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Arithmetic performance of children with cerebral palsy: The influence of cognitive and motor factors

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ABSTRACT

Children diagnosed with cerebral palsy (CP) often show difficulties in arithmetic compared to their typically developing peers. The present study explores whether cognitive and motor variables are related to arithmetic performance of a large group of primary school children with CP. More specifically, the relative influence of non-verbal intelligence, working memory, word decoding capacities, gross- and fine motor skills on arithmetic performance is examined using structural equation modeling. One-hundred sixteen primary school children with a formal diagnosis of CP participated (76 males, *M* = 7; 3 years, SD = 3 months). In agreement with previous studies our results showed that the cognitive and motor predictors were all positively correlated to each other. Furthermore, in the cognitive model, non-verbal intelligence and word decoding were related to arithmetic in primary school. Our combined model (that included both motor and cognitive variables) showed that word decoding and fine motor skills were the strongest predictors of arithmetic performance. To conclude, this study was the first to show the influence of word decoding and fine motor skills on arithmetic performance of children with CP.

1. Introduction

Cerebral palsy (CP) is characterized by an atypical development of movement and posture which is the result of non-progressive disturbances in the developing brain. Next to compromised motor control, CP is often accompanied by additional problems related to sensation, perception, behavior, communication and cognition (Rosenbaum et al., 2007). Although the motor performance and the deviations therein have been described in some detail, knowledge about the cognitive skills and scholastic performance in CP is limited (Straub & Obrzut, 2009). This is remarkable given the high prevalence of learning problems related to arithmetic (26%) and reading (19%) in children with hemiplegic CP (Frampton, Yude, & Goodman, 1998).

Numbers and arithmetic are an important aspect of our society. People are confronted with numerical information in everyday activities, such as looking up a page in a book or paying for groceries (Butterworth, 2005). The study of the

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numerical and arithmetic capacities of children with CP has received only minor attention (Rooijen, Verhoeven, & Steenbergen, 2011). The few existing studies show that children with CP are regularly delayed in counting, subitizing, and simple arithmetic operations compared with their typically developing peers. In addition, the longitudinal study of Jenks, de Moor, & van Lieshout, 2009; Jenks, van Lieshout, & de Moor, 2009 showed that particularly children with CP in special education[1] lagged behind and were not able to catch up with their typically developing peers in primary school. However, due to the dearth of studies on this topic general conclusions cannot be drawn about the antecedents and developmental trajectories of arithmetic abilities in these children (van Rooijen, Verhoeven, & Steenbergen, 2011).

In the present study we explored the influence of cognitive and motor factors on arithmetic performance in a large sample of primary school children with CP. We will provide an in-depth analysis of the cognitive and motor factors contributing to arithmetic performance of children with CP. This analysis will provide a starting point for intervention and remediation programs. In what follows, we will elaborate on the contribution of the cognitive and motor factors to arithmetic.

1.1. Cognitive predictors

Research in typically developing children has revealed several constructs which contribute to the development of arithmetic during primary school (e.g. Duncan et al., 2007). Domain-general neuropsychological factors, such as intelligence and working memory were shown to be related to arithmetic development (e.g. De Smedt et al., 2009; Kroesbergen, Van Luit, Van Lieshout, Van Loosbroek, & Van de Rijt, 2009). Moreover, arithmetic performance cannot be disentangled from language development (e.g. LeFevre et al., 2010). In the following paragraphs, the influence of intelligence, working memory and word decoding will be successively discussed in more detail.

The relationship between general intelligence level and arithmetic performance at school is well established in typically developing children (Deary, Strand, Smith, & Fernandes, 2007; Lynn & Mikk, 2007). There is a large variation in intelligence scores among subtypes of CP (Fennell & Dikel, 2001). Therefore, intelligence is generally included in research examining the cognitive abilities of children with CP (Jenks, de Moor, et al., 2009; Peeters, Verhoeven, & de Moor, 2009).

By the same token, working memory was found to be strongly related to arithmetic problem solving (Rasmussen & Bisanz, 2005). In a recent review, Raghubar, Barnes and Hecht (2010) found a robust relationship between working memory components and arithmetic. However, they commented that '(. . .) the relations between working memory and math are complex and likely depend on several factors including, but not limited to: age, skill level, language of instruction, the way in which mathematical problems are presented, the type of mathematical skill under consideration and whether that skill is in the process of being acquired, consolidated, or mastered' (p. 10). Moreover, research on the arithmetic capacities of children with CP has highlighted the influence of working memory on addition and subtraction problems (Jenks et al., 2007).

When children have to learn to count and attribute names to quantities, language becomes influential in learning arithmetic. In addition, a language system is necessary to construct and solve more complex arithmetic problems (Butterworth, 2005). Several studies have reported a strong correlation between language skills, such as phonological awareness, and arithmetic (e.g. Hecht, Torgesen, Wagner, & Rashotte, 2001). Dehaene, Piazza, Pinel, & Cohen (2003) have argued that a separate circuit of the parietal cortex is attributed to processing arithmetic problems that contain a verbal component. However, the role of word decoding capacities in the cognitive performance of children with CP has not yet been established in previous research. Therefore, we will examine the influence of word decoding on arithmetic.

1.2. Motor predictors

The math skills of typically developing primary school children were found to be correlated with their gross motor skills as measured with a standardized screening instrument (Early Screening Inventory Revised (ESI-R) (Son & Meisels, 2006). In children with CP the severity of motor impairments, as assessed with the Gross Motor Function Classification System (GMFCS), was correlated with their intellectual functioning (Smits et al., 2011). In addition, learning problems were also dependent on the severity of the gross motor impairment. Specifically, high scores on the GMFCS that indicate severe compromised motor control were positively correlated with the presence of learning problems (Beckung & Hagberg, 2000). In contrast, Jenks, van Lieshout, et al. (2009) did not find a relationship between the GMFCS scores and arithmetic performance in primary school children with CP.

In addition to the role of gross motor abilities, fine motor skills may even be more strongly related to arithmetic. Across the majority of cultures, children start using finger-counting strategies spontaneously (Luca, Granà, Semenza, Seron, & Pesenti, 2006). Furthermore, strong correlations were found between the unstructured use of finger-counting strategies and accuracy in number combinations (e.g. how much is *a* and *b*?) by children in kindergarten (Jordan, Kaplan, Ramineni, & Locuniak, 2008). Goldin-Meadow, Nusbaum, Kelly, & Wagner (2001) have examined the role of gesturing in arithmetic. Children and adults were presented with challenging problems. Children solved problems similar to $4 + 5 + 3 = \ldots + 3$ and adults received problems like $x^2 - 5x + 6 = (\ldots)(\ldots)$. While explaining the arithmetic problems, both groups performed significantly better when they were allowed to 'talk' with their hands compared to the situation in which they were not

[1] In the Netherlands mainstream-and special education exist in parallel.

allowed to use their hands. Because of this established relationship between motor skills and cognition, we will also examine the extent to which gross- and fine motor skills in children with CP contribute to their performance on addition and subtraction tasks.

1.3. Present study

In the present study, the relative influence of cognitive and motor variables that were previously shown to be related to arithmetic performance in primary school children will be examined. A multifactor approach will be used to provide an in depth analysis of the role of these factors on the arithmetic scores in a large group of seven-year-old children diagnosed with CP. In order to investigate the relative influence of these factors, structural equation modeling will be used.

2. Method

2.1. Participants

This study is part of the 'Pediatric Rehabilitation Research in The Netherlands' (PERRIN) CP 5-9 project. Children were recruited from two departments of rehabilitation medicine of University Medical Centers (University Medical Center Utrecht and VU University Medical Center, Amsterdam) and four Rehabilitation Centers (Rehabilitation Center De Hoogstraat, Utrecht; Rehabilitation Center Amsterdam; Rehabilitation Center De Trappenberg, Huizen; and Rehabilitation Center Breda) in the Netherlands. Ethical approval for the study was given by the Committee for Medical Ethics of the University Medical Center Utrecht.

In the present study, data of 116 children were included (76 males, $M = 7$; 3 years, SD = 3 months, range 6; 6–7; 8 years). Children were included based on a formal diagnosis of cerebral palsy (Rosenbaum et al., 2007). Children diagnosed with other diseases or disorders which affected motor performance were excluded from the study. 98 children had spastic CP (84%), 14 (12%) had dyskinetic CP and 4 (3%) had ataxic CP. Of the children with spastic CP, 56 (48%) had bilateral CP and 42 had unilateral CP (20% right; 16% left). Concerning the GMFCS, 56 children (48%) were classified in level I, 20 children (17%) were classified in level II, 17 children (15%) were classified in level III, 9 children (8%) were classified in level IV, and 14 children (12%) were classified in level V. All parents signed an informed consent form for the participation of their children.

A few children were unable to perform the tasks due to auditory-, visual or sensory difficulties; this data is therefore missing. Some additional, results are lacking because cognitive tasks were either too challenging for the children or had not yet been a part of their school curriculum. Furthermore, some parents failed to return the questionnaire on fine motor functioning.

2.2. Instruments

2.2.1. Motor abilities

The Gross Motor Function Measure (GMFM-66) was used to assess the gross motor functioning of the children (Russell, Rosenbaum, Avery, & Lane, 2002). The GMFM is an observational instrument developed to assess the overall gross motor capacity of children with CP without the use of mobility aids or orthoses. The Gross Motor Ability Estimator has been used to calculate an interval score, which ranges from 0 (lowest motor function) to 100 (highest motor function) (Avery, Russell, Raina, Walter, & Rosenbaum, 2003).

The fine motor skills of the children were assessed with the Abilhand questionnaire (Arnould, Penta, Renders, & Thonnard, 2004). The Abilhand examines children's manual ability in daily activities and is completed by their parents. Parents are presented with 10 items related to the daily activities of their child and are required to indicate whether this action is 'impossible', 'difficult', or 'easy' for their child to perform. The scores range between −10 and 10 (see Arnould et al., 2004 for a more detailed description).

2.2.2. Cognitive abilities

To assess the non-verbal intelligence of the children the Raven Colored Progressive Matrices (Raven, 1965) was used. Every item consists of a visual design of with a piece is missing. The child must choose a piece from 6 possible pieces to complete the design. The total raw score consists of the amount of items (0–36) answered correctly. A non-verbal intelligence score was calculated based on normative data in the instruction manual (Schuhfried, 2002).

Subtests of the WISC-III (Kort et al., 2002) were used as a measure of working memory abilities. The digit span forward and the digit span backwards were administered to measure the working memory abilities of the children. A series of numbers are presented to the children. Children must then repeat the numbers in the same or reverse order. At every step, the numbers presented increased by 1. The test ended if the number series was incorrectly repeated twice.

The word decoding abilities of children were assessed using the Student Monitoring System for Language Performance (Kraemer, Nelissen, Janssen, & Noteboom, 1995). On three separate pages, a total of 450 words were presented with increasing complexity. The children were asked to read out-loud as many words as possible in 1 min. The sum score of all items that have been read correctly was used.

2.2.3. Arithmetic

Arithmetic performance of the children was measured with a Dutch standardized arithmetic achievement test, the Student Monitoring System for Arithmetic Performance (Krom, 1996). The task consists of separate parts for addition, subtraction and multiplication problems. In the present study, only addition and subtraction problems were used because the children had not yet received any education on multiplication. Children received 40 items for each component, which were presented in an increasing order of difficulty. For each sub-test, children were asked to answer as many problems as they could in 1 min. The sum score of items which were answered correctly was used as outcome measure.

2.3. Statistical analyses

The data was analyzed by structural equation modeling (SEM) using AMOS 7 (Arbuckle, 2006). The fit indices χ^2, χ^2/df, Root Mean Square Error of Approximation (RMSEA), Comparative Fit Index (CFI) and Tucker Lewis coefficient (TLI) were used to evaluate the fit of the models. The chi-square index is a "badness-of-fit" index and should be non-significant ($p > .05$). Although no strict criteria exist regarding the value of the χ^2/df ratio, generally a value less than 3 is regarded as acceptable. A RMSEA value smaller than .05 indicates a good fit, whereas a value between the .05 and .08 indicates a reasonable fit. A CFI – and TLI value of higher than .90 indicates a sufficiently good fit (Kline, 2005).

3. Results

3.1. Preliminary analyses

Preliminary analyses were performed to investigate whether the motor- and cognitive variables are related. The means and standard deviations of the included factors can be found in Table 1.

To investigate the relationship between the tasks, zero-order correlations between the scores of the included tests were computed (Table 2). All variables are positively related to one another. Only numbers forwards and gross motor skills are not significantly correlated with each other. Arithmetic performance of the children is significantly related with all of the cognitive- and motor predictors. Moreover, these correlations are of medium and large effect sizes (Cohen, 1988).

3.2. Model with cognitive predictors

The cognitive model is presented in Fig. 1A. The model provides a good fit of the data. This can be observed from the chi-square fit index and the χ^2/df ratio that both show a good fit, χ^2 (2, $N = 116$) = .15, $p = .94$, $\chi^2/df = .06$. Moreover, the

Table 1
Descriptive statistics (Means and standard deviations).

	N	*M*	SD
Cognitive variables			
Arithmetic	82	11.61	10.76
Non-verbal intelligence	108	77.10	35.72
WM: numbers forwards	88	5.76	1.99
WM: numbers backwards	88	2.66	1.60
Word decoding	82	49.15	61.16
Motor variables			
Gross motor skills	110	67.44	22.35
Fine motor abilities	88	.58	3.49

WM, working memory.

Table 2
Correlations between motor- and cognitive variables ($N = 110$).

	Gross motor abilities	Fine motor abilities	Non-verbal intelligence	Numbers FW	Numbers BW	Word decoding
Fine motor abilities	.82**					
Non-verbal intelligence	.74**	.76**				
Numbers FW[a]	.13	.33**	.37**			
Numbers BW[b]	.40**	.41**	.61**	.55**		
Word decoding	.34**	.43**	.43**	.31**	.40**	
Arithmetic	.41**	.61**	.61**	.37**	.56**	.80**

[a] Forwards.
[b] Backwards.
** $p < .01$.

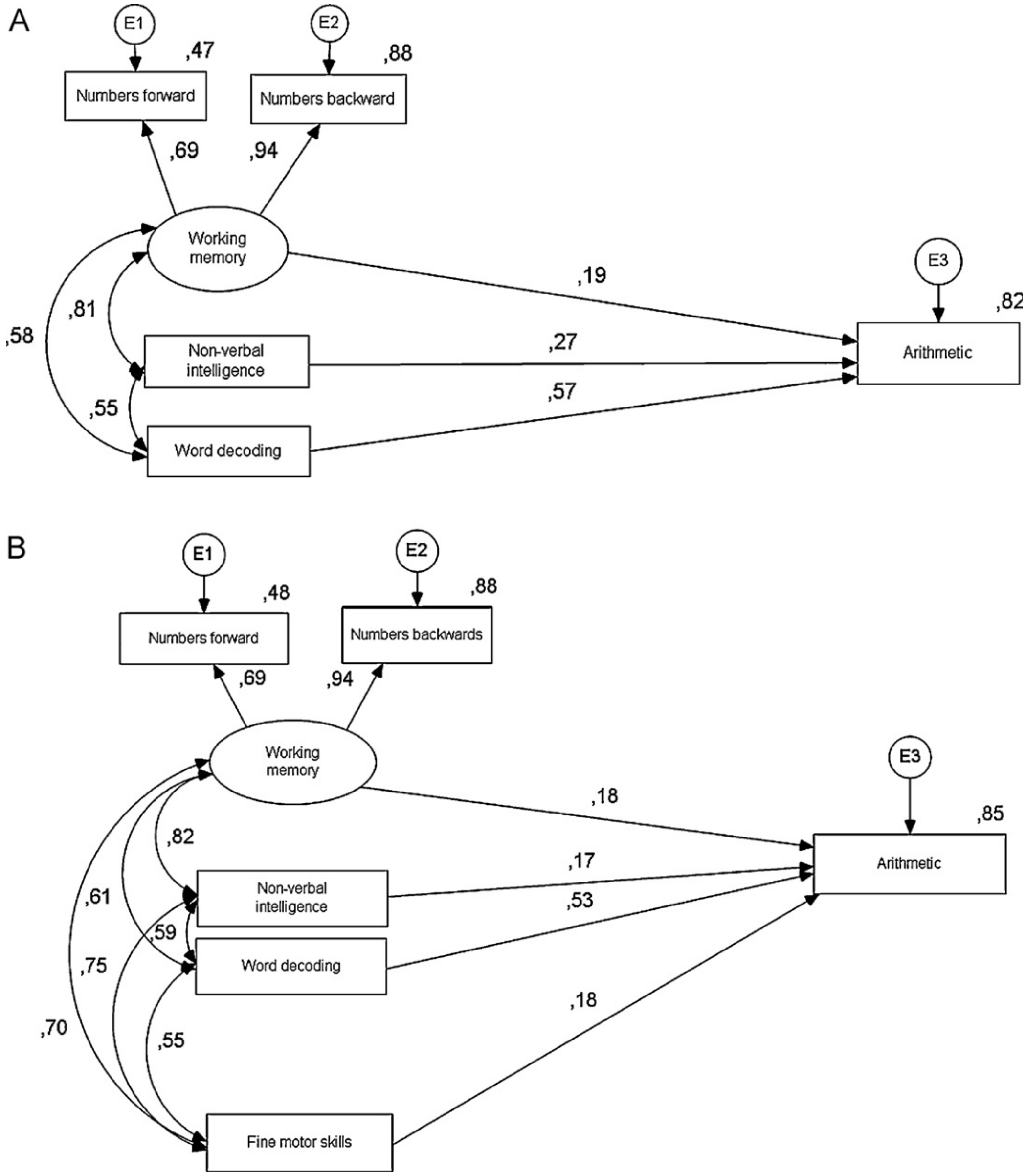

Fig. 1. (A) Model with cognitive variables predicting arithmetic performance ($N = 116$). (B) Combined model in which cognitive and motor variables are presented ($N = 116$).

comparative fit indices and RMSEA confirm that the model fits the data well, respectively CFI = 1.00, TLI = 1.00, RMSEA = .00 (see Table 3).

In the first model, the forwards and backwards reproduction of number series are combined as a working memory measure (respectively $\beta = .69$, $p < .001$, $\beta = .94$, $p < .001$). The word decoding scores of primary school children are the main predictor of their arithmetic performance ($\beta = .57$, $p < .001$). In addition, non-verbal intelligence is a significant predictor for arithmetic of children with CP ($\beta = .27$, $p < .001$). The relationship between working memory and arithmetic is not significant ($\beta = .19$, $p = .10$). Importantly, the cognitive model is able to predict 82% of the variance of the arithmetic performance of children.

3.3. Combined model with cognitive- and motor predictors

In the combined model, both the cognitive and motor factors are included to predict the arithmetic performance of children with CP (see Fig. 1B). The path between the gross motor skills and arithmetic of the children was removed because

Table 3
Summary of the comparison between both models ($N = 116$).

Model	χ^2	*Df*	*p*	χ^2/df	CFI	TLI	RMSEA (90% CI of RMSEA)
Cognitive	.15	2	.94	.06	1.00	1.00	.00 (.00–.03)
Combined	.69	3	.88	.23	1.00	1.06	.00 (.00–.08)

Notes. CFI, comparative fit index; TLI, Tucker Lewis coefficient; RMSEA, Root mean square error of approximation.

this improved the fit of the model. The chi-square fit index and χ^2/df ratio indicate that the model fits the data well (χ^2 (3, $N = 116$) = .69, $p = .88$, $\chi^2/df = .23$). Moreover, the comparative and absolute fit indices also indicate a good fit of the model (CFI = 1.00, TLI = 1.06, RMSEA = .00). To summarize, the combined model fits the data very well (see Table 3).

The model is presented in Fig. 1B. Remarkably, both working memory and non-verbal intelligence are not significantly related to arithmetic performance, respectively $\beta = .18$, $p = .11$ and $\beta = .17$, $p = .08$. However, the fine motor skills of the children are predictive of the arithmetic scores, $\beta = .18$, $p = .02$. Furthermore, the word decoding skills are the most important predictor of arithmetic, $\beta = .53$, $p < .001$. 85% of the variance in the arithmetic performance skills of the children with CP is explained by this model.

4. Discussion

In a large sample of seven-year-old children with CP, we explored the relative influence of cognitive and motor factors on arithmetic performance. Preliminary analyses showed that the cognitive and motor variables were all positively correlated to each other, which confirms the previously found relations between these variables. In the cognitive model, non-verbal intelligence and word decoding scores were predictive of arithmetic at primary school. The arithmetic scores of these children were particularly influenced by word decoding skills. In our combined model, word decoding scores and fine motor skills were the strongest predictors of arithmetic performance.

The substantial role of word decoding skills supports previous research on the development of arithmetic in typically developing children (e.g. De Smedt et al., 2009; Dehaene et al., 2003). Importantly, we controlled for intelligence level and working memory capacities of the children. This implies that the variation in word decoding abilities cannot be attributed to a difference in general intelligence or working memory skills. Although the design of this study does not allow for conclusions about the direction of the relations, it has been argued that phonological capacities (i.e. knowledge on a symbolic representation system) are an important prerequisite for arithmetic performance that involve knowledge on the symbolic number system (LeFevre et al., 2010). As a consequence, improving the word decoding capacities of children with CP might enhance their arithmetic performance.

In the combined model, the fine motor skills of children were more predictive of mathematical performance than general intelligence level and working memory abilities. This is in line with previous research highlighting the importance of fine motor skills for arithmetic scores in typically developing children (e.g. Goldin-Meadow et al., 2001; Son & Meisels, 2006). However, CP is a neuro-developmental disorder which affects both motor functioning and cognition (Rosenbaum et al., 2007). Therefore, it is not possible to determine a causal path between fine motor skills and arithmetic performance; in particularly because cross-sectional data was used in the present study. Thus, fine motor skills and arithmetic performance are strongly related but the direction of this relation has to be established in future research.

In the present study, gross motor capacities did not show a significant relationship with arithmetic performance of children with CP and this aspect was removed from the final model. This confirms the longitudinal data of Jenks, van Lieshout, et al. (2009), but contradicts the studies of Smits et al. (2011) and Beckung and Hagberg (2000) who found a relationship between gross motor functioning and cognitive functioning. The reason for these conflicting results might be that Jenks, van Lieshout, et al. (2009) and the present study studied the influence of several cognitive factors on arithmetic performance, whereas Smits et al. (2011) and Beckung and Hagberg (2000) focused on one aspect of cognitive functioning (i.e. non-verbal intelligence and learning disabilities). That is, gross motor skills are related to arithmetic performance but this relationship probably became non-significant due to the inclusion of the fine motor skills and cognitive factors. Apart from this methodological argument a more process-oriented explanation would be that, compared to gross motor skills, fine motor skills might be more related to cognitive performance of children (e.g. Goldin-Meadow, Cook, & Mitchell, 2009).

Furthermore, working memory abilities were not significantly related to addition- and subtraction scores of primary school children with CP. However, numbers forwards and backwards and the other cognitive correlates were all positively and significantly related to each other and the correlations had a medium to large effect size (Cohen, 1988). A possible explanation is given by Fuchs et al. (2010) who state that: '(. . .) the development of mathematical cognition does not depend on a uniform set of numerical or general cognitive competencies but rather that the relative contributions of numerosity and domain-general explanations to the development of mathematical cognition differs depending on the nature of mathematics performance'. This would imply that future research concerning the arithmetic performance of children with CP would benefit from the inclusion of more differentiation in types of arithmetic problems.

4.1. Future research

This explorative study is the first to show that motor and cognitive variables are both related to the arithmetic performance of children with CP. Simultaneously, this study has led to important insights for future research. First, a limitation of the current study is that the visual-spatial working memory abilities of the children were not assessed. Recent studies have attributed a major role for the visual–spatial sketchpad in the development of arithmetic in typically developing children (e.g. Bull, Espy, & Wiebe, 2008). In addition, children with CP were shown to have deficiencies in the visual spatial domain which were strongly related to their reaction time on simple addition- and subtraction problems (Jenks, van Lieshout, et al., 2009). Second, medical background variables such as prematurity of birth and the presence of epilepsy were not included. Previous studies have indicated that prematurity of birth is a risk factor for cognitive deficits (Bhutta, Cleves, Casey, Cradock, & Anand, 2002), and epilepsy has been related to lower accuracy on basic arithmetic problems (Jenks, de Moor, et al. 2009). Moreover, research indicates that the cognitive development of children can partially be attributed to the quality of their education (Jenks, de Moor, van Lieshout, & Withagen, 2010). Therefore, future studies should consider medical- and environmental factors more closely to obtain a more detailed overview of the factors affecting arithmetic performance in primary school children with CP.

In sum, children with CP were found to be delayed in arithmetic compared to their typically developing peers (van Rooijen et al., 2011). The present study emphasizes the role of word decoding capacities for arithmetic performance in children with CP. Stated differently, language skills of children are strongly related to their arithmetic scores on measures involving the symbolic number system. Thus, the familiarity with the symbolic number system could be an important requirement for arithmetic in children with CP. In addition, training of fine motor skills might ameliorate their arithmetic performance. Due to the present lack of knowledge on the antecedents and development of scholastic performance this area would benefit substantially from more research.

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