typically developing children in gross motor skills. More importantly, we found a specific relationship between reading and locomotor skills, and a trend was observed between mathematics and object-control skills in children with LD. The present study highlights the importance of specific motor interventions directed at boosting both the motor and the academic performance of children with LD.

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# Chapter 4
# A longitudinal study on gross motor development in children with learning disorders

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**Abstract**

This longitudinal study examined the development of gross motor skills, and sex-differences therein, in 7-to11-years-old children with learning disorders (LD) and compared the results with typically developing children to determine the performance level of children with LD. In children with LD (n = 56; 39 boys, 17 girls), gross motor skills were assessed with the Test of Gross Motor Development-2 and measured annually during a 3-year period. Motor scores of 253 typically developing children (125 boys, 112 girls) were collected for references values. The multilevel analyses showed that the ball skills of children with LD improved with age ($p <.001$), especially between 7 and 9 years, but the locomotor skills did not ($p = .50$). Boys had higher ball skill scores than girls ($p = .002$) and these differences were constant over time. Typically developing children outperformed the children with LD on the locomotor skills and ball skills at all ages, except the locomotor skills at age 7. Children with LD develop their ball skills later in the primary school-period compared to typically developing peers. However, 11 year-old children with LD had a lag in locomotor skills and ball skills of at least four and three years, respectively, compared to their peers.

Keywords: primary-school-age children, locomotor skills, ball skills, learning disorders

## Introduction

Children typically attain proficiency in gross motor skills such as running, hopping, throwing, and catching during their primary school years through a process of maturation and practice (Davies & Rose, 2000; Gabbard, 2008). These are all basic skills that help children function as fully and as independently as possible in their surroundings (Pangrazi, 2007) and are commonly considered the building blocks for the development of more complex motor and sport-specific skills (Stodden et al., 2008; Wall, 2004). Additionally, gross motor skills are positively related to children's cognitive functioning, e.g. academic achievement and executive functioning (Lopes, Santos, Pereira, & Lopes, 2013; Murray et al., 2006; Piek, Dawson, Smith, & Gasson, 2008). Thus, sufficiently developed gross motor skills are thought to boost children's participation in physical activities and sports as well as the development of their cognitive abilities.

It has been shown that primary-school-age children with learning disorders[2] (LD) have inferior gross motor skills compared to typically developing peers (Simons, Daly, Theodorou, Caron, Simons, & Andoniadou, 2008; Westendorp, Houwen, Hartman, & Visscher, 2011a; Westendorp, Hartman, Houwen, Smith, & Visscher, 2011b). However, far less is known about the gross motor development of children with LD during the primary-school years. One cross-sectional study in children with mild intellectual disabilities (a subgroup of children with LD), ages 7-10 years, showed a positive age effect with small effect sizes for ball skills. No age effects were found for locomotor skills (Simons et al., 2008). Longitudinal research considering the development of gross motor skills in children with LD has not yet been conducted. Longitudinal research is important as it provides information about within-individual changes with age rather than changes between different individuals. Identifying possible developmental changes in gross motor skill performance in children with LD will give insight into possible accelerations or stabilization in the development. This knowledge is crucial as it is likely to provide clues for interventions directed at improving motor performance in this population.

Besides age, sex differences may play a role in the gross motor skill development of children with LD. Sex differences in gross motor skill development have been established in typically developing children. The ball skill scores of boys generally exceeded that of girls (Barnett, van Beurden, Morgan, Brooks, & Beard, 2010; Butterfield, Angell, & Mason, 2012), but boys and girls did not differ in their locomotor skill scores (Barnett et al., 2010; Ulrich, 2000). In children with LD mixed results have been found regarding sex differences in gross motor skill performance. Simons et al. (2008) found that boys outperformed girls in ball skills, however, Woodard and Surburg (1997) reported higher scores for boys on both locomotor skills and ball skills compared to girls. Until now, it is still unknown whether the developmental trajectory of gross motor skills is different for boys and girls with LD. This information is important whether or not interventions should be different for boys and girls.

In sum, it is generally agreed that children with LD have lower gross motor skill performance compared to typically developing children. However, no studies focused on the developmental trajectory of gross motor skills using longitudinal research. Insight in

[2] Children with learning disorders are defined here as children with problems in academic skills like reading and mathematics that attend Dutch special-needs primary schools.

the longitudinal development of gross motor skills contribute to the current knowledge about the gross motor skill performance in children with LD.

The aim of this longitudinal study was, therefore, to chart the developmental trajectory of gross motor skills (i.e. locomotor skills and ball skills), and sex-differences therein, in 7-to-11 year-old children with LD and to compare the results with typically developing children to determine the performance level of children with LD. Based on the developmental skill-learning gap hypothesis (Wall, 2004), we hypothesized that the gap between children with LD and their more competent peers becomes wider. Children with a normal or high gross motor proficiency begin to use their motor skills in more open and complex settings, whereas children with less adequately developed gross motor skills find it difficult to participate in these complex settings, making it more difficult for them to acquire the expertise they require to participate (Wall, 2004). Given that children with LD tend to have poorer gross motor skills than their typically developing peers, the gap between the two groups may become larger with age.

**Material and methods**

*Participants*

Fifty-six children with LD (39 boys, 17 girls), aged between 7 and 11 years old in the year of enrolment, participated in this longitudinal study. They were recruited from a special-needs primary school located in the northern Netherlands. Over a period of three years the children's gross motor skills were measured annually in January. Not all 56 children participated in all three measurements, as some children enrolled in the school during the 3-year period, some others left or were absent due to illness. Thirty-five children performed all three measurements, 16 children performed two measurements, and five children were assessed one time. An overview of the numbers of children per measurement per age group is given in Table 4.1, with a total of 142 measurements.

For each child, the individual school files containing information about child characteristics (e.g. age, sex, IQ), a short medical history, and comorbid disorders were screened. Fifteen children had a comorbid disorder, i.e. 9 children were diagnosed as having Attention Deficit Hyperactivity Disorder, 3 children were diagnosed as having Autism Spectrum Disorders, and 3 children were diagnosed with both. The children's mean intelligence quotient was 84.2 (SD 11.0; range 60-109).

To determine the performance level of children with LD, 253 typically developing peers (125 boys and 112 girls), attending two mainstream schools in the same region, were included in the present study to provide reference values. The age range of the children was 7 to 11 years (mean age 9.5 years; SD 1.2) and children's grade level was appropriate to their age, indicating that their ability on academic performance was in the normal range (i.e. the expected level in relation to their learning experiences).

Informed consent was obtained for all children and all procedures were approved by the institutional Ethics Committee of the Center for Human Movement Sciences, University Medical Center Groningen, University of Groningen, as being in accordance with the ethical guidelines of the American Psychological Association.

***Table 4.1*** *Number of children with learning disorders per measurement per age group*

| Age | Number of participants | | | |
|---|---|---|---|---|
| | T1 | T2 | T3 | Total |
| 7 years | 10 | 0 | 0 | 10 |
| 8 years | 14 | 17 | 0 | 31 |
| 9 years | 20 | 13 | 12 | 45 |
| 10 years | 2 | 22 | 12 | 36 |
| 11 years | 0 | 1 | 19 | 20 |
| Total | 46 | 53 | 43 | 142 |

*Assessment of motor skills*

The Test of Gross Motor Development-2 (TGMD-2; Ulrich, 2000) was used to measure motor skill performance. The TGMD-2 is a qualitative, process-orientated measure (i.e. evaluates movement based on the demonstration of performance criteria which provided information of how the movement was performed) to assess 12 gross motor skills. The gross motor skills are divided into 6 locomotor skills (run, gallop, hop, leap, jump, and slide) and 6 ball skills (two-hand strike, stationary bounce, catch, kick, overhand throw, and underhand roll). Each skill is executed twice and evaluated based on the presence (success; score 1) or absence (failure; score 0) of three to five qualitative performance criteria. The highest total raw score for both subtests is 48. The higher the (total) score, the better the performance. Evidence of the reliability and validity of the TGMD-2 to assess gross motor skills has been reported for typically developing children (Ulrich, 2000) and for children with a mild intellectual disability (Simons et al., 2008). The TGMD-2 was individually administered at their school gym by specially trained test administrators.

The TGMD-2 has good psychometric qualities to assess gross motor skill performance of typically developing children, according to the test manual (Ulrich, 2000). The internal consistency, the test-retest, and the interrater reliability varied between .85 and .98 for both subtests and the total TGMD-2. The construct validity, measured with a confirmatory factor analysis, was good ($\chi^2$= 280.3; GFI = .96; AGFI = .95) (Ulrich, 2000). Reliability and validity studies of the TGMD-2 in children with mild intellectual disabilities and learning disabilities showed similar values as reported by Ulrich (Simons et al., 2008; Zhang, 2001).

*Data analysis*

Multilevel modeling (MLwiN 2.23) was used to investigate the longitudinal changes in gross motor skills in children with LD. In multilevel models, longitudinal data, which are not independent and nested within children, can be analyzed. The advantage of multilevel models is that the amount of measurements may vary per child, as MLwiN assumes data is missing at random (Snijders & Bosker, 2011). Multilevel models were created for the locomotor skills and the ball skills, whereby Level 1 values are the repeated measures *within* individual children and Level 2 values are the differences *between* individual children. To examine the developmental changes in locomotor skills and ball skills, age (i.e. linear) and age$^2$ (i.e. quadratic) were considered as possible predictors. Both age and age$^2$ were entered in the model to find the best model fit. That is, to examine if the best model fit was a linear or quadratic curve, or a combination of both. Age 7 is used as the reference age to create simple models, whereby the intercept shows the predicted score for 7-year olds. Value one represented age 8, value two represented age 9, value three represented age 10, and value four represented age 11.

Additionally, sex and the possible interactions between age and sex were entered in the model. Random intercepts were considered allowing a unique intercept for each individual child (Snijders & Bosker, 2011). Also, random slopes were entered into the model to properly account for correlations amongst repeated measures in individuals (Snijders & Bosker, 2011). All models were adjusted for comorbid disorders and IQ. The possible predictors (i.e. age, age$^2$, and sex) were entered separately into the initial model. During each step, goodness of fit was evaluated by comparing the -2*Log Likelihood (IGLS deviance) of the previous model with the most recent model. Variables that did not contribute significantly to the model ($p > .05$) were removed from further analysis. Predictions were calculated based on the final models.

To determine the between-group differences in children with LD and typically developing children at each age, the gross motor skill scores of children with LD were compared with typically developing peers using ANCOVAs with sex as the covariate (SPSS version 20.0). The ANCOVAs were conducted separately per age. To determine the meaningfulness of group effects, correlational effect sizes were calculated in accordance with Rosnow, Rosenthal, and Rubin (2000). An effect size correlation of $r = .10$ was defined as small, $r = .30$ as moderate, and an effect size of $r = .50$ as large (Field, 2005). An alpha of .05 was adopted for all tests of significance.

**Results**

*Locomotor skill development*

Table 4.2 lists the estimated model of the locomotor skills. The predictors age ($p = .50$), age$^2$ ($p = .55$), sex ($p = .34$), comorbid disorder ($p = .43$), and IQ ($p = .36$) did not significantly contribute to the locomotor skill model and were therefore not included in the final model. The interaction between age and sex was not significant ($p = .50$) indicating that the developmental trajectory of the locomotor skills was not different for boys and girls. Random slopes did not improve the model fit ($p > .05$). The predicted curve for the locomotor skills is plotted in Figure 4.1. The graph shows that the locomotor skills did not improve between ages 7 to 11.

***Table 4.2** Multilevel model for the locomotor skills*

| **Fixed effects** | **Coefficient** | **Standard error** | **p** |
|---|---|---|---|
| Intercept (constant) | 36.991 | 0.590 | <0.001 |
| **Random effects** | **Variance** | | |
| *Level 2 random effects* | | | |
| Intercept variance | 14.685 | 3.734 | <0.001 |
| *Level 1 variance* | | | |
| Residual variance | 11.329 | 1.723 | |
| Deviance | 827.821 | | |
| Deviance empty model | 866.503 | | |
| p < .05 | | | |

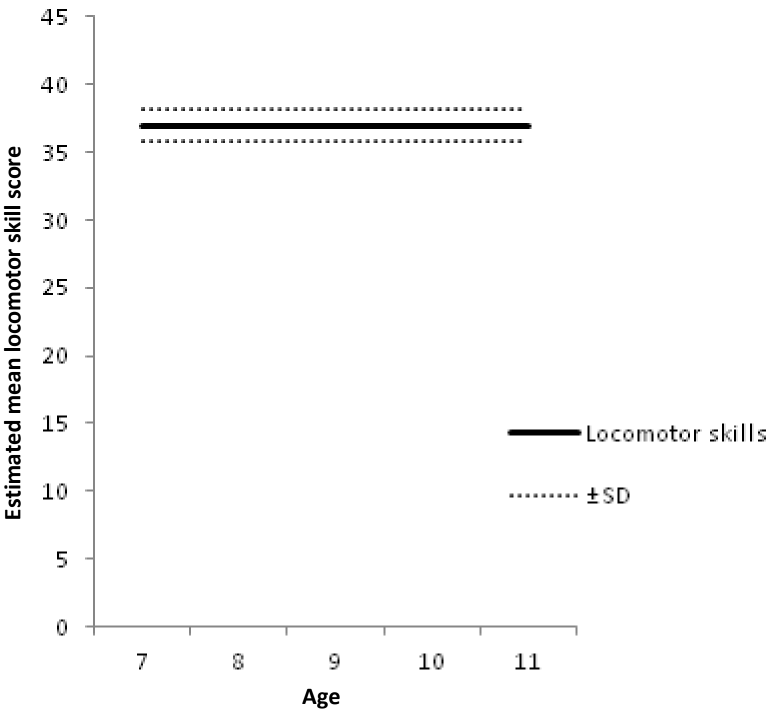


***Figure 4. 1** Locomotor skill development from age 7-11*

*Ball skill development*

For the ball skills model, age, $age^2$, and sex significantly improved the model. Comorbid disorder (p = .28) and IQ (p = .92) did not improve the model fit and were therefore not included in the final model. The interaction between age and sex was not significant (p = .82) indicating parallel developmental trajectories for boys and girls. Also, random slopes did not improve the model fit ($p > .05$). The final estimated ball skill model including age, $age^2$, and sex as significant predictors, is presented in Table 4.3. The following equations were derived from this ball skill model:

$$\text{Ball skill performance for boys} = 28.334 + 5.777 * age - 0.802 * age^2$$
$$\text{Ball skill performance for girls} = 24.362 + 5.777 * age - 0.802 * age^2$$

In these equations, age 7 is the reference age and represented as zero, value one represented age 8, value two represented age 9, value three represented age 10, and value four represented age 11. For instance, it is predicted that boys at age 9 will score $28.334 + 5.777 * 2 - 0.802 * 2^2 = 36.68$ on the ball skills.

The predicted ball skill curves for boys and girls are plotted in Figure 4.2. The observed quadratic age effect indicates an accelerated development between 7 and 9 years with a plateau around 10 years of age for boys as well as for girls. Children were estimated to improve the most from age 7 to 8 (almost 5 points), followed by age 8 to 9 (3.4 points).

***Table 4.3*** *Multilevel model for the ball skills*

| **Fixed effects** | **Coefficient** | **Standard error** | **p** |
|---|---|---|---|
| Intercept (constant) | 28.334 | 1.228 | <0.001 |
| Age | 5.777 | 1.022 | <0.001 |
| $Age^2$ | -0.802 | .219 | <0.001 |
| Boy | 0 | 0 | |
| Girl | -3.972 | 1.199 | 0.002 |
| **Random effects** | **Variance** | **Standard error** | |
| *Level 2 random effects* | | | |
| Intercept variance | 11.724 | 3.236 | <0.001 |
| *Level 1 variance* | | | |
| Residual variance | 12.197 | 1.860 | |
| Deviance | 826.160 | | |
| Deviance empty model | 907.327 | | |
| p < .05 | | | |

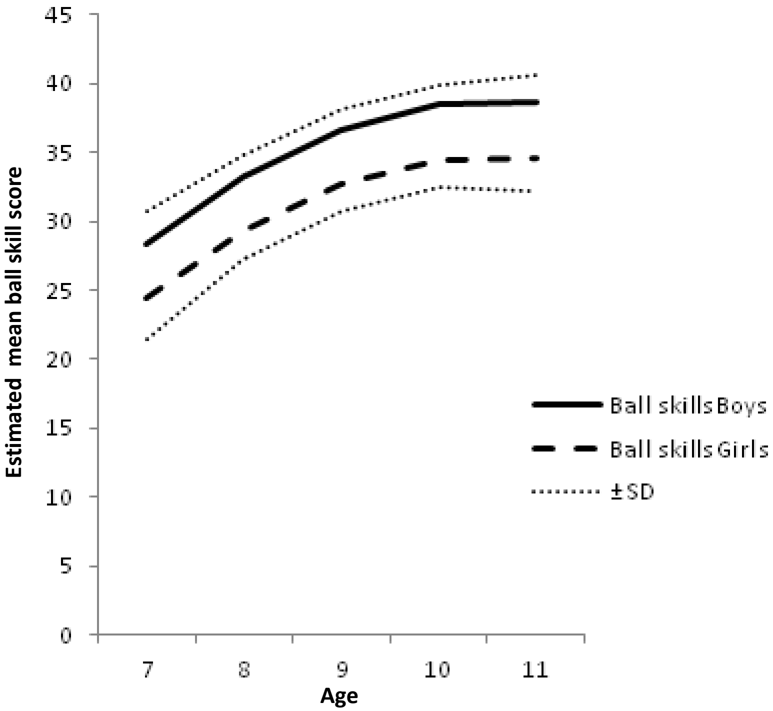


***Figure 4.**2. Ball skill development from age 7-11 for boys and girls. Standard deviations (SD) are only illustrated in one direction for clarity, in reality SD's should be illustrated both ways.*

*Age-related between-group differences on gross motor skills*

Table 4.4 shows the estimated mean gross motor skill scores for the children with LD and typically developing children presented by age. The between-group analyses showed that the typically developing children significantly outperformed the children with LD on the locomotor skills and ball skills at all ages, except on the locomotor skills at age 7. For the locomotor skills, at age 8 the effect sizes was large and at age 9, 10, and 11 moderate effect sizes were found. For the ball skills, large effect sizes were found at age 7 and 8, moderate effect sizes at age 9 and 10, and a small effect size was found at age 11. This indicates that the gap in locomotor skills between children with LD and typically developing children varied across the ages and the gap in ball skills between both groups decreased with increasing age.

***Table 4.4*** *Estimated mean gross motor skill scores for children with learning disorders and typically developing children presented by age*

| | Locomotor skills | | | | | | | | Ball skills | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Children with LD | | | TD children | | | | | Children with LD | | | TD children | | | | |
| Age | n | M[1] | SE | n | M[1] | SE | p | ES | n | M[1] | SE | n | M[1] | SE | p | ES |
| 7 years | 10 | 39.3 | .98 | 11 | 39.6 | .94 | .805 | .06 | 10 | 26.2 | 1.7 | 11 | 37.1 | 1.6 | <.001 | .74 |
| 8 years | 31 | 35.9 | .70 | 42 | 41.5 | .60 | <.001 | .59 | 31 | 32.0 | .74 | 42 | 39.1 | .63 | <.001 | .65 |
| 9 years | 45 | 37.4 | .65 | 53 | 40.8 | .60 | <.001 | .36 | 45 | 35.4 | .64 | 53 | 39.5 | .59 | <.001 | .43 |
| 10 years | 36 | 37.9 | .74 | 74 | 41.0 | .52 | .001 | .31 | 36 | 36.3 | .75 | 74 | 39.6 | .52 | <.001 | .33 |
| 11 years | 20 | 36.6 | .84 | 57 | 41.2 | .50 | <.001 | .48 | 20 | 37.5 | 1.0 | 57 | 40.3 | .62 | 0.21 | .24 |

Note: LD = learning disorders; TD = typically developing; ES = effect sizes
1 = Estimated mean score, statistically adjusted for sex

**Discussion**

The aim of this longitudinal study was to chart the developmental trajectory of gross motor skills (i.e. locomotor skills and ball skills), and sex-differences therein, in 7-to-11 year-old children with LD and to compare the results with typically developing children to determine the performance level of children with LD.

The results of the present study showed that the ball skills of children with LD improved during ages 7 to 11, but no improvement was found for the locomotor skills. The observed quadratic age effect in the development of ball skills indicates an accelerated development between 7 and 9 years with a plateau around 10 years of age. In typically developing children, the preschool and the early primary school years are recognized as the critical timeframe to develop proficiency in gross motor skills (Gabbard, 2008; Ulrich, 2000). The scores of the typically developing children presented here, showed a similar pattern with little improvement after 7 years of age. Notable is the large ball skill difference between both groups at age 7 years, while the difference between both groups at age 11 is much smaller. Therefore, we might conclude that children with LD develop their ball skills later in the primary school-period compared to their typically developing peers. However, at the end of the primary school period there is still a gap between both groups of children. Eleven-year-old children with LD perform under the level of the 8 year-old typically developing children, indicating a lag in ball skills of at least three years.

No age-related developmental changes were found for the locomotor skills in children with LD. A possible explanation for this finding might be that this study is conducted in primary-school-age children between 7 and 11 years of age and not in younger children. In typically developing children, locomotor skills develop rapidly before 7 years of age (Gabbard, 2008). It might be that children with LD also show the most improvement in locomotor skills before 7 years of age. However, the between-group comparisons showed that children with LD scored lower than the typically developing children at all ages, except at age 7. At the end of the primary school period children with LD did not achieve the performance level of 7 year-old typically developing children indicating a lag in locomotor skills of at least four years.

The between-group performance lag for both the locomotor skills and ball skills persisted over the years. In the present study, gross motor skills were assessed in a relatively static setting that required competence in basic skills (Wall, 2004). If children's skills were evaluated in more complex and open environments (e.g. sport settings), the results would probably have reflected a growing age-related lag in the performance of the LD group. Smyth and Anderson (2000) suggested that this performance lag could negatively affect the children's active participation in games on the playground and they indeed found children with less proficient motor skills to spend more time alone and to participate less in playground games than the more competent children. Poor motor performance may also affect the pleasure children with LD experience in sports and games as playing with typically developing peers, because in the Netherlands in many organized sports children are mainly divided in groups based on their age rather than on their performance level.

Our results showed sex differences in ball skill performance, boys had higher scores than girls, but no sex differences were found on the locomotor skills. No significant interaction effects were found between age and sex indicating that the developmental patterns were not different for boys and girls and that these trajectories were parallel over time. The sex differences in gross motor skill performance in children with LD are comparable with studies in typically developing peers (Barnett et al., 2010; Butterfield et al., 2012). Butterfield et al. (2012) reported sex differences in ball skills in typically developing children favoring boys, but parallel growth curves for boys and girls.

The present study is the first longitudinal study investigating developmental changes in gross motor skills in children with LD. Insight is given into the gross motor skill development during a large part of the primary school period. However, the development trajectory before 7 years of age is still unknown. Therefore, future studies interested in gross motor skill development should focus on children younger than 7 years old. Second, the present study included a relatively small sample of 7-year-old children, which might have resulted in relatively high locomotor skills scores at age 7 compared to the other ages due to some high individual scores. Furthermore, the study population included some children with comorbid disorders, which may have influenced the data. However, the results showed that both comorbidity and IQ did not significantly influence the locomotor skill and the ball skill model. This indicated that the developmental trajectory of gross motor skills was not different for children with a comorbid disorder and children without a comorbid disorder and for children with a below average IQ and children with an IQ in the normal range. The results can be, therefore, generalized to all children with LD in Dutch special-needs primary schools.

The present study has some practical implications. First, this study stresses the importance of providing interventions for children with LD to help them develop and maintain adequate levels of gross motor proficiency. Second, there was a wide range in gross motor skill scores suggesting a variety in gross motor performance between children with LD. Motor interventions in children with LD should take into account this variability by using different skill levels in the exercises in the intervention sessions in order to challenge individual children at their own motor skill level. Finally, as motor skills and cognitive skills are related (Cameron et al., 2012; Diamond, 2000), early detection of motor skill problems is recommended and might be useful in the identification of problems with later school performance.

**Conclusion**

The present study showed that the ball skills of children with LD developed between 7 to 11 years of age, but the locomotor skills did not improve. Children with LD developed their ball skills later in the primary school years compared to typically developing peers, however, the development pattern was similar. Furthermore, for the ball skills sex differences were revealed, boys scored higher than girls, and parallel growth trajectories for boys and girls were found. At all ages typically developing children outperformed children with LD highlighting the need for motor interventions in children with LD to minimize the delay in motor development and thus possibly in other areas such as their sports participation and school performance.

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# Chapter 5
# Specific associations between gross motor skills and executive functioning in children with learning disorders: a longitudinal study

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*Submitted*

**Abstract**

This study examined whether the performance on different subsets of gross motor skills (i.e. locomotor skills and ball skills) was related to the performance on different executive functioning (EF) components (i.e. inhibition, cognitive flexibility, working memory, problem solving) one and two years later in children with learning disorders (LD), aged 7 to 11 years. The gross motor skills of 53 children with LD were measured at baseline with the Test of Gross Motor Development-2 and their EF was assessed at baseline, one year, and two years later with the Tower of London, the Trailmaking test, the Self-Ordered Pointing task, and the Stroop test. Positive associations were found between ball skills, specifically between the items throwing and kicking, and problem solving one year later. Inverse relationships were found between the TGMD-2 motor skills scores and inhibition one year later. It seems that the association between gross motor skills and EF in children with LD is specific rather than general.

Keywords: primary-school-age children, locomotor skills, ball skills, learning disorders, cognitive functioning

**Introduction**

It is generally agreed that motor and cognitive development are interrelated (Diamond, 2000). From a neuropsychological perspective, the close association between motor and cognitive development can be explained by the co activation of the cerebellum, important for complex and coordinated movements, and the prefrontal cortex, critical for higher-order cognitive functioning, i.e. executive functioning (Diamond, 2000). Executive functioning (EF) is an umbrella term that includes a number of interrelated higher cognitive processes necessary for purposeful and goal-directed behavior (Welsh, Friedman, & Spieker, 2008). Typical EF processes are inhibition, cognitive flexibility, working memory, planning, and problem solving (Diamond, 2013, Miyaka Friedman, Emerson, Witzki, Howerter, & Wager, 2000). Additionally, research showed a parallel development for motor and cognitive skills with an accelerated development between ages 5 and 10 years (Anderson, 2002; Best, Miller, & Jones, 2009; Gabbard, 2008).

Both motor skills and EF are positively associated with the development of academic abilities (e.g. Best, Miller & Naglieri, 2011; Cameron et al., 2012; Grissmer, Grimm, Aiyer, Murrah, & Steele, 2010). For children with learning disorders[1] (LD), characterized by major problems in academic abilities, but also by poor motor skill performance (e.g. Simons et al., 2008; Westendorp, Houwen, Hartman, & Visscher, 2011a; Westendorp, Hartman, Houwen, Smith & Visscher, 2011b) and poor EF (Hartman, Houwen, Scherder, & Visscher, 2010; Sikora, Haley, Edwards, & Butler, 2002; Toll, Van der Ven, Kroesbergen, & Van Luit, 2010; Van der Sluis, De Jong, & Van der Leij, 2004), insight into possible relationships between motor performance and EF may provide useful knowledge for the development of (motor) interventions in order to facilitate their motor and cognitive functioning of these children. Furthermore, it gives clues for the development of education policy regarding education in special-needs primary schools as well as in typical primary schools.

Previous research has found positive associations between motor skill performance and EF in typically developing children (e.g. Livesy, Keen, Rouse, & White, 2006; Roebers & Kauer, 2009; Wassenberg et al., 2005) as well as in children with LD (Hartman et al., 2010). Although positive associations have been found, longitudinal research is needed to facilitate causal inferences (Haapala, 2013; Rigoli, Piek, Kane, Whillier, Baxter, & Wilson, 2013). There has been few longitudinal studies in typically developing children examining associations between motor skills and EF (Murray et al., 2006; Niederer et al., 2011; Piek, Dawson, Smith, & Gasson, 2008; Rigoli et al., 2013). Recently, Rigoli et al. (2013) showed in children with movement difficulty, aged 5-11 years, that better fine motor skills (but not gross motor skills) at baseline predicted better visual working memory performance at 18-month follow-up. Conversely, this relationship was not found in children without movement difficulty (i.e. control children). Niederer et al. (2011) demonstrated that better dynamic balance at baseline was associated with improvements in spatial working memory 9 months later. Piek et al. (2008) found in 6-to-12-years-old children, who had been assessed at ages 4 months to 4 years, a significant relationship between gross motor skills in the preschool ages and cognitive skills (i.e. processing speed and working memory) at school age (from 6 to 12 years). No significant relationships were found between early fine motor skills and later cognitive skills. Finally, Murray et al. (2006) found a significant linear relationship between the age of learning to stand without support and EF (i.e. categorisation with or without working memory load) at age 35, the earlier the attainment of the milestone, the better the categorisation in adulthood. In sum, these longitudinal studies provide evidence that higher levels of motor skills predict better cognitive skills.

The question remains whether or not motor skill performance is related to later EF performance in children with LD and whether the possible associations hold for all motor skills and EF components or only to specific ones (i.e. a general association or specific association).

The aim of this study was, therefore, to examine in 7-to-11 year-old children with LD whether the performance on different subsets of gross motor skills (i.e. locomotor skills and ball skills) was related to the performance on different EF components (i.e. inhibition, cognitive flexibility, working memory, problem solving) one and two years later.

## Method

*Participants*

Fifty-three children with LD (36 boys, 17 girls), aged between 7 and 10 years in the year of enrolment, participated in this longitudinal study. They were recruited from a primary special-needs school located in the northern Netherlands. Children's gross motor skills were measured at baseline (T0) and children's EF were measured at baseline, one (T1), and two (T2) years later, except inhibition which was not assessed at baseline. Not all 56 children participated in all three measurements as some children left the school during the 3-year period or were absent during the assessments due to illness.

For each child, the individual school files containing information about child characteristics (e.g. age, sex, IQ), a short medical history, and comorbid disorders were screened. Fourteen children had a comorbid disorder, i.e. were diagnosed with Attention Deficit Hyperactivity Disorder (ADHD) or Autism Spectrum Disorders. The children's mean Intelligence Quotient was 84.8 (SD 10.7; range 66-109).

*Assessment of motor skills*

The Test of Gross Motor Development-2 (TGMD-2; Ulrich, 2000) was used to measure motor skill performance. The TGMD-2 is a qualitative, process-orientated measure (i.e. evaluates movement based on the demonstration of performance criteria which provided information of how the movement was performed) to assess 12 gross motor skills divided into locomotor skills (run, gallop, hop, leap, jump, and slide) and ball skills (two-hand strike, stationary bounce, catch, kick, overhand throw, and underhand roll). Each skill is executed twice and evaluated based on the presence (success; score 1) or absence (failure; score 0) of three to five qualitative performance criteria. The highest total raw score for both subtests is 48. The higher the (total) score, the better the performance. Evidence of the reliability and validity of the TGMD-2 to assess gross motor skills has been reported for typically developing children (Ulrich, 2000) and for children with mild intellectual disabilities (Simons et al., 2008).

*Assessment of executive functioning*

Four tests were used to measure EF: the Tower of London (Shallice, 1982), the TrailMaking test (Reitan & Wolfson, 2004), the Self-Ordered Pointing Task (Petrides & Milner, 1982), and the Stroop test (Stroop, 1935). All EF test have frequently been used for the assessment of EF in children (Strauss, Sherman, & Spreen, 2006).

*Tower of London (TOL)*

The TOL measures specifically problem solving and planning ability (summarized as problem solving) and consists of a board with three pegs of different lengths and three coloured balls (red, blue, and yellow) with holes that can be manipulated on the pegs. Children have to solve 12 problems by transforming a fixed start state into a depicted goal state by applying three important rules: 1) only one ball can be moved at a time; 2) a ball cannot be moved while another ball is lying on top of it; 3) the longest peg can carry three balls, the middle peg two and the shortest peg only one ball. Children were instructed to solve each problem within a minimum number of moves as given by the researcher, while a maximum of three trials was allowed to solve each problem. A problem was solved correctly, when the goal state was achieved within the minimum number of moves allowed for that problem. The test was preceded by a practice problem and children were encouraged to strive for accuracy as well as speed. The score on the TOL was determined by assigning three, two, or one point(s) per problem based on the number of trials required to solve the problem, with three points reflecting one trial, two points two trials, and one point three trials. The TOL total score was the sum of the points for all 12 problems with a maximum of 36.

*TrailMaking Test (TMT)*

The TMT was used for the assessment of cognitive flexibility. The TMT is a paper-and-pencil task which consists of two parts, TMT A and TMT B. In TMT A, children were asked to draw a line to connect encircled digits (1 to 25) randomly arranged on a sheet of paper in ascending order (i.e. 1-2-3-4-5, etc.). This provides an estimate of attention and psychomotor speed (i.e. movement or motor activity associated with mental processes) (Straus et al., 2006). In TMT B, a series of encircled digits (1 to 13) and letters (A to L) should be connected in ascending order by alternating between digits and letters (i.e. 1-A-2-B-3-C-4-D-5-F, etc.) providing an estimate of cognitive flexibility (Straus et al., 2006). The children were instructed to execute both parts as quickly as possible. Both parts were preceded by an example. The time taken to complete each part was used as the test score. In order to give a more accurate measure of cognitive flexibility and to control for the effect of psychomotor speed, the TMT Delta was calculated by subtracting the total time of TMT A from the total time TMT B. (Eggermont, Milberg, Lipsitz, Scherder, Leveille, 2009).

*Self-Ordered Pointing Task (SOPT)*

The SOPT was used to assess working memory and consisted of 4 series of cards with abstract designs. The series of cards contains 6, 8, 10, and 12 abstract designs respectively. For a specific series, the same set of abstract designs was used, but they were arranged differently on each card, In a specific series, there were as many different cards as there were designs. For example, in the series with 6 abstract designs, there were 6 cards, on each card the same 6 abstract designs were printed, but the position of the abstract designs differ on each card. Children were instructed to point to a different design on each card without repeating a design already pointed to and after all cards of a series the child have pointed all different designs of that series. The test administrator turned around the cards, children were asked only to point to a design on the card. Children were instructed to point the designs in any order they wished, but that they were not allowed to use a standard order (i.e. point to the same location on two consecutive cards) or to point a specific design more than once. Children were encouraged to strive for accuracy and work on an adequately velocity. Prior to the official test, children were given a practice with a series of 3 designs. The aim of the test was that children point each design of a series one time. The difficulty of the test and the appeal on working memory increases with the increases of the amount of cards per series, respectively 6, 8, 10, and 12. The test sore was the numbers of errors that has been made for each series separately.

*Stroop Test*

Response inhibition refers to three interrelated processes: (i) inhibition of a prepotent response, (ii) stopping of an ongoing response and (iii) interference control. Interference control is the inhibition of a habitual response in favor of a less familiar one. In the present study, the standard Stroop Color-Word test was used as a measure of interference control. In this test the automatic response of word reading has to be suppressed and prevented from interfering with naming the color of the color word. The Stroop Color-Word test consists of 3 cards: a Word Card with 100 color words (red, green, yellow and blue) printed in black ink, a Color Card with 100 colored rectangles (red, green, yellow and blue) and a Color-Word Card on which the names of the colors are printed in an incongruent color of ink. During the word reading condition (i.e Word Card), children have to read aloud as quickly as possible the names of the colors printed in black ink. During the color naming condition (i.e. Color Card), children have to mention the colors of the rectangles as quickly as possible. Finally, during the color-word condition (i.e. Color-Word Card) have to name the color of the ink as quickly as possible and not to read the word itself. The total time needed for each card and the amount of errors were administered. The test score was the ratio score ($I_R$), with $I_R$ = C/CW for time per item. The time per item was calculated by divided the total time of a card through 100 (i.e. the total items on each card). A higher ratio score means less interference from incongruent words when naming the colors in the color-word condition (Lansbergen, Kenemans, & Engeland, 2007).

*Procedure*

Informed consent was obtained for all children and all procedures were approved by the institutional Ethics Committee of Human Movement Sciences, University Medical Center Groningen, University of Groningen, as being in accordance with the ethical guidelines of the American Psychological Association. The TGMD-2 and the EF tests were individually administered by specially trained test administrators.

*Data analysis*

Descriptive statistics were explored with ANCOVAs controlled for age, sex, and IQ. To predict EF, hierarchical linear regression analyses were conducted per EF task with motor skills as independent variable and EF one and two years later as the dependent variable. The analyses were done for the total locomotor subtest score and the total ball subtest score. In case of significant results, separate regression analyses were performed with the different items per subtest (i.e. run, gallop, hop, leap, jump, slide, strike, bounce, catch, kick, throw, and roll) as independent variables. All models were adjusted for age, sex, and IQ. These covariates were entered in the regression model on the first step and the motor variable was entered in the second step in all regression models. In the regression model with the Stroop interference ratio as the independent variable, the time per item of the Stroop Word Card (card 1) was also entered as covariate in the analysis to correct for base-word reading (Lansbergen et al., 2007). The statistics were performed using SPSS software (version 20.0) and the significance level was set at .05.

## Results

*Descriptive statistics*

The estimated mean (i.e. mean adjusted for age, sex, and IQ) locomotor skill score at baseline was 37.7 (SE .64; range 23-46; N = 53) and the baseline estimated mean ball skill score was 36.3 (SD .57; range 27-46; N = 53). In Table 5.1, estimated mean, standard errors and range of the EF scores at baseline, one and two years later are presented. Table 5.1 showed improvement on all EF components across the years.

***Table 5.1*** *Estimated Mean EF scores at baseline, one and two years later*

| | **Baseline** | | | | **One year later** | | | | **Two years later** | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | N | M[a] | SE | Range | N | M[a] | SE | Range | N | M[a] | SE | Range |
| TOL (points)[b] | 47 | 28.8 | .40 | 20-36 | 47 | 29.5 | .45 | 23-36 | 35 | 29.8 | .59 | 20-35 |
| TMT (sec)[c] | 45 | 92.7 | 9.1 | 22-280 | 44 | 63.4 | 4.8 | 21-174 | 36 | 59.9 | .4.4 | 6-109 |
| SOPT (errors)[c] | 50 | 8.1 | .50 | 3-22 | 47 | 5.9 | .35 | 1-11 | 35 | 5.8 | .34 | 2-10 |
| Stroop (sec)[b] | 0 | - | - | - | 38 | .58 | .02 | .40-.73 | 35 | .63 | .02 | .35-.87 |

[a] statistically adjusted for age, sex, and IQ.
[b] the higher the score, the better the performance.
[c] the lower the score, the better the performance.
TOL = Tower of London; TMT = Trailmaking test (TMTB-TMTA); SOPT = Self-Ordered Pointing Task; Stroop = Interference ratio stroop test

*Associations between motor skills and executive functioning 1 year later*

Regression analysis showed that the locomotor skill subtest was negatively associated with the Stroop interference ratio as measure for inhibition (F = 4.706, B = -.010, Beta = -.559, t = -3.687, p = .001, 95% CI -.016 to -.005) with age, sex, IQ, and base-word reading as covariates in the model. The total model explained 42.4 % of the variance of inhibition with locomotor skills accounting for 24.4 %. The analyses per locomotor skill item revealed that only hopping (F = 2.745, B = -.020, Beta = -.365, t = -2.355, p = .025, 95% CI -.037 to -.003, $R^2$ = .121) was significant associated (negative relationship) to inhibition. Locomotor skill performance was not significantly related to working memory, cognitive flexibility, and problem solving (p > .05).

Ball skill performance was predictive for problem solving (F = 4.123, B = .289, Beta = .426, t = 2.614, p = .012, 95% CI .066 to .513) once age, sex, and IQ were taken into account. The model explained 28.2% of the variance of problem solving with ball skills accounting for 11.7%. The analyses per ball skill item demonstrated that kicking (F = 4.336, B = 1.154, Beta = .379, t = 2.746, p = .009, 95% CI .306 to 2.002, $R^2$ = .127) and throwing (F = 4.062, B = .609, Beta = .353, t = 2.574, p = .014, 95% CI .132 to 1.086, $R^2$ = .114) were significant related to problem solving. Ball skill performance was also significantly related to inhibition (F = 3.410, B = -.010, Beta = -.497, t = -2.876, p = .007, 95% CI -.016 to -.003). The total variance of this model was 34.8 % with ball skills accounting for 14.9 %. The analyses per ball skill item showed that throwing (F = 2.945, B = -.019, Beta = -.388, t = -2.532, p = .017, 95% CI -.034 to -.004, $R^2$ = .136) and rolling (F = 3.762, B = -.024, Beta = -.469, t = -3.117, p = .004, 95% CI -.040 to -.008, $R^2$ = .191) were predictive for the performance in inhibition. Ball skill performance was not significantly related to working memory and cognitive flexibility (p > .05).

*Associations between motor skills and executive functioning 2 years later*

The regression analysis with the EF components two years later as the dependent variable showed that both the locomotor skills and the ball skills were not significantly related to the EF components.

**Discussion**

The present study addressed the question whether the performance on different subsets of gross motor skills (i.e. locomotor skills and ball skills) is related to the performance on different EF components (i.e. inhibition, cognitive flexibility, working memory, and problem solving) one and two years later in 7-to-11 years-old children with LD. Ball skill performance was significantly related to the performance on problem solving one year later. More specifically, the ball skill items kicking and throwing contributed significantly to problem solving one year later. Furthermore, both locomotor skills and ball skills were significantly related to the Stroop interference ratio as measure for inhibition. However, the found relationship was negative indicating that the higher the motor skill performance at baseline, the lower the performance in inhibition one year later.

The observed positive relationship between ball skills and the performance in problem solving one year later is partly in line with the cross-sectional study of Hartman et al. (2010) who reported, in 7-to-12 years-old children with intellectual disabilities (a subgroup of children with LD), that the better children's motor skill performance (both locomotor skills and ball skills), the better their performance in problem solving. The longitudinal study of Piek et al. (2008) has found a positive relationship between gross motor skills in the preschool age and working memory at school age (i.e. 6 -12 years), while the present study did not. Furthermore, Rigoli et al. (2013) found that fine motor skills predicted later working memory performance and gross motor skills did not. Rigoli et al. (2013) suggested that the different findings in the literature may vary according to the developmental level of the motor and cognitive skills highlighting the need for more research to examine these relationships.

Several factors may account for the relationship between ball skills and problem solving one years later observed in the present study. First of all, the complexity of both skills may be an explanation of the observed link between ball skills and problem solving. Ball skills are assumed to be more complex motor skills compared to locomotor skills, because ball skills are generally practised in complex play and sport settings (Houwen, Visscher, Hartman, & Lemmink, 2007). Problem solving can be seen as a complex, higher-order EF, because it is built from the three core EF components inhibition, working memory, and cognitive flexibility (Diamond, 2013). The analysis per ball skill item showed that especially throwing and kicking significantly contributed to problem solving. Both skills are frequently used in complex play and sport-settings such as football and handball. It is assumed that children who regularly participate in such sports, have higher performance in kicking and throwing (Barnett, van Beurden, Morgan, Brooks, & Beard, 2009; Stodden et al., 2008). Regularly participation in complex play and sport- settings may lead in turn to higher performance in problem solving (Best, 2010). Second, the developmental timescales of the motor skills and the EF components may play an important role in our findings. Westendorp et al. (in press) found in children with LD, an accelerated development of the ball skills between 7 and 9 years of age with a plateau around 10 years of age, while no developmental changes for the locomotor skills were revealed. The different EF components follow also different developmental timescales from early childhood to adolescence (Best, Miller, & Jones, 2009; Huizinga, Dolan, & Van der Molen, 2006). For example, inhibition performance improves largely in young children from ages 3 to 8 years, while planning ability develops form middle childhood (simple planning task) to late childhood or adolescence in case of complex planning tasks (Best et al., 2009). Although improvement on all EF tasks was found in this study, it is possible that the performance in inhibition, working memory, and cognitive flexibility improved more at younger age in children with LD. The variety in developmental timescales of the subsets of gross motor skills and the EF components may, therefore, account for the specific relationship between ball skills and problem solving, because this study is conducted in 7-to- 11 years-old children with LD. If this study was performed in younger children, probably other specific relationships were found.

An unexpected finding was that no significant associations between gross motor skill scores at baseline and EF two years later were found. A factor that may account for this finding is that in the last assessment (two years later) the amount of participants decreased considerably compared to baseline data and the assessment one year later due to illness or school leaving making it harder to find significant results.

Based on the findings in the present study, we posit the assumption that the relationship between motor skills and EF is specific and depends on the developmental time scales of both skills. Wassenberg et al., (2005) also have found specific associations between motor performance and some EF components rather than with all EF components in their cross-sectional study. That they found other specific relationships between motor skills and EF compared to the present study may due to the age range of their study population, i.e. 5 and 6 years-old children. The developmental phase of motor skills and EF is different in 5 and 6 year old children compared to 7- to- 11 years-old children. We speculate that the relationship between motor performance and EF is strong when both skills show developmental accelerations and have not been mastered yet (Serrien, Ivry, & Swinnen, 2007). In the development phase, skills are novel, not automatized and need conscious control. Learning new skills requires cognitive information processing and involvement of prefrontal areas (Serrien et al., 2007). Neuroimaging studies showed more connection across different brain regions during skill learning and the execution of complex skills (Serrien, Ivry, & Swinnen, 2007). Furthermore, Diamond (2000) suggested a neural connection between the cerebellum, important for complex movements, and the prefrontal cortex, important for EF, especially when task are novel, complex and executed in changing and unexpected environments. Future research should focus on children across a wider age ranges to detect whether or not the relationship between motor performance and EF depends on the developmental timescales of the skills.

Notable is the negative relationship between the performance in locomotor skills and ball skills and the Stroop interference ratio. A possible explanation for this finding might be the use of the Stroop test in children with large reading disorders. In the Color-Word Card of the Stroop test, the automatic response of word reading has to be suppressed and prevented from interfering with naming the color of the color word (Lansbergen et al., 2007). In children with reading disorders, the lack of reading dominance (i.e. less reading automaticity) causes that these children show slowness in word naming and therefore less interference compared to normal readers, because normal readers has to suppressed their automatic reaction (Golden & Golden, 2002; Leon-Carrion, García-Orza, & Pérez-Santamaría, 2004). Although the Stroop test has several advantages (e.g. simple, short test assessment and not based on intelligence), for the assessment of inhibition in a study sample with relatively much children with large reading disorders, it is recommended to use another test which depends not on reading automaticity.

In the present study, insight is given in the associations between the performance of gross motor skills at baseline and the performance of four different EF components one and two years later in children with LD. Although valuable information is obtained in this study, it was restricted to 7- to-11 years old children, while is known that the development of both motor skills and EF starts in young children. Future research should, therefore, include children with a wider age range. Furthermore, this study was restricted to a period of 3 years. It is recommended to assess children's motor skills and EF over a longer period, preferably from pre-school years to adolescence to obtain insight in the total development of the child regarding gross motor skills and EF.

**Conclusion**

It seems that the relationship between gross motor skills and EF in children with LD is specific rather than general. More specifically, higher ball skill scores were related to problem solving one year later. The development of motor skills, especially ball skills, should therefore be an important component in physical education programs and education policy. However, we have to be careful in drawing conclusions about these important developmental issues. Large study populations and intervention studies are recommended in future research about this topic.

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# Chapter 6
# Effect of a ball skill intervention on children's ball skills and cognitive functions

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**Abstract**

*Purpose:* This study examined the effect of a 16-week ball skill intervention on the ball skills, executive functioning (in terms of problem solving and cognitive flexibility), and in how far improved EF leads to improved reading and mathematics performance of children with learning disorders. *Methods:* Ninety-one children with learning disorders (aged 7-11 years old) were recruited from six classes in a Dutch special-needs primary school. The six classes were assigned randomly either to the intervention or the control group. The control group received the school's regular physical education lessons. In the intervention group, ball skills were practiced in relative static, simple settings as well as in more dynamic and cognitive demanding settings. Both groups received two 40 minutes lessons per week. Children's scores on the Test of Gross Motor Development-2 (ball skills), Tower of London (problem solving), Trailmaking Test (cognitive flexibility), Dutch Analysis of Individual Word Forms (reading), and the Dutch World in Numbers test (mathematics) at pre-test, post-test, and retention-test were used to examine intervention effects. *Results:* The results showed that the intervention group significantly improved their ball skills, while the control group did not. No intervention effects were found on the cognitive parameters. However, within the intervention group a positive relationship ($r = .41$, $p = .007$) was found between the change in ball skill performance and the change in problem solving: the larger children's improvement in ball skills, the larger their improvement in problem solving. *Conclusion:* The present ball skill intervention is an effective instrument to improve the ball skills of children with learning disorders. Further research is needed to examine the impact of the ball skill intervention on the cognitive parameters in this population.

Keywords: motor intervention, children with learning disorders, primary-school-aged children, gross motor skills, executive functioning, academic achievement

## Introduction

It is well known that motor development and cognitive development are interrelated (Diamond, 2000). From a neuropsychological perspective, the close association between motor and cognitive development is mediated by the co activation of the cerebellum, important for complex and coordinated movements, and the prefrontal cortex, critical for higher-order cognitive functioning, i.e. executive functioning. Executive functioning (EF) is an umbrella term that includes a number of interrelated higher cognitive processes necessary for purposeful and goal-directed behavior (Welsh, Friedman, & Spieker, 2008). Typical EF processes are inhibition, cognitive flexibility, attention, working memory, planning, and problem solving (Diamond & Lee, 2006; Welsh, Friedman, & Spieker, 2008). The neural link between the cerebellum and the prefrontal cortex occurs when tasks are complex and executed in novel and changing environments (Diamond, 2000). In addition, motor skills and EF follow are similar developmental timescale with an accelerated development between 5 and 10 years of age (Anderson, 2002; Best, Miller, & Jones, 2009; Ulrich, 2000).

Both motor performance and EF are important in the overall development of children (Bushnell & Boudreau, 1993; Moffitt et al, 2011). Furthermore, EF plays a critical role in the development of academic abilities (Lopes, Santos, Pereira, & Lopes, 2013; Best, Miller, & Naglieri, 2011). Children who have major problems in academic abilities are children with learning disorders[3] (LD). Research has shown that these children generally have poor motor skill performance (Frey, & Chow, 2006; Simons, Daly, Theodorou, Caron, Simons, & Andoniadou, 2008; Westendorp, Houwen, Hartman, & Visscher, 2011a; Westendorp, Hartman, Houwen, Smith, & Visscher, 2011b) as well as poor performance in EF (Hartman, Houwen, Scherder, & Visscher, 2010; Van der Sluis, De Jong, & Van der Leij, 2004). Therefore, targeting motor skills and EF in children with LD may be crucial to boost their academic performance.

A recent meta-analysis reported positive effects of motor skill interventions on the improvement of fundamental motor skills in children (Logan, Robinson, Wilson, & Lucas, 2011). The studies included in the meta-analysis were conducted in different populations: typically developing children, children who are overweight or obese, children with developmental disorders or at risk of developmental disorders and children with developmental language disorders. Logan et al., found moderate effects of the interventions on locomotor skills (effect size Cohen's d = .45) as well as on ball skills (Cohen's d = .41). The overall effect size for the control groups (i.e. free play) was very small (d=.006) indicating that fundamental motor skills do not develop naturally, but they need to be taught, practised, and reinforced through developmentally appropriate movement programmes (Logan et al., 2011).

In addition, several studies have shown positive effects of movement interventions on EF and academic skills in typically developing children (Best, 2010; Tomporowski, Lambourne, & Okumara, 2011) and in children who are overweight (Davis et al, 2011). However, these studies focused on the effects of physical activity on EF and/or academic

[3] Children with learning disorders are defined here as children with problems in academic skills like reading and mathematics that attend Dutch special-needs primary schools. Since 2001 in the Netherlands children with an IQ between 50-79 without a physical disability and children with learning and/or pedagogic problems with an IQ of 80 and above attend the same primary special-needs-school (Jongmans, Smits-Engelsman, & Schoemaker, 2003).

skills, rather than the effects of motor skills per se. To the best of our knowledge, research focusing on the effect of motor skill interventions on cognitive functioning is limited. Ericsson (2008) examined the impact of extended physical education and motor training on motor skills (e.g. balance, hand-eye coordination, and bilateral coordination), academic skills, and attention. This study showed that extended physical education and motor training (5 versus 2 times per week) improved children's motor skills and demonstrated positive effects on reading, writing, and mathematics, but not on attention (Ericsson, 2008). Furthermore, Ericsson and Karsson (2012) examined, in a 9-year intervention study, the impact of extended physical education and motor skill training on motor skills and school performance (i.e. qualification for upper secondary school and school marks). The authors concluded that the intervention group had better motor skill performance in all follow-up assessments. Furthermore, in year 9, boys in the intervention group had higher school marks and were more often qualified for upper secondary school compared to boys in the control group. No differences in school performance were found between girls in the intervention and control group (Ericsson & Karsson, 2012). The studies by Ericsson and Ericsson and Karsson extend current knowledge of this topic; however, the studies were only focused on academic achievement and not on EF.

As it seems that complex motor skills are strongly associated with EF (Best, 2010), it may be expected that an intervention focusing on complex motor skills may facilitate children's EF. Budde and colleagues (2008) compared the effect of coordinative exercises on cognition with that of non-coordinative, simpler exercise. It was found that coordinative exercises had more effect on the performance of concentration and attention tasks than non-coordinative, simpler exercises. The authors concluded that the complex coordinative exercises required frontal-dependent cognitive processes, which enhanced prefrontal neural functioning, whereas the non-coordinative, simpler exercises did not rely on the prefrontal neural circuit (Budde, Voelcker-Rehage, Pietraßyk-Kendziorra, Ribeiro, & Tidow, 2008). In a motor skill intervention aimed at improving EF, it is important that complex motor skills are performed. Ball skills are assumed to be complex motor skills, because they are generally practised in complex play and sport settings (Houwen, Visscher, Hartman, & Lemmink, 2007). The current intervention, therefore, focused on ball skills, practiced under different conditions varying from simple, static settings to dynamic complex play settings like team games. The dynamic and novel character of team games make them ideal situations to effectively train EF since EF is especially important in novel and demanding situations (Diamond & Lee, 2006). In dynamic sport settings (e.g. team games) cognitive skills such as action planning, problem solving, and cognitive flexibility are important factors for successful performance (Best, 2010; Wall, 2004). Cognitive flexibility is a core component of EF. It refers to the ability to switch rapidly between simultaneous goals (Anderson, 2002) and is of critical importance in environments in which attention demands are constantly changing (Best, 2010; Wall, 2004). Action planning and problem-solving (further summarized as problem-solving) are complex EF tasks and are critical parts of goal-oriented behavior. They embody the ability to formulate actions in advance and to approach a task in an organized, strategic and efficient manner (Anderson, 2002). In the current intervention ball skills were often practiced in dynamic sport settings, therefore, it was assumed that especially these EF tasks (i.e. problem-solving and cognitive flexibility) would be facilitated. Both problem-solving and cognitive flexibility are frequently linked to the development of academic abilities in children, especially in mathematics and reading (Best et al., 2011). It is thought that improvements in EF facilitate improvements in academic abilities (Best, Miller, & Jones, 2009), or that adequate EF develops prior to behaviors affecting academic abilities (Riggs, Blair, & Greenberg, 2004). Cognitive flexibility has been found to be involved in mathematics (Bull, Espy. & Wiebe, 2008) and reading performance (Van der Sluis et al., 2004) and problem-solving seems to be fundamental for mathematic skills (Sikora, Haley, Edwards, & Butler, 2002). Therefore, we expected that through enhancing these EF tasks children's academic skills may improve after the intervention.

The aim of the present study was to examine whether a ball skill intervention has an effect on the performance of 1) ball skills, 2) EF in terms of problem solving and cognitive flexibility, and 3) in how far improved EF leads to improved reading and mathematics in children with LD.

**Method**

*Participants*

Ninety-one children with LD, aged between 7 and 11 years old, were recruited from a special-needs primary school located in the northern Netherlands. Informed consent was obtained for all children and all procedures were approved by the institutional Ethics Committee of Human Movement Sciences, University Medical Center Groningen, University of Groningen, as being in accordance with the ethical guidelines of the American Psychological Association.

The 91 children were from six different classes. These six classes were assigned randomly either to the intervention group or the control group. Three classes with a total of 45 children participated in the intervention group and three classes with a total of 46 children participated in the control group. Children only participated in the study if they had no physical disability (n = 0). Children who attended less than 80% of the sessions were excluded from the study sample (intervention group n = 2; control group n = 2). The definitive study sample consisted of 87 children: 43 children in the intervention group (31 boys, 12 girls) and 44 children in the control group (28 boys, 16 girls).

For each child, the individual school files containing child characteristics (e.g. age, sex, IQ), a short medical history, and the child academic system were screened. The child academic system provides an overview of a child's progress in academic skills by evaluating these skills twice a year. The progress in academic skills is expressed in a learning lag per academic domain. For example a child with a learning lag of .35 on reading has not mastered 35% of the reading level that would have been expected given the months of formal education.

**Instruments**

*Ball skill assessment*

The Test of Gross Motor Development-2 (TGMD-2) (Ulrich, 2000) was used to measure ball skill performance. The TGMD-2 is a qualitative, process-orientated measure (i.e. evaluates movement based on the demonstration of performance criteria which provided information of how the movement was performed) to assess 12 gross motor skills divided into locomotor skills (run, gallop, hop, leap, jump, and slide) and ball skills (two-hand strike, stationary bounce, catch, kick, overhand throw, and underhand roll). Each skill was executed twice and evaluated based on the presence (success; score 1) or absence (failure; score 0) of three to five qualitative performance criteria. The highest total raw score for both subtests is 48. The higher the score, the better the performance. The reliability and validity of the TGMD-2 to assess gross motor skills has been reported for typically developing children (Ulrich, 2000) and for children with LD (Simons et al, 2008). Since the present study evaluated a ball skill intervention only the ball skill subtest of the TGMD-2 are reported.

*Assessment of executive functioning*

Two tests were used. The Tower of London (Shallice, 1982), which specifically measures problem solving and planning ability (summarized as problem solving), and the TrailMaking test (Reitan & Wolfson, 2004) for the assessment of cognitive flexibility.

*Tower of London (TOL)*

The TOL consists of a board with three pegs of different lengths and three coloured balls (red, blue, and yellow) with holes that can be manipulated on the pegs. Children have to solve 12 problems by transforming a fixed start state into a depicted goal state by applying three important rules: 1) only one ball can be moved at a time; 2) a ball cannot be moved while another ball is lying on top of it; 3) the longest peg can carry three balls, the middle peg two and the shortest peg only one ball. Children were instructed to solve each problem within a minimum number of moves as given by the researcher, while a maximum of three trials was allowed to solve each problem. A problem was solved correctly, when the goal state was achieved within the minimum number of moves allowed for that problem. The test was preceded by a practice problem and children were encouraged to strive for accuracy as well as speed. The score on the TOL was determined by assigning three, two, or one point(s) per problem based on the number of trials required to solve the problem, with three points reflecting one trial, two points two trials, and one point three trials. The TOL total score was the sum of the points for all 12 problems with a maximum of 36. The TOL has been tested and validated for use with children (Anderson, Anderson, & Lajoie, 1996).

*TrailMaking Test (TMT)*

The TMT is a paper-and-pencil task which consists of two parts, TMT A and TMT B. In TMT A, children were asked to draw a line to connect encircled digits (1 to 25) randomly arranged on a sheet of paper in ascending order (i.e. 1-2-3-4-5, etc.). This provides an estimate of attention and psychomotor speed (i.e. movement or motor activity associated with mental processes) (Strauss, Sherman, & Spreen, 2006). In TMT B, a series of encircled digits (1 to 13) and letters (A to L) should be connected in ascending order by alternating between digits and letters (i.e. 1-A-2-B-3-C-4-D-5-F, etc.) providing an estimate of cognitive flexibility (Strauss et al., 2006). The children were instructed to execute both parts as quickly as possible. Both parts were preceded by an example. The time taken to complete each part was used as the test score. In order to give a more accurate measure of cognitive flexibility and to control for the effect of psychomotor speed, the TMT Delta was calculated by subtracting the total time of TMT A from the total time TMT B (Eggermont, Milberg, Lipsitz, Scherder, & Leveille, 2009). The TMT has been used and validated in children from age 7 (Strauss et al., 2006).

*Assessment of academic skills*

The progress in reading and mathematics was obtained from the child academic system of the school. The school used the Dutch AVI (Analyse van Individualiserings Vormen or Analysis of Individual Word Forms) (Visser, Van Laarhoven, & Ter Beek, 1998) to assess children’s reading abilities. During the test the child was required to read out several short stories, each displayed on a card, whose sentence structures and word complexity gradually increase in difficulty per card. The amount of mistakes (i.e. reading a word wrong, skipping, adding or replacing a word) and the time that was needed to read the text were scored. The total score depends on the amount of mistakes, the reading speed and the difficulty of the text. The reliability (r varied from .86 to .93 per AVI-card), the content validity, and the construct validity of the AVI test are good (Krom, Jongen, Verhelst, Kamphuis, & Kleintjes, 2010). The school assessed the progress in mathematical skills using the WIG (Wereld in Getallen or World in Numbers) (Huitema, Van der Klis, & Timmermans, 2001). During this test children were asked to solve mathematical problems taken from everyday life. The test contains tasks aimed at math fluency (i.e. rapid calculation of single-digit addition, subtraction, and multiplication facts) and more complex mathematical problems, which rely on more cognitive skills like planning and problem solving. The WIG is a common method for teaching and assessing the progress in mathematics in the Netherlands.

*Pilot study*

A pilot intervention (nine weeks, two times per week) was conducted at the same school to examine whether or not the exercises were appropriate for the children and their performance level. Information was gathered about the structure and the content of separate sessions, for example how much time it takes to give adequate instructions and to execute the exercises. The information obtained was used for the development of the final intervention sessions

*Ball skill intervention*

The intervention is based on the constraints-led approach of motor skill learning (Davids, Button, & Bennet, 2008). Essential in this approach are three types of constraints influencing motor skill learning: constraints related to the child (e.g. age, learning disorder), the demands of the task (e.g. ball catching with one hand, game rules), and constraints related to the physical or social environment (e.g. temperature, peers, teacher). Those constraints limit behavior; however, they also give opportunities for motor skill learning, because task- and environmental constraints can be manipulated. For example, the teacher can purposefully manipulate the demands of the task through simplifying the task for children with the most severe motor problems and vice versa. The current intervention focused primarily on the manipulation of the task and the social environment, because they are easy to manipulate by a physical education teacher. Besides manipulation of constraints, the role of the teacher and the child are important in the development of motor skills. For children self-exploration, problem solving, and an active involvement in their own learning process are critical factors in motor skill development (Valvano & Rapport, 2006). Targeted support and feedback by a teacher plays an important role in this process (Davids et al., 2008). Therefore, in the current intervention the teacher served as a 'mediator' meaning that the teacher monitored, guided and facilitated the learning process of individual children (Davids et al., 2008) through the manipulation of task constraints. For example, the teacher increased the distance to a basket for children who were successful in scoring goals and vice versa.

The current intervention focused on learning ball skills in a structured way. This means that the ball skills were first practiced in more simple, static settings with simple exercises like throwing and catching with two children or bouncing and turning around cones. The simple exercises in static settings were aimed at an adequate development of basic ball skills (i.e. automatization of ball skills). Automatization of basic ball skills enables children to apply these skills to participate in ball games that require more advanced ball skills and cognitive skills (Wall, 2004). Later on, the tasks became more complex such as throwing, catching, and bouncing during a ball game, where children needed to pay attention to teammates, opponents, game rules, and time, which required more cognitive engagement than simple exercises. In the current intervention, the first four weeks focused only on simple ball exercises followed by 12 weeks wherein simple exercises were repeated and more complex ball exercises and ball games were added.

The intervention consisted of 32 sessions, twice a week over 16 weeks, and focused on improving six ball skills (i.e. strike, bounce, catch, kick, throw, and roll). Each session lasted approximately 40 minutes and consisted of a warming-up (5 min.), 30 minutes ball skill training, and a cooling-down (5 min.). In a population with much variability in ball skill performance, like in children with LD, is it important that children are challenged based on their own skill level (Valentini & Rudisill, 2004). To optimize the learning environment and challenge each individual child, each class in the intervention group (in Dutch special-needs primary schools a class consists of a maximum of 16 children) was divided into two groups of a maximum of 8 children based on their ball skill level assessed by the physical education teachers. Two teachers conducted the intervention, so the teacher/child ratio was 2:16 in all intervention sessions. Within the two groups the same exercises were performed, but under different task constraints in order to fit individual skill levels.

**Procedure**

*Assessment*

In this study an experimental pre-post-retention design was used. The scores on the ball skill test, executive functioning tasks, and academic tests of both groups at $T_0$ (i.e. pre-test) were used as the baseline data. The scores on $T_1$ (i.e. post-test, directly after the intervention) and $T_2$ (i.e. retention-test, six months after the end of the intervention) were used to examine intervention effects.

The TGMD-2, the TOL, and the TMT were individually administered by specially trained test administrators. All test administrators were blind to which children attended the intervention group or the control group. Before the testing, they received training to become familiar with the test protocol and the test scoring.

*Intervention*

One week after the pre-test, the ball skill intervention started during the physical education lessons at school. Two physical education teachers from the school performed the intervention. In the same period, the control group received from the same teachers, regular physical education of the same duration and frequency as the intervention program, but the teachers alternated teaching physical education to the control group. The teacher-child ratio was 1:16, which is the normal ratio in Dutch special-needs primary schools. The control group received a varied program consisting of gymnastics (30%), circuit training (12%), athletics (10%), ball games (44%), and other training (4%). Prior to the intervention, all sessions were discussed with the physical education teachers to ensure that they fully understood what was intended with the intervention.

*Observations*

During the intervention sessions, the researcher observed the first four sessions to verify whether or not the teachers conducted the program as intended and to give verbal feedback if needed. After this period, the researcher observed selectively and unannounced six sessions to obtain information about the way of practicing, the content of the sessions and to score the exact session time of the intervention and the control group in order to compare both groups.

**Data analysis**

The descriptive statistics were performed using SPSS software (version 20.0) and the significance level was set at .05. Independent t-tests were conducted to examine differences in group characteristics between the intervention and the control group. Differences at baseline on the TGMD-2 ball skill scores, the TOL scores, the TMT scores, and the learning lags on reading and mathematics between the intervention and the control group were explored with ANCOVAs controlled for IQ.

In the present study, children were nested within classes. To take this into account multilevel modeling (MLwiN 2.23) was used to investigate intervention effects. Multilevel modeling is considered to be the most appropriate data analysis technique for nested data (Snijders & Bosker, 2011). Multilevel models were created for the scores on the ball skills and EF tasks (i.e. TOL and TMT) separately, with individual child differences at level 1 and class differences at level 2. Group (intervention or control), sex, and the interaction between group and sex were entered separately in the initial models as possible predictors. Random intercepts for class (level 2) were considered, accounting for possible class differences (Snijders & Bosker, 2011). All models were adjusted for the baseline score on the outcome variable and IQ. Goodness of fit was evaluated by comparing the -2*Log Likelihood of the previous model with the most recent model. Variables with a non-significant contribution to the model ($p <.05$) were removed for further analysis. The scores on the TMT were not normally distributed, therefore the TMT scores were transformed to z-scores.

As it was expected that through enhancing EF children's academic skills may improve after the intervention, Pearson's correlations were conducted to determine whether changes in EF between baseline and post-test ($T_1$ - $T_0$) and between baseline and retention-test ($T_2$ - $T_0$) were related to changes in scores on reading and mathematics in the intervention period (i.e. delta).

**Results**

*Groups characteristics, ball skills, executive functioning, and academic achievement at baseline*

The characteristics of both groups are shown in Table 6.1. There was no significant difference between the groups in terms of age ($p$ = .071), sex ($p$ = .404), and comorbidity (i.e. Attention Deficit Hyperactivity Disorder or Autism Spectrum Disorder) ($p$ = .361). The control group had a significantly higher IQ compared to the intervention group (t = -2.884. p = .005). Table 6.2 lists the mean TGMD-2 ball skill scores, the TOL scores, the TMT scores, and the learning lags on reading and mathematics for the intervention and control group during pre-test, post-test, and retention-test. The pre-test scores for the TGMD-2 ball skills (p = .165), the TOL (p = .716), the TMT (p = .989), the learning lag on reading (p = .492), and the learning lag on mathematics (p = .921) were not significantly different between the groups. This indicated that both groups had comparable performance on ball skills, problem solving, cognitive flexibility, reading, and mathematics at the start of the intervention.

***Table 6.1*** *Characteristics of the intervention group and the control group*

| | Intervention group<br>n = 43 | | Control group<br>n = 44 | | |
|---|---|---|---|---|---|
| | M | SD | M | SD | p-value |
| Age (in years) | 9.4 | .83 | 9.1 | .96 | .071 |
| IQ | 77.5 | 11.8 | 84.3 | 10.2 | .005 |
| | n | | n | | p-value |
| Sex– boys | 31 (72%) | | 28 (64%) | | .404 |
| Sex– girls | 12 (28%) | | 16 (36%) | | |
| Co morbidity | 9 (21%) | | 13 (30%) | | .361 |

Note: Co morbidity = Attention Deficit Hyperactivity Disorder or Autism Spectrum Disorder

***Table 6.2*** *Estimated Mean TGMD-2ball skill scores, TOL scores, TMT scores (TMT B – TMT A), learning lags on reading and mathematics for the intervention group and the control group during pre-test, post-test, and retention-test*

| | Pre-test | | | Post-test | | | Retention-test | | |
|---|---|---|---|---|---|---|---|---|---|
| | EM[b] | SE | Range | EM[b] | SE | Range | EM[b] | SE | Range |
| Ball | 35.0 | .70 | 26-44 | 38.0* | .70 | 28-46 | 37.3 | .88 | 25-45 |
| TOL | 28.7 | .53 | 19-35 | 28.7 | .53 | 20-33 | 29.3 | .51 | 21-35 |
| TMT | 121.1 (15.7) | | 14-395 | 94.7 (8.5) | | 25-220 | 75.5 (6.0) | | 30-159 |
| LL Read[c] | .41 | .05 | .00-.97 | .44 | .05 | .00-.98 | .51[e] | .07 | .00-.98 |
| LL Math[d] | .44 | .04 | .00-.86 | .45 | .04 | .00-.88 | .48 | .04 | .00-.89 |
| | **Pre-test** | | | **Post-test** | | | **Retention-test** | | |
| | EM[b] | SE | Range | EM[b] | SE | Range | EM[b] | SE | Range |
| Ball | 36.6 | .69 | 27-46 | 36.0* | .69 | 23-45 | 35.9 | .88 | 23-46 |
| TOL | 27.9 | .53 | 18-36 | 28.5 | .52 | 20-36 | 29.3 | .52 | 23-36 |
| TMT | 124.5 (16.3) | | 21-576 | 88.8 (8.8) | | 21-228 | 73.8 (6.2) | | 21-203 |
| LL Read[c] | .36 | .05 | .00-.98 | .32 | .05 | .00-.98 | .37[e] | .07 | .00-.80 |
| LL Math[d] | .45 | .04 | .00-.78 | .48 | .04 | .00-.83 | .47 | .04 | .00-.83 |

Note: a: TMT intervention group n = 42, control group n = 39; b: statistically adjusted for IQ; c: LL Read = learning lag reading, d: LL Math = learning lag mathematics; e: scores based on 23 children in the intervention group and 22 children in the control group; * = significant different from each other

*Effect of the intervention on ball skill performance*

Results of the multilevel modeling (Table 6.3) show a significant effect of group (intervention or control) on ball skill performance favoring the intervention group on the post-test (p <.0001) and on the retention-test (p = .002), explaining 15.1% and 12.3 % of the total variance respectively. Sex and the interaction between sex and group were not significant at post-test and at retention-test and were therefore not included in the final model. The random intercept for class was significant at post-test (p = .003), but not on the retention-test (p = .26), indicating different intercepts for each class on the ball skill score at post-test.

***Table 6.3**: Results of multilevel analysis for the intervention effects on ball skill performance at post-test and retention-test*

| **Post-test** | Model 1 | | | Model 2 | | |
|---|---|---|---|---|---|---|
| **Fixed effects** | **β** | **SE** | **p** | **β** | **SE** | **p** |
| Intercept (constant) | 13.396 | 3.125 | | 12.489 | 4.245 | |
| Baseline ball skill scores | 0.619 | 0.083 | <0.001 | 0.618 | 0.083 | <0.001 |
| Intervention | 2.913 | 0.777 | <0.001 | 2.991 | 0.818 | <0.001 |
| IQ | | | | 0.011 | 0.033 | 0.747 |
| **Random effects** | **Variance** | **SE** | | **Variance** | **SE** | |
| Class level | 1.0391 | 1.767 | | 1.101 | 1.777 | |
| Child level | 10.349 | 2.230 | | 10.279 | 2.222 | |
| Deviance | 458.110 | | | 458.004 | | |
| Deviance empty model | 508.661 | | | 508.661 | | |
| **Retention-test** | Model 1 | | | Model 2 | | |
| **Fixed effects** | **β** | **SE** | **p** | **β** | **SE** | **p** |
| Intercept (constant) | 3.159 | 3.475 | | 3.954 | 4.626 | |
| Baseline ball skill score | 0.894 | 0.094 | <0.001 | 0.895 | 0.094 | <0.001 |
| Intervention | 2.740 | 0.834 | 0.002 | 2.674 | 0.872 | 0.002 |
| IQ | | | | -0.010 | 0.038 | 0.82 |
| **Random effects** | **Variance** | **SE** | | **Variance** | **SE** | |
| Class level | 0.00 | 0.00 | | 0.00 | 0.00 | |
| Child level | 13.845 | 2.162 | | 13.834 | 2.160 | |
| Deviance | 448.197 | | | 448.129 | | |
| Deviance empty model | 510.864 | | | 510.864 | | |

Notes: β = regression coeffiecient; SE = standard error;
Model 1 is the crude analysis, where the intervention effect is controlled for baseline ball skill scores. Model 2 is the adjusted analysis, where the effect of the intervention is corrected for IQ. For the intervention variable, the control group is the reference category.

*Effect of the intervention on executive functioning*

*Problem solving*

Group (intervention or control), sex and the interaction between sex and group did not significantly influence the model at post-test as well as at retention-test. The random intercept for class did not improve the model fit, indicating that there was no class effect of the intervention. As no intervention effects were found with multilevel modeling, Pearson's correlations were conducted to determine whether *changes* in ball skills between pre-test and post-test ($T_1$ - $T_0$) were related to *changes* in TOL scores between pre-test and post-test ($T_1$ - $T_0$) and retention test ($T_2$ - $T_0$) in both groups separately (i.e. delta). In the intervention group, no correlation was found between the change in ball skills from pre-test to post-test and the change in TOL performance from pre-test to post-test ($r = .010$, $p = .947$). A positive significant correlation was obtained between the change in ball skills from pre-test to post-test and the change in TOL performance from pre-test to retention-test ($r = .41$, $p = .007$). This indicates that the larger the improvement in ball skills from pre-test to post-test, the larger the improvement in TOL performance from pre-test to retention-test. In the control group, no significant relationships were found between the change in ball skills from pre-test to post-test and the change in TOL performance from pre-test to post-test ($p = .992$) or from pre-test to retention-test ($p = .095$).

*Cognitive flexibility*

The predictors group (intervention or control), sex and the interaction between sex and group did not significantly improve the model fit indicating no intervention effects on cognitive flexibility. The random intercept for class was not significant. As no effect of the intervention was found with multilevel modeling, Pearson's correlations were conducted to determine whether *changes* in ball skills between pre-test and post-test ($T_1$ - $T_0$) were related to *changes* in scores on the TMT between pre-test and post-test ($T_1$ - $T_0$) and retention test ($T_2$ - $T_0$) in both groups separately. No significant correlations ($p > .05$) were observed between the change in ball skills and the change in cognitive flexibility in the intervention period and six months after the intervention in both groups.

*Effect of the intervention on academic achievement*

As it was hypothesized that by enhancing EF children's academic abilities may improve after the intervention, Pearson's correlations were only conducted for the changes on TOL performance and the changes on reading and mathematics in the intervention period. This because only a relation between ball skill performance and TOL performance was found in the intervention group. No significant correlations were found between the changes in TOL performance and the changes in learning lags on reading and mathematics (all p values > .05) in the intervention period and the retention-test six months after the intervention.

**Discussion**

This study examined the effects of a 16-week ball skill intervention on the performance of 1) ball skills, 2) EF tasks (i.e. problem solving and cognitive flexibility), and 3) in how far improved EF leads to improved reading and mathematics in children aged 7- to 11-years old with LD. Children who received the ball skill intervention over a period of 16-weeks demonstrated a significant improvement in their ball skill performance, while the children in the control group did not. To our knowledge, this is the first study that focused on the improvement of ball skills in children with LD. The findings of the present study were supported by the meta-analysis of Logan et al. (2011). The meta-analysis included interventions with much variation in duration and frequency (duration of 6 to15 weeks and 480 to 1440 minutes), however, they found no significant relationship between the effect size of the intervention and the total intervention time. Further research is needed to examine the optimal intervention time (duration and frequency). However, based on the present study, it can be concluded that an intervention time of 16 weeks and 960 minutes of specific ball skill training is sufficient for improving the ball skills of children with LD.

The results of the present study showed that children with LD benefited from participation in the current ball skill intervention. The control group showed no improvement in their ball skills in this period, although 44% of their gym lessons consisted of ball games. A possible explanation for the difference between the groups is that the intervention group practiced their ball skills in a structured way: in simple, static practice settings and in complex, dynamic settings that were adapted to aid the child's mastery of the motor skills. The control group practiced the ball skills only in ball games. It appears that children with LD have impaired ball skills (Hartman, Houwen, Scherder, & Visscher, 2010; Westendorp et al., 2011a). Practicing ball skills in a simple setting was, therefore, aimed at the development and mastery of a basic level of ball skills, which is needed in complex ball games (Wall, 2004). As the control group did not practice basic ball skills such as throwing a ball to the wall, bouncing without moving the feet or kicking a ball to another child, it might be that these children have not developed a basic level of ball skills. The complex ball games, therefore, might have been too difficult for the children in the control group resulting in less ball skill development and may explain the relatively low ball skill scores of these children.

The children in the intervention group could practice the ball skills at their own skill level, because the teacher modified the practice setting or task for individual children. This was not the case in the control group: the whole group performed the same exercise with the same difficulty level. Furthermore, due to the teacher-child ratio (2:16) children in the intervention group received more individual feedback compared to the control group. Finally, the amount of time devoted to ball skills was different for the intervention group and the control group, which may also explain the difference in the improvement in ball skill performance. To summarize, structured practice of ball skills (i.e. from simple to complex) and offering ball skill exercises matching individual skill levels may be critical factors in the development of ball skills in children with LD.

The second aim of the current study was to enhance EF and academic performance of children with LD, specifically their problem solving, cognitive flexibility, and performance in reading and mathematics. The results showed no significant interaction effects between group and time for any parameters suggesting no intervention effects on the cognitive parameters. However, within the intervention group, a significant positive correlation was found between the changes in ball skills and the changes on the TOL performance from pre- to retention test. This indicates that children who improved more on their ball skills from pre- to post-test demonstrated more improvement in TOL performance from pre- to retention-test compared to children in the intervention group who improved less on their ball skills. A possible explanation for this finding might be that the children who improved more on their ball skills were better able to apply the ball skills in the complex exercises in the intervention (i.e. the ball games) than the children with less improvement in ball skills. During exercises in the complex and changing settings a greater demand on cognitive skills was required (Best, 2010). Engagement in more cognitively demanding situations is difficult for children with relatively low ball skill proficiency. For adequate ball skill performance in these more cognitively demanding situations, a basic level of ball skills is required, so that the ball skills are automatized or well-developed and the children can pay attention to the cognitive elements (Wall, 2004). We suppose, therefore, that the children with greater ball skill improvement could more fully participate in the complex exercises in the intervention and thereby have better facilitated their problem solving, compared to the children with lower ball skill improvement. The improvement in TOL performance between pre- to retention-test might indicate a lagged effect. More research is needed to confirm this suggestion. In addition, future research should examine whether a longer intervention program may have more impact on executive functioning in children with LD. In a longer intervention program the children could practice the ball skills more frequently in complex and cognitive demanding situations, which may have more effect on children's EF.

There are some study limitations. First of all, it was not possible to randomly assign individual children to the intervention group or the control group, but only classes of children. The reason for this is that the study set out to develop an intervention that is applicable in primary schools and could be conducted during the physical education lessons at these schools. Although the intervention group and the control group differed on IQ, they were comparable on age, sex, baseline scores on ball skills, EF, and learning lags on reading and mathematics. Therefore, the statistical analyses were controlled for IQ. Furthermore, in the present study two EF tasks were assessed namely problem solving and cognitive flexibility, however, it is possible that other aspects of EF improved after the intervention, for example response inhibition. In future intervention studies investigating EF it is recommended that researchers examine intervention effects on the whole spectrum of EF. It is believed that despite these limitations, the present ball skill intervention is a valuable contribution to the physical education practice and extends the current literature on this topic.

*Practical implications*

This study has several practical implications. First, children with LD could benefit from participation in a structured ball skill intervention in relatively small groups. For this reason children should regularly practice their ball skills during physical education at primary schools through a structured program, which will enable them to develop their skills at their own level. Indeed, it is recommended to begin such programs in early childhood education to promote ball skills development in young children (Logan et al., 2011). Future studies may wish to investigate whether the findings here a specific to ball skills, or are also present when training less complex fundamental movement skills.

Second, this study demonstrated that larger improvement in ball skills led to larger improvement in children's problem solving. This finding stresses the importance of well-developed motor skills for cognitive development, and specifically well-developed ball skills for problem solving. Physical education in primary schools is an excellent environment to facilitate children's motor skill development as well as their cognitive development through the implementation of structured motor skills interventions. Therefore, primary schools should invest in physical education and should not spare on this topic.

**Conclusion**

In conclusion, the current ball skill intervention is an effective instrument to improve the ball skills of children with LD. No intervention effects were found on the cognitive parameters. However, within the intervention group, children who showed more improvement in ball skills demonstrated more improvement in problem solving, compared to children who improved less in ball skills. Therefore, although the current study did not demonstrate large effects on executive functioning and academic achievement, evidence was found to suggest that practicing ball skills might have a positive influence on EF, specifically on problem solving.

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# Chapter 7
# Discussion and conclusions

**Aim of the thesis**

The general aim of this thesis was to examine the development of gross motor skills and the possible relationship between gross motor skills and cognitive performance [i.e. executive functioning (EF) and academic skill] in primary school-aged children with LD. Specifically, insight is provided into the level of gross motor skills in children with LD, compared to their typically developing peers and how these gross motor skills develop with age between 7 and 11 years of age. Furthermore, associations between children's gross motor skill performance and cognitive performance were investigated. Finally, a motor intervention was developed and implemented and the possible effects on children's gross motor skills and cognitive performance were examined.

**Main findings**

*Gross motor development and performance*

In the cross-sectional studies in Chapters 2 and 3, it was shown that children with LD (both children with LD with a below average IQ as well as children with LD with a normal IQ) generally have inferior gross motor skill performance compared with their typically developing peers. These results are in line with other studies (Simons, Daly, Theodorou, Caron, Simons, & Andoniadou, 2008; Hartman, Houwen, Scherder, & Visscher, 2010; Woodard & Surburg, 2001; Zhang, 2001). Additionally, Chapters 2 and 3 also showed that children with LD have lower ball skill scores compared to locomotor skill scores. It appeared that children with LD had the most problems with the more complex motor skills wherein more parts of the body were involved simultaneously for example during jumping or throwing (Chapter 2). Furthermore, it was shown that the children who participated in sports had higher ball skill performance than children with LD who did not participate in sports, however, the children who participated in sports did not attain the performance level of typically developing children.

Although cross-sectional research on the gross motor skills of children with LD is important to detect possible motor problems in this population, it gives no insight into the development changes of these skills over the years. Understanding developmental changes in gross motor skills would give insight into possible accelerations or stabilization in the development. This knowledge is crucial for the development of interventions for children with LD.

The longitudinal study in Chapter 4 gives insight into the developmental changes in gross motor skills that occur in children with LD between 7 and 11 years old. It showed that typically developing children outperformed children with LD at all ages, except for the locomotor skills at age 7. Furthermore, the longitudinal analyses showed that the ball skills of children with LD improved with age, with an accelerated development between 7 and 9 years old and a plateau around 10 years of age. Based on these findings, we conclude that, although ball skills are improved at the end of the primary school-period there is still a gap with children with LD at least 3 years behind their typically developing peers.

The results of Chapters 2, 3, and 4 underline the importance of specific attention (i.e. training) to ball skill of children with LD. Additionally, as it seems that the gap between children with LD and their peers is already present before the age of seven (Chapter 4), future research into gross motor skill development should focus on children across a wider age range, including younger children, to gain more insight into the age at which children with LD begin to develop motor problems. Knowledge about the gross motor skill development of children with LD throughout their entire childhood would enable timely intervention in order to decrease motor problems in this population.

*Relationship between gross motor skill performance and cognitive performance*

It is generally agreed that motor development and cognitive development are intertwined rather than being independent processes (Diamond, 2000). The results presented in this thesis support this notion by showing relationships between children's gross motor skills and academic skills (Chapter 3) and between gross motor skills and EF (Chapter 5). Furthermore, Chapters 3 and 5 extend the current literature (e.g. Michel, Roethlisberger, Neuenschwander, & Roebers, 2011; Piek, Dawson, Smith, & Gasson , 2008; Rigoli, Piek, Kane, Whillier, Baxter, & Wilson, 2013; Wassenberg et al., 2005) by showing that the relationship between gross motor skills and cognitive performance appears to be specific rather than general. Chapter 3 showed specific relationships between locomotor skills and reading performance and between ball skills and performance in mathematics. Additionally, Chapter 5 demonstrated a specific association between ball skills and problem solving (one year later) rather than a general association between gross motor skills and EF. An interesting question rising from these results is whether or not the relationship between gross motor skills and academic skills is mediated by EF, as it is known that EF plays a critical role in the development of academic skills (Best, Miller & Jones, 2009; Best, Miller, & Naglieri, 2011; Bull, Espy, & Wiebe, 2008). A recent study of Rigoli, Piek, Kane, and Oosterlaan (2012) concluded that in adolescents motor coordination has an indirect impact on academic skills through working memory. However, Cameron et al. (2012) showed that fine motor skills and EF both independently contributed to children's academic skills in kindergarten (Cameron et al., 2012). Understanding the possible indirect or mediating role of EF in the relationship between gross motor skills and academic skills will enable targeted interventions.

*Motor skill intervention*

To our knowledge, this is the first intervention study in children with LD focusing on both the improvement of their motor skills and stimulating cognitive performance, i.e. problem solving and cognitive flexibility. Chapter 6 showed that children in the intervention group significantly improved their ball skills, while the children in the control group did not. During the intervention, the ball skills were practiced two times per week during the regular physical education classes (40 minutes per session) for a duration of 16 weeks (total 960 minutes). No difference between the intervention and the control group were found on the EF tasks. However, within the intervention group, children who showed more improvement in ball skills demonstrated more improvement in problem solving (but not in cognitive flexibility), compared to children who showed less improvement in ball skills.

Although the results suggested that practicing ball skills might have positive effects on EF, specifically on problem solving, the current intervention did not demonstrate large effects on EF. Ball skills were practiced in a structured way progressing from simple to complex tasks. Research has shown that practicing simple exercises is not effective for improving EF, because simpler exercises do not rely on activation of the prefrontal neural circuit (Budde, Voelcker-Rehage, Pietraßyk-Kendziorra, Ribeiro, Tidow, 2008). The time spent on simple ball exercises in our intervention may therefore not have stimulated the children's EF. It seems that a that a longer or more intensive intervention program with more time dedicated to complex ball skills is needed to enhance EF. Furthermore, EF may be more sensitive to a motor skill intervention at one developmental time point rather than another and this may vary between the different EF components (Best, 2010). Future motor interventions studies should focus on dose-response relationships by including intervention groups receiving different doses of motor skill training in different age categories. In addition, an interesting question for future research is whether other forms of motor skill training, such as gymnastics or dance, may also be effective to stimulate EF in children with LD (Diamond & Lee, 2011).

**Reflections on the thesis**

Conducting research with children and performing an intervention give rise to some study observations that may be relevant for future research. Issues regarding the study population, the intervention, and the measurements used in this thesis will be discussed.

*Study population*

Children attending Dutch special-needs schools are a heterogeneous group of children, including children with LD with a below average IQ, and children with LD with a normal IQ with or without a comorbid disorder. In the first chapters of this thesis, we focused on subgroups of children with LD, i.e. children with LD with a below average IQ (Chapter 2) and children with LD with a normal IQ with problems in one or more domains of academic achievement (Chapter 3) in order to give insight into the motor problems of these subgroups. Chapters 2 and 3 have shown that both groups of children had inferior gross motor skill performance compared to typically developing children. In the longitudinal study in Chapter 4 we looked at the developmental changes in gross motor skills over a period of 4 years. This study showed that IQ and comorbid disorders (Attention Deficit Hyperactivity Disorder and Autism Spectrum Disorders) did not influence the developmental trajectories of gross motor skills, indicating that the gross motor skill trajectories are comparable for all children in Dutch special-needs primary schools. The studies in Chapter 5 and 6 therefore included all children in Dutch special-needs primary schools.

*Intervention*

The aim of this thesis was to develop an intervention applicable in a school setting. Important starting points for the present intervention were: 1) the physical education teacher could perform the intervention during the regular physical education classes and, 2) all children should be able to participate in the intervention. After the intervention of 16 weeks, we conducted a process evaluation in order to examine whether or not the intervention was applicable in a school setting and whether or not the exercises in the intervention were practically achievable during the intervention sessions and fitted the gross motor skill level of children in Dutch special-needs primary schools. Based on the process evaluation we concluded that the ball skill intervention was suitable for a heterogeneous population of children. By offering ball skill exercises matching individual skill levels resulted that most of the children were challenged on their own skill level. In a population with large variability in ball skill performance, like children with LD, this is it important (Valentini & Rudisill, 2004). Furthermore, the physical education teacher reported that this group of children needed specific attention and individual feedback. This was possible due to the teacher-child ratio (2:16). We are aware that this is not the standard in educational practice. However, we recommend that children receive appropriate practice, encouragement and adequate feedback in learning gross motor skills (see also Goodway & Branta, 2003). Finally, in the evaluations most of the children reported that they had experienced enjoyable physical education classes through the variation in types of exercises. It is critical that physical education classes and learning of gross motor skills should be fun, so that children are motivated to participate during the physical education classes (Hardy, Barnett, Espinel, & Okely, 2013). In conclusion, the current intervention was appropriate for children in Dutch special-needs primary schools.

*Measurements*

In this thesis the Test of Gross Motor Development-2 (TGMD-2; Ulrich, 2000) was used for the assessment of gross motor skills. The TGMD-2 measures gross motor skills in a relatively static setting, while in the intervention the ball skills were practiced in static as well as in more complex, dynamic settings. To measure improvement of ball skills in a complex setting more context specific measurements are needed. To our knowledge, reliable and valid instruments assessing gross motor skills in complex settings have not yet been developed. Such instruments would provide a valuable contribution to the current motor skill instruments, as it would give more insight into the competence of gross motor skills in more play- and sport-specific settings.

**Implications for educational practice**

The present thesis has several practical implications for teachers and educators working with children with LD as well as for educational policy-makers. Teachers will already be aware that children with LD attending Dutch special-needs primary schools are a heterogeneous group in terms of their academic performance, but this thesis showed that they are also heterogeneous in terms of their gross motor skill performance. Physical education teachers should take this variability in gross motor proficiency into account during their physical education classes by using different skill levels in the exercises and by giving individual and specific feedback rather than only class-level instruction. Different skill levels and individual instruction are generally applied in teaching academic skills. For example, many Dutch primary-schools offering reading education in group 1 (6 and 7 years old children) based on the method 'Safe learn to read' which uses four different reading levels. Children receive reading education fitting their individual skill level. This should also be the case in the physical education classes, especially in special-needs primary schools because of the heterogeneity of the population. In addition, the specific relationship between motor performance and (later) cognitive performance, as noted in

Chapter 3 and 5, stresses the importance of developing adequate gross motor skill performance. Physical education teachers should focus on these skills in their physical education classes. The development of gross motor skills should also be an important component in early childhood education programs in order to decrease motor problems.

Policy-makers should be aware of the importance of physical education classes for the overall development of the child. Furthermore, primary schools are the ideal settings for sport, exercise, and movement education, because almost all children in the Netherlands attend a primary school allowing more children to be reached than in optional sport and leisure activities after schooltime. Therefore, the Dutch government should invest in physical education classes at primary school level, for example through expanding the norm of minimal hours physical education classes per week (for primary school the norm is 2 times per week, 45 minutes per lesson, and for special-needs primary schools the norm is 3 times per week, 45 minutes).

**Conclusions**

The results presented in this thesis were based on cross-sectional and longitudinal data. Based on the findings in the separate studies the following conclusions are made:

1. Children with LD generally have inferior gross motor skill performance compared to their typically developing peers.
2. Although children with LD are able to develop their motor skills to the end of the primary school years there is still a gap where children with LD are at least 3 years behind their typically developing peers
3. Specific attention to motor skill training in children with LD appears to be necessary.
4. The relationship between gross motor skills and cognitive performance appears to be specific rather than general.
5. The ball skill intervention is an effective instrument to improve the ball skills of children with LD.
6. Practicing ball skills appears to influence EF positively, specifically on problem solving.

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# Summary

In the Netherlands, almost forty thousand children attend special-needs primary schools. Children in Dutch special-needs primary schools [from now called children with learning disorders ( LD)] have learning lags in one or more academic skills (i.e. reading, spelling, and mathematics) causing by specific learning problems, behaviour problems and/or a lower intelligence level. The focus in the education of children with learning disorders as well as in scientific research about this group of children is primarily on their cognitive performance. Far less attention is given to the motor development of children with LD, although it is known that motor development is an important factor in child development, for example in the cognitive development. Research focussing on the motor development of children with LD and the possible relationship with their cognitive development may, therefore, lead to better understanding and support of these children in the educational setting. The aim of this thesis was to examine the development of gross motor skills and the possible relationship between motor skills and cognitive performance (i.e. executive functioning and academic skills) in children with LD aged between 7 and 12 years. The three main questions addressed were:

1) What is the level of gross motor skill performance of children with LD compared to typically developing children and how do gross motor skills develop with age in children with LD?
2) Is there a relationship between gross motor skills and children's cognitive performance?
3) What is the effect of a motor intervention on children's gross motor skills and their cognitive performance?

In Chapter 2, the level of gross motor skill performance and the relationship between gross motor skills and sports participation are investigated. The gross motor skill performance of children with intellectual disabilities (IQ between 50-80; a subgroup of children with LD) is compared with typically developing children using the de Test of Gross Motor Development -2 (TGMD-2). A self-report measure was used to assess the children's participation in organized sports. Compared to their typically developing counterparts, children with intellectual disabilities scored significantly lower on both the locomotor and ball skills (i.e. object-control skills). The results suggest that children with intellectual disabilities had particularly problems with complex motor skills, whereby more parts of the body were involved simultaneously for example during jumping or throwing. Furthermore, a positive relationship is found between the level of ball skills and organized sports participation in children with intellectual disabilities (small to moderate relationship) as well as in typically developing children (small relationship) meaning that children who participated in sports had higher ball skill scores than children who did not participated in sports. Moreover, the sports participation of children with intellectual disabilities was extremely lower (39%) compared to that of typically developing children (84%).

In Chapter 3, the gross motor skill scores of children with learning disabilities (children with LD with an IQ in the normal range, i.e. 80 or above; a subgroup of children with LD) are compared with their typically developing peers to gain insight into the motor problems of these children. Furthermore, the relationship between gross motor skills and

different domains of academic achievement (i.e. reading, spelling, and mathematics) are investigated in children with learning disabilities. The results showed that the children with learning disabilities scored significantly lower on the locomotor skills and the ball skills compared to typically developing children as assessed with the TGMD-2. The effect sizes obtained (i.e. large for ball skills and moderate for locomotor skills) indicate that the gap between the performance of children with learning disabilities and their typically developing counterparts was larger for the ball skills than for the locomotor skills. Additionally, in children with learning disabilities a specific relationship was observed between reading and locomotor skills and a trend was found for a relationship between mathematics and ball skills: the larger children's learning lag, the poorer their motor skill scores.

The longitudinal development of gross motor skills from 7- to- 11 years old in children with LD is evaluated in Chapter 4. This study included children with LD with a low IQ as well as children with LD with a normal IQ, i.e. children with intellectual disabilities and children with learning disabilities. The results showed that the ball skills of children with LD improved during ages 7 to 11, especially between 7 and 9 years. Notable is the large ball skill difference between both groups at age 7 years, while the difference between both groups at age 11 is much smaller. No improvement was found for the locomotor skills during ages 7 to 11. The effect of sex, IQ and comorbid disorders (i.e. ADHD and autism spectrum disorders) on the ball skills is also examined. Boys had higher scores than girls. However, the developmental patterns were not different for boys and girls indicating that these trajectories were parallel over time. No significant effects were found of comorbid disorders and IQ on the ball skill development. This indicated that the developmental trajectory of gross motor skills was not different for children with a comorbid disorder and children without a comorbid disorder and for children with a below average IQ and children with an IQ in the normal range.

Furthermore, the gross motor skill development of children with LD is compared with that of typically developing peers. Children with LD had lower performance on the locomotor skills and ball skills at all ages, except the locomotor skills at age 7. At the end of the primary school-period (11 years of age) there is still between both groups of children. Eleven- year-old children with LD had a lag in locomotor skills and ball skills of at least four and three years, respectively, compared to their peers.

In Chapter 5 a longitudinal study on the relationship between gross motor skills and executive functioning is conducted in children with LD, aged 7 to 11 years. The performance on different subsets of gross motor skills (i.e. locomotor skills and ball skills) was related to the performance on different components of executive functioning (i.e. inhibition, cognitive flexibility, working memory, problem solving) one and two years later. A positive significant relationship was found between children's ball skill performance and their performance on problem solving one year later. This indicate that the better children's ball skill performance, the better their performance in problem solving one year later. Based on Chapter 3 and Chapter 5 we concluded that the relationship between gross motor skills and cognitive performance is specific rather than a general association. Chapter 6 examined the effect of a 16-week ball skill intervention on the ball skills, executive functioning (in terms of problem solving and cognitive flexibility), and in how far improved executive functioning leads to improved reading and mathematics performance. The children in the intervention group significantly improved their ball skills, while the children in the control group did not. No intervention effects were found on the cognitive parameters. However, within the intervention group a positive relationship (moderate relation) was found between the change in ball skill performance and the change in problem solving: the larger children's improvement in ball skills, the larger their improvement in problem solving. Based on the results, we concluded that the ball skill intervention is an effective instrument to improve the ball skills of children with LD. Although the current study did not demonstrate large effects on executive functioning and academic achievement, evidence was found to suggest that practicing ball skills might have a positive influence on cognition, specifically on problem solving. Further research is needed to examine the impact of the ball skill intervention on the cognitive parameters in this population.

In the general discussion in Chapter 7, the main findings of this thesis are reviewed. Furthermore, practical implications and recommendations for future research as well as recommendations for the educational practice are provided.

The following conclusions are drawn from the findings in the separate studies in this thesis:

1. Children with LD generally have inferior gross motor skill performance compared to their typically developing peers.
2. Although children with LD are able to develop their motor skills to the end of the primary school years there is still a gap where children with LD are at least 3 years behind their typically developing peers
3. Specific attention to motor skill training in children with LD appears to be necessary.
4. The relationship between gross motor skills and cognitive performance appears to be specific rather than general.
5. The ball skill intervention is an effective instrument to improve the ball skills of children with LD.
6. Practicing ball skills appears to influence EF positively, specifically on problem solving.

The present thesis has several practical implications. The results of this thesis emphasized the importance of well-developed gross motor skills. Therefore the development of gross motor skills should be an important component of the physical education lessons. It is recommended to take individual performance levels of children into account through using different skill levels in the exercises and by giving individual and specific feedback. Hopefully, this thesis contributes to a raising awareness in society and policy of the importance of physical education classes for the overall development of the child.

# Samenvatting

In Nederland gaan circa veertig duizend kinderen naar het speciaal basisonderwijs. Het speciaal basisonderwijs biedt onderwijs aan kinderen met leerproblemen. Dit zijn kinderen die extra zorg nodig hebben om zich goed te kunnen ontwikkelen wegens specifieke leerproblemen, gedragsproblemen en/of een verlaagd intelligentie niveau. In zowel het onderwijs aan deze kinderen als het onderzoek naar deze doelgroep ligt de focus op de cognitieve ontwikkeling. Veel minder aandacht is er voor de motorische ontwikkeling, terwijl de motorische ontwikkeling een belangrijke rol speelt in de algehele ontwikkeling van het kind, zoals de cognitieve ontwikkeling. Onderzoek naar de motorische ontwikkeling van kinderen met leerproblemen in het speciaal basisonderwijs en de mogelijke relaties met de cognitieve ontwikkeling is daarom van belang voor het ontwikkelen van passend onderwijs voor deze kinderen. Het doel van dit proefschrift was om inzicht te krijgen in de grove motorische ontwikkeling en de mogelijke relaties tussen de grove motorische ontwikkeling en cognitieve ontwikkeling (executieve functies en schoolprestaties) van kinderen met leerproblemen in het speciaal basisonderwijs in de leeftijd van 7 tot en met 12 jaar. De drie hoofdvragen van het onderzoek waren:

1. Wat is het niveau van de grove motorische vaardigheden van kinderen met leerproblemen in het speciaal basisonderwijs vergeleken met kinderen in het reguliere onderwijs en hoe ontwikkelen deze vaardigheden zich naarmate kinderen ouder worden?
2. Is er een relatie tussen grove motorische vaardigheden en cognitieve vaardigheden?
3. Wat is het effect van een motorische interventie op motorische vaardigheden en cognitieve vaardigheden?

In hoofdstuk 2 is het niveau van de grove motorische vaardigheden onderzocht en de relatie tussen grove motorische vaardigheden en sportdeelname. Voor dit onderzoek zijn kinderen met leerproblemen en een verlaagd intelligentieniveau (IQ tussen 50 en 80; subgroep binnen het speciaal basisonderwijs) en kinderen in het reguliere onderwijs getest met de Test of Gross Motor Development -2 (TGMD-2). Om de sportdeelname van de kinderen in kaart te brengen is een vragenlijst afgenomen. Uit de resultaten is gebleken dat de kinderen met leerproblemen en een verlaagd intelligentieniveau minder goed scoorden dan reguliere kinderen op zowel de verplaatsvaardigheden als de balvaardigheden. Het bleek dat de kinderen met een verlaagd intelligentie niveau de meeste problemen hadden met complexe motorische vaardigheden, waarbij verschillende lichaamsdelen tegelijk gebruikt moeten worden bijvoorbeeld bij springen en gooien. Verder is een positieve relatie gevonden tussen het niveau van de balvaardigheden en lidmaatschap van een sportvereniging bij de kinderen met een verlaagd intelligentieniveau (zwak tot matige relatie) en bij reguliere kinderen (zwakke relatie). Dit houdt in dat kinderen die aan sport doen hoger scoorden op de balvaardigheden subtest van de TGMD-2 dan kinderen die niet aan sport doen. Opvallend was dat de sportdeelname in georganiseerde sport van de kinderen met een verlaagd intelligentieniveau aanzienlijk lager was (39%) dan van kinderen in het reguliere onderwijs (84%).

In hoofdstuk 3 is de grove motoriek van kinderen met leerproblemen, maar met een normaal intelligentieniveau (IQ 80 en hoger; subgroep binnen het speciaal basisonderwijs), vergeleken met dat van reguliere leeftijdsgenootjes. Tevens is de relatie tussen de grove motorische vaardigheden en de prestaties op lezen en rekenen van de kinderen met leerproblemen onderzocht. Uit het onderzoek bleek dat de kinderen met leerproblemen met een normaal intelligentieniveau lager scoorden op zowel de verplaatsvaardigheden subtest als de balvaardigheden subtest van de TGMD-2 dan reguliere kinderen. De effect size voor de verplaatsvaardigheden was matig en voor de balvaardigheden sterk wat inhoudt dat de achterstand van kinderen met leerproblemen ten opzichte van reguliere kinderen groter was op de balvaardigheden dan op de verplaatsvaardigheden. Tevens is er een positieve significante relatie gevonden tussen het niveau van de verplaatsvaardigheden en het leesniveau van de kinderen. Dit houdt in dat hoe beter de verplaatsvaardigheden van de kinderen waren hoe hoger ze scoorden op de leestest. Eenzelfde verband is gevonden tussen het niveau van de balvaardigheden en de prestaties op rekenen, hoewel dit verband net niet significant ($p = .052$) was.

De longitudinale ontwikkeling van de grove motorische vaardigheden van kinderen met leerproblemen in het speciaal basisonderwijs is beschreven in hoofdstuk 4. In deze studie zijn zowel de kinderen met leerproblemen en een normaal intelligentieniveau als kinderen met leerproblemen en een verlaagd intelligentieniveau onderzocht. De resultaten laten zien dat de kinderen beter scoorden op de balvaardigheden naarmate ze ouder werden. Op 7-jarige leeftijd scoorden de kinderen gemiddeld 26 punten op de subtest balvaardigheden van de TGMD-2 en op 11-jarige leeftijd gemiddeld 37 punten. De meeste ontwikkeling op balvaardigheden vond plaats tussen 7- en 9-jarige leeftijd. Op de verplaatsvaardigheden lieten de kinderen geen significante verbetering zien tussen 7- en 11-jarige leeftijd. Ook is het effect van geslacht, intelligentie niveau en nevenstoornis (ADHD, autisme verwante stoornissen) op de balvaardigheden onderzocht. Jongens scoorden significant hoger dan meisjes op de balvaardigheden. Echter, het ontwikkelingspatroon van de jongens en de meisjes op de balvaardigheden verliep parallel. Dit houdt in dat op elke leeftijd het verschil tussen de jongens en de meisjes na genoeg even groot was. Er zijn geen significante effecten van intelligentieniveau en nevenstoornis op de ontwikkeling van de balvaardigheden gevonden. Dit houdt in dat de ontwikkeling van de balvaardigheden tussen 7- en 11-jarige leeftijd niet significant verschillend was voor kinderen met leerproblemen en een normaal intelligentieniveau en kinderen met leerproblemen en een verlaagd intelligentieniveau. Hetzelfde geldt voor kinderen met een nevenstoornis als kinderen zonder nevenstoornis.

Daarnaast is in hoofdstuk 4 de ontwikkeling van grove motorische vaardigheden van de kinderen met leerproblemen (met een normaal intelligentieniveau en een verlaagd intelligentieniveau samen) vergeleken met de ontwikkeling van leeftijdsgenootjes in het reguliere onderwijs. Hieruit bleek dat op elke leeftijd de kinderen met leerproblemen significant lager scoorden op zowel de verplaatsvaardigheden als op de balvaardigheden, uitgezonderd de verplaatsvaardigheden op 7-jarige leeftijd. Aan het eind van de basisschoolperiode (11-jarige leeftijd) was het verschil in vaardigheidsniveau tussen de kinderen met leerproblemen en reguliere kinderen drie jaar op de balvaardigheden en vier jaar op de verplaatsvaardigheden.

In hoofdstuk 5 is onderzoek uitgevoerd naar de longitudinale relatie tussen de grove motorische vaardigheden en het executief functioneren van de kinderen met leerproblemen (met een normaal intelligentieniveau en een verlaagd intelligentieniveau samen). In deze studie is onderzocht of het niveau van de grove motorische vaardigheden op jongere leeftijd effect heeft op de prestatie op het executief functioneren in hetzelfde jaar, een jaar later en twee jaar later. Hiervoor zijn 4 executieve functies gemeten te weten 'planning en probleemoplossend vermogen', het 'werkgeheugen', 'cognitieve flexibiliteit' en 'inhibitie'. Een positieve significante relatie is gevonden tussen het niveau van de balvaardigheden en de prestatie op 'planning en probleemoplossend vermogen' een jaar later. Dit houdt in dat hoe beter de balvaardigheden van de kinderen ontwikkeld waren, hoe hoger de kinderen scoorden op planning en probleemoplossend vermogen een jaar later. Uit de hoofdstukken 3 en 5 kunnen we concluderen dat de relatie tussen de grove motorische vaardigheden en cognitieve vaardigheden een specifieke relatie lijkt te zijn en geen algemene relatie.

In hoofdstuk 6 zijn de effecten van de motorische interventie (het balvaardigheidsprogramma) op de balvaardigheden, de executieve functies en de schoolprestaties van kinderen met leerproblemen beschreven. Uit de resultaten bleek dat de kinderen die het balvaardigheidsprogramma gevolgd hebben hun balvaardigheden meer ontwikkeld hebben, dan de kinderen uit de controle groep die het programma niet hebben gevolgd. Er is geen direct effect van het programma op de executieve functies - gemeten met de Tower of London voor planning en probleemoplossend vermogen, en de Trailmaking test voor cognitieve flexibiliteit- en op de prestaties op lezen en rekenen aangetoond. Wel is gebleken dat binnen de groep kinderen die het programma hebben gevolgd, dat kinderen die een grotere verbetering lieten zien op de balvaardigheden, ook een grotere verbetering vertoonden op de executieve functie 'planning en probleemoplossend vermogen' ten opzichte van kinderen die minder vooruit waren gegaan op de balvaardigheden. Uit dit onderzoek kunnen we concluderen dat het balvaardigheidsprogramma effectief is om de balvaardigheden van kinderen met leerproblemen in het speciaal basisonderwijs te verbeteren. Verder is er een eerste indicatie dat het trainen van balvaardigheden effect kan hebben op cognitieve vaardigheden, in het bijzonder op planning en probleemoplossend vermogen. Echter, vervolgstudies met een langer programma zijn nodig om het effect van het balvaardigheidsprogramma op cognitie verder te onderzoeken.

In hoofdstuk 7 worden de belangrijkste bevindingen van dit proefschrift bediscussieerd. Daarnaast worden aanbevelingen gedaan voor zowel vervolg onderzoek als voor het onderwijs.

De belangrijkste conclusies die we op basis van dit proefschrift kunnen trekken zijn:

1. Kinderen met leerproblemen in het speciaal basisonderwijs hebben over het algemeen slechtere grove motorische vaardigheden dan leeftijdgenootjes in het reguliere onderwijs.
2. Kinderen met leerproblemen in het speciaal basisonderwijs ontwikkelen hun grove motorische vaardigheden naarmate ze ouder worden, echter op 11-jarige leeftijd is er nog steeds een achterstand van tenminste 3 jaar ten opzichte van

11-jarige reguliere kinderen.

3. De relatie tussen grove motorische vaardigheden en cognitieve vaardigheden lijkt een specifieke relatie in plaats van een algemene relatie te zijn.
4. Specifieke aandacht voor het oefenen van grove motorische vaardigheden is noodzakelijk voor kinderen met leerproblemen in het speciaal basisonderwijs.
5. Het balvaardigheidsprogramma is een effectief programma om de balvaardigheden van kinderen met leerproblemen in het speciaal basisonderwijs te verbeteren.
6. Trainen van balvaardigheden bij kinderen met leerproblemen lijkt positieve invloed te hebben op hun executieve functies, in het bijzonder op planningsvaardigheden en het probleemoplossend vermogen. Er is meer onderzoek nodig naar effecten van motorische interventies op cognitieve prestaties van kinderen met leerproblemen.

Op basis van de resultaten van het proefschrift volgt een aantal praktische implicaties. Aan de leerkrachten bewegingsonderwijs wordt aanbevolen specifieke aandacht te besteden aan het ontwikkelen van grove motorische vaardigheden tijdens de lessen bewegingsonderwijs. Hierbij is het van belang rekening te houden met niveauverschillen van de kinderen door oefeningen op verschillende niveaus aan te bieden en door kinderen individueel en specifieke feedback te geven. De resultaten onderstrepen het belang van een goede grove motorische ontwikkeling en daarmee het belang van kwalitatief goed bewegingsonderwijs voor kinderen. De resultaten dragen hopelijk bij aan een grotere bewustwording in de samenleving en de politiek dat het bewegingsonderwijs als een belangrijk schoolvak moet worden beschouwd.

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# Curriculum Vitae

Marieke Westendorp is geboren op 1 oktober 1981 te Zuidlaren. Na het behalen van haar VWO diploma aan het Gomarus College in Groningen in 2000, is zij gestart met de opleiding Bewegingswetenschappen aan de Rijksuniversiteit Groningen. Naast de opleiding Bewegingswetenschappen in Groningen, heeft Marieke de afstudeerrichting Psychomotorische Therapie bij de opleiding Bewegingswetenschappen aan de Vrije Universiteit in Amsterdam gevolgd. In het kader hiervan heeft zij een praktijkstage gedaan als psychomotorische therapeut bij het Regionaal Expertise Centrum Noord Nederland cluster 4 (Renn4). In haar afstudeeronderzoek heeft zij onderzoek gedaan naar de grove motorische ontwikkeling van dove kinderen. In 2005 heeft Marieke haar opleiding afgerond met het doctoraalexamen in de richting 'Sport'.

Van 2005 tot 2008 heeft zij gewerkt als projectmedewerker bij het Koninklijk Nederlands Genootschap voor Fysiotherapie. In oktober 2008 keerde Marieke terug naar Groningen en startte zij als promovendus bij het Centrum voor Bewegingswetenschappen. Het doel van het promotieonderzoek was inzicht verkrijgen in de motorische ontwikkeling en de mogelijke relaties tussen motorische vaardigheden en cognitieve vaardigheden bij kinderen in het speciaal basisonderwijs.

# List of publications

**International publications (peer-reviewed)**

Hartman, E., Smith, J., Westendorp, M., & Visscher, C. Development of physical fitness in children with intellectual disabilities (*in press). Journal of Intellectual Disability Research*.

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**National publications**

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