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## Working memory and fine motor skills predict early numeracy performance of children with cerebral palsy

Maaïke Van Rooijen<sup>1,2</sup>, Ludo Verhoeven<sup>1</sup>, and Bert Steenbergen<sup>1</sup>

<sup>1</sup>Department of Orthopedagogics, Behavioural Science Institute, Radboud University Nijmegen, The Netherlands

<sup>2</sup>Department of Educational Sciences, Groningen Institute for Educational Research, GION, University of Groningen, The Netherlands

Early numeracy is an important precursor for arithmetic performance, academic proficiency, and work success. Besides their apparent motor difficulties, children with cerebral palsy (CP) often show additional cognitive disturbances. In this study, we examine whether working memory, non-verbal intelligence, linguistic skills, counting and fine motor skills are positively related to the early numeracy performance of 6-year-old children with CP. A total of 56 children ( $M = 6.0$ ,  $SD = 0.61$ , 37 boys) from Dutch special education schools participated in this cross-sectional study. Of the total group, 81% of the children have the spastic type of CP (33% unilateral and 66% bilateral), 9% have been diagnosed as having diskinetik CP, 8% have been diagnosed as having spastic and diskinetik CP and 2% have been diagnosed as having a combination of diskinetik and ataktik CP. The children completed standardized tests assessing early numeracy performance, working memory, non-verbal intelligence, sentence understanding and fine motor skills. In addition, an experimental task was administered to examine their basic counting performance. Structural equation modeling showed that working memory and fine motor skills were significantly related to the early numeracy performance of the children ( $\beta = .79$  and  $p < .001$ ,  $\beta = .41$  and  $p < .001$ , respectively). Furthermore, counting was a mediating variable between working memory and early numeracy ( $\beta = .57$ ,  $p < .001$ ). Together, these findings highlight the importance of working memory for early numeracy performance in children with CP and they warrant further research into the efficacy of intervention programs aimed at working memory training.

**Keywords:** Early numeracy; Cerebral palsy; Working memory; Fine motor skills; Cognition.

Cerebral palsy (CP) is predominantly associated with disorders in motor performance, but it is increasingly acknowledged that children with CP also display disturbances in sensation, behavior, communication and cognition (Rosenbaum et al., 2007). Additionally, among all types of CP there is a high prevalence (44%) of learning problems (Himmelmann, Beckung, Hagberg, & Uvebrant, 2006; Østensjø, Carlberg, & Vøllestad, 2003; Schenker, Coster, & Parush, 2005). More specifically, it was found that the

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Address correspondence to Maaïke van Rooijen, Groningen Institute of Educational Research, GION, Grote Rozenstraat 3, 9712 TG, Groningen, The Netherlands. E-mail: [maaïke.van.rooijen@rug.nl](mailto:maaïke.van.rooijen@rug.nl)

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prevalence of arithmetic learning difficulties (28%) is larger compared to language problems (17%) (Frampton, Yude, & Goodman, 1998).

Numeracy and arithmetic skills not only play a fundamental role in daily life activities, for instance when the groceries have to be paid (Butterworth, 2005), but they are also conditional for later academic and work success (Chiswick, Lee, & Miller, 2003). Previous research has not only shown that children with CP are regularly delayed in the acquisition of counting, subitizing and simple arithmetic operations (van Rooijen, Verhoeven, & Steenbergen, 2011), but also described the cognitive and motor factors that affect performance on addition and subtraction tasks (e.g., Jenks, De Moor, & Van Lieshout, 2009; van Rooijen et al., 2012). Still, research has largely neglected early numeracy performance in these children (van Rooijen et al., 2011). We decided to focus specifically on early numeracy performance because more advanced arithmetic problems build on fundamental capacities like counting and equating quantities in a hierarchical manner (Butterworth, 2005) and numeracy has been found to be a unique predictor of school readiness (Fuchs et al., 2010).

Generally, children with CP are delayed in cognitive functioning compared to their peers (Straub & Obrzut, 2009). CP is attributed to a non-progressive injury to the developing brain (Rosenbaum et al., 2007). It is not yet known whether these brain injuries cause children to lag behind their peers or that it leads to a deviant trajectory for developing arithmetic skills. Considering the lack of studies on numeracy development in children with CP (van Rooijen et al., 2011), we included research about typically developing children on numeracy performance for reference and to develop hypotheses. If the same factors are predictive of numeracy performance in children with CP as in typically developing children then this would be an indication that they follow the same, but delayed, trajectory in the development of numeracy performance.

Previous research on early numeracy in typically developing children has shown that performance is affected by both domain-general abilities, such as working memory and non-verbal intelligence (e.g., Lee et al., 2012), and domain-specific abilities, such as counting and subitizing (Kroesbergen, Van Luit, Van Lieshout, Van Loosbroek, & Van de Rijt, 2009; Moeller, Pixner, Zuber, Kaufmann, & Nuerk, 2011). Likewise, manual dexterity and linguistic skills were shown to affect numeracy and arithmetic as well (Goldin-Meadow, Cook, & Mitchell, 2009; Kleemans, Segers, & Verhoeven, 2011). As far as we know, previous studies have not yet investigated whether the same cognitive and motor factors also influence the early numeracy performance of children with CP. Based on research on arithmetic performance in children with CP, we will discuss these factors in the following paragraphs in more detail.

Working memory is associated with learning to count and solve addition tasks (Noël, 2009), and has also been shown to predict early mathematical achievement in typically developing children (De Smedt et al., 2009). In addition, working memory, as measured by executive functioning, could explain group differences in children with CP in basic calculations (Jenks et al., 2009). Furthermore, the visuospatial sketchpad and central executive system are positively related to counting, which in turn is a prominent predictor of arithmetic accuracy in primary school children with CP. Intelligence significantly contributes to the prediction of arithmetical reasoning in typically developing children in the first and second grades. In addition, in primary school children with CP, non-verbal intelligence has been positively related to the ability to solve addition and subtraction problems (Jenks et al., 2007).

In order to solve more advanced arithmetic tasks children have to link number words with their meaning (Butterworth, 2005). Early literacy skill domains, such as vocabulary and phonological awareness, are predictive of the general numeracy knowledge in 4-year-olds (Purpura, Hume, Sims, & Lonigan, 2011). In a recent study, we showed that word knowledge and arithmetic performance are positively related in children with CP (van Rooijen et al., 2012).

Furthermore, Kroesbergen et al. (2009) concluded that a significant part of the variance in counting skills in typically developing children could be explained by subitizing. Subitizing is the ability to identify a quantity of a certain amount of items that are presented too briefly to make counting possible. Arp and Fagard (2005) found that only 15% of the children with CP in the 4- to 6-year-old age group they tested were efficient at subitizing. Given this result, we decided to use a less complex task to examine whether basic counting skills are related to the early numeracy performance of children with CP. In this task children were allowed more time to view the items.

Next to cognitive factors, fine motor skills have been shown to contribute substantially to academic achievement at kindergarten entry level (Cameron et al., 2012). Fingers can be used as a learning tool for counting (Bender & Beller, 2012), and for developing a mental number line (Wood & Fischer, 2008). It is evident that children with CP are compromised with respect to manual dexterity, which may in turn negatively affect their numerical development.

To summarize, previous research has delineated several important factors that contribute to early numeracy performance in typically developing children, and which were found to be related to the arithmetic skills of children with CP. In the present study, we will explore whether working memory, non-verbal intelligence, linguistic skills, counting and fine motor skills are positively related to the early numeracy performance of 6-year-old children with CP. Structural equation modeling (SEM) will be used to allow us not only to investigate the direct relations, but also to create latent variables and examine possible mediation effects. Based on the results in typically developing children we expect working memory to be a dominant predictor of early numeracy performance. Moreover, we hypothesize that counting as a basic numeracy skill is positively related to early numeracy.

## METHOD

### Participants

A total of 56 children participated in the present study (37 boys and 19 girls). The mean age was 6.0 ( $SD = 0.61$ ). Of this group, 42 children (81%) have the spastic type of CP (33% unilateral and 66% bilateral), 5 children (9%) have been diagnosed as having diskintetic CP, 4 children (8%) have been diagnosed as having spastic and diskintetic CP, and 1 child (2%) has been diagnosed as having a combination of diskintetic and atactic CP.<sup>1</sup> 10 children (21%) are classified at level 1 of the Gross Motor Function Classification Scale (GMFCS; Palisano et al., 2000), 17 children (35%) at level 2, 6 children (12%) at level 3, 8 children (17%) at level 4, and 7 children (15%) at level 5.<sup>2</sup> The parents of each child provided written informed consent for their child's participation.

<sup>1</sup>The schools were not able to provide information on the type of CP for 4 children.

<sup>2</sup>The schools were not able to provide the GMFCS level classifications of 8 children.

**Table 1** Descriptive Statistics of the Included Variables.

	N	Mean (SD)	Minimum	Maximum
Early numeracy	52	16.8 (8.4)	2	39
Non-verbal intelligence	50	14.2 (4.3)	3	28
Verbal working memory	46	15.9 (5.5)	3	29
Visuospatial working memory	51	3.1 (1.9)	0	10
Updating	45	2.6 (3.7)	0	18
Sentence understanding	51	29.1 (6.8)	12	41
Fine motor skills	55	27.2 (17.5)	0	75
Counting (% correct)	42	79.9 (14.0)	53	100

All primary schools for special education in the Netherlands which specialize in educating children with motor disabilities were asked to participate. Children were included based on a formal diagnosis of CP (Rosenbaum et al., 2007) and a date of birth between August 2004 and February 2006. All children were tested individually in a quiet room at their school during the spring of 2011. Some data is missing because children were not able to perform the task (see Table 1).

## Instruments

**Early Numeracy Performance.** The Early Numeracy Test Revised (ENT-R) is a standardized Dutch test for assessing the early numeracy performance of children between 4 and 9 years of age (Van Luit, Van de Rijt, & Pennings, 1994). The ENT-R consists of two parts. The first part is dedicated to Piagetian concepts. Subtests aim to measure concepts of comparison, classification, one-to-one correspondence, and seriation. The second part focuses on counting skills, that is, subtasks assess the use of counting words, structured counting, resultative counting, general understanding of numbers and estimation. In the estimation task children had to locate a given number (e.g., 2) on a horizontal line where both ends were labeled (e.g., 1–10). The test consists of 45 items. If an item is answered correctly then the child receives one point. The total score of all items represents the early numeracy performance.

**Working Memory.** The verbal working memory of the children was assessed with the word recall subtest of the Dutch version of the Automated Working Memory Assessment (AWMA; Alloway, 2007). Children were asked to repeat a sequence of words that they heard. The first sequence consisted of two words and the number of words was increased by one each time. If more than two sequences of the same length were repeated incorrectly, the test was terminated. The total amount of correctly repeated sequences was used as an indication of word recall performance.

The Corsi block-tapping task was administered to measure the visuospatial working memory span (Corsi, 1972). Nine small blocks were mounted on a horizontal board and the child was asked to repeat the sequence of blocks tapped by the experimenter. The sequences of tapping were based on the validation study of Kessels, van Zandvoort, Postma, Kappelle, & de Haan (2000). The sequence of the blocks increased in difficulty

by one and the task was ended when two sequences of the same length were repeated incorrectly. We used the total amount of correctly tapped sequences to create a total score.

Updating capacities were assessed with the backwards digit recall of the AMWA (Alloway, 2007). A sequence of digits was presented and the child was asked to repeat the digits in a backward order. The task started with a sequence of two digits which increased in difficulty by one. The task was terminated when the child repeated two items of a sequence incorrectly. The total number of correctly repeated items was included in the analyses.

**Non-Verbal Intelligence.** Raven's Coloured Progressive Matrices (CPM) were used to assess non-verbal intelligence (Raven, 1965). Every item consists of a visual design in which a piece is missing. The child must choose a piece from 6 possible pieces to complete the design. The total score consists of the amount of items (0–36) answered correctly.

**Sentence Understanding.** The sentence understanding task of the standardized Dutch Language Proficiency Test for children was administered to assess the knowledge of function words (Verhoeven & Vermeer, 2001). Three pictures were presented to the child upon which he or she had to decide which picture best matched the sentence that was read to them. For instance, pictures of a cat sitting in front of, behind, and in a basket were shown and the question was: "Which cat is sitting in the basket?" The test consists of 42 items and the total amount of correctly answered items was used in the analyses.

**Counting.** A dot counting task was developed to measure counting using the Presentation software (2004). Different numbers of dots were presented in a random or canonical order on a laptop computer screen. The number of dots varied from one to six. Each number was presented 10 times, yielding a total of 60 items. The dots were visible until the child gave a verbal response. The percentage of correctly answered items was used in the statistical analyses.

**Fine Motor Skills.** The Box & Block task is an instrument to assess gross dexterity (Mathiowetz, Volland, Kashman, & Weber, 1985). The task is made up of a box which is divided into two equal halves by a partition. The children were asked to shift as many blocks as possible to the other side of the box in 1 minute. The children performed the task with both hands separately and the combined score was used in the analyses.

### Statistical Analyses

First, confirmatory factor analyses were conducted on the ENT-R to validate the numeracy construct for children with CP. Second, path analyses to test the relations between the investigated factors and early numeracy performance were performed. The results of the Corsi block-tapping task, verbal recall task and backward digit recall were combined to create a latent working memory factor. All structural equation models were tested using AMOS 20 (Arbuckle, 2012).

The fit indices  $\chi^2$ , 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 ( $p > .05$ ). An RMSEA value smaller than .08 and CFI and TLI values higher than .90 indicate a sufficiently good fit. To compare the different models, the difference in chi-square can be evaluated for nested models. If the model becomes more parsimonious, the change in chi-square should be non-significant. In addition, the Akaike Information Criterion (AIC) is a comparative fit index to contrast the fit of all types of model. The lower the value of this statistic, the better the fit of the model (Kline, 2005).

## RESULTS

### Descriptive Statistics

All variables were positively related to each other (Table 2). Only the correlation between verbal working memory and visuospatial working memory, and the correlation between verbal working memory and fine motor skills, were not significant. Early numeracy performance and counting in particular correlated highly ( $r = .74, p < .001$ ).

### Main Analyses

In the first model, working memory, non-verbal intelligence, sentence understanding, counting and fine motor skills were included as precursors of early numeracy performance (Figure 1). The fit indices of the first model indicated that the model fitted the data well ( $\chi^2 = 7.76, p > .05$ ). The comparative fit indices also indicated that the model fitted the data well (TLI = 1.00, CFI = 1.00). Finally, the RMSEA value also indicated a good fit (RMSEA = .00). In the next step of the analyses, the non-significant relations were removed from the model, if this did not lead to a significant increase of the chi-square index (see Table 3 for the fit indices of the tested models). Respectively, sentence understanding (model 2), non-verbal intelligence (model 3) and counting (model 4) were removed. Only working memory and fine motor skills were significant

**Table 2** Correlations between the Observed Variables.

	Early numeracy	Verbal WM	Visuo-spatial WM	Updating	Non-verbal intelligence	Sentence understanding	Counting
Verbal WM	.40**						
Visuospatial WM	.45**	.23					
Updating	.63**	.39**	.43**				
Non-verbal intelligence	.59**	.31*	.38**	.52**			
Sentence understanding	.62**	.49**	.42**	.48**	.65**		
Counting	.74**	.32*	.44**	.55**	.43**	.42**	
Fine motor skills	.69**	.14	.36*	.35**	.38**	.45**	.44**

Notes. \* $p < .05$ , \*\* $p < .01$ . Missing values were excluded pairwise.

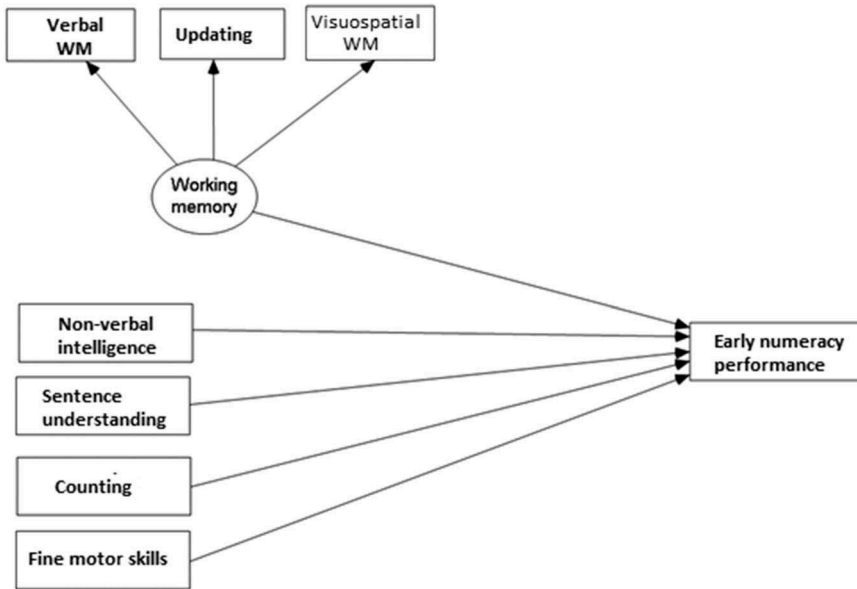


Figure 1 Theoretical model displaying possible precursors of early numeracy performance.

Table 3 Fit Indices for the Various Models.

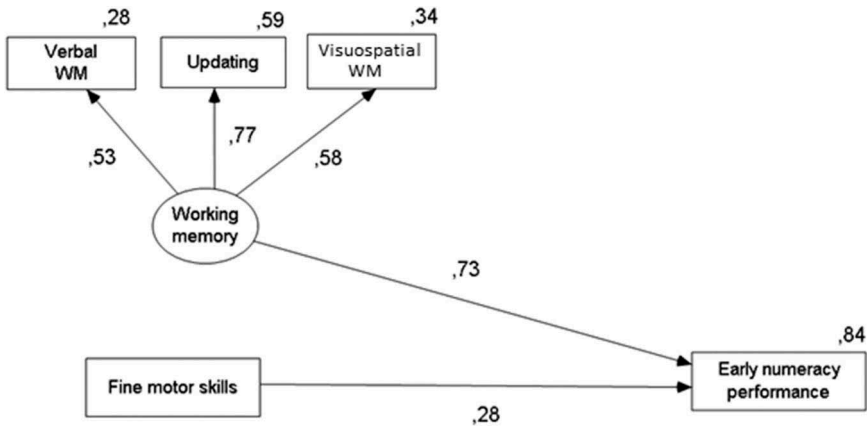
Models	$\chi^2$	df	$\Delta\chi^2$	p	TLI	CFI	RMSEA	AIC
Model 1: Theoretical model	7.76	10			1.00	1.00	.00	75.76
Model 2: Sentence understanding removed	8.11	11	0.34	.56	1.00	1.00	.00	74.11
Model 3: Non-verbal intelligence removed	8.16	12	0.05	.82	1.00	1.00	.00	72.16
Model 4: Counting removed	9.94	13	1.79	.54	1.00	1.00	.00	71.94
Model 5: Counting as mediator	11.60	8			.89	.96	.09	49.59

Note.  $\Delta\chi^2$  = difference in chi-square compared to the previous model; TLI = Tucker-Lewis Index; CFI = Comparative fit index; RMSEA = Root Mean Square Error of Approximation; AIC = Akaike information criterion.

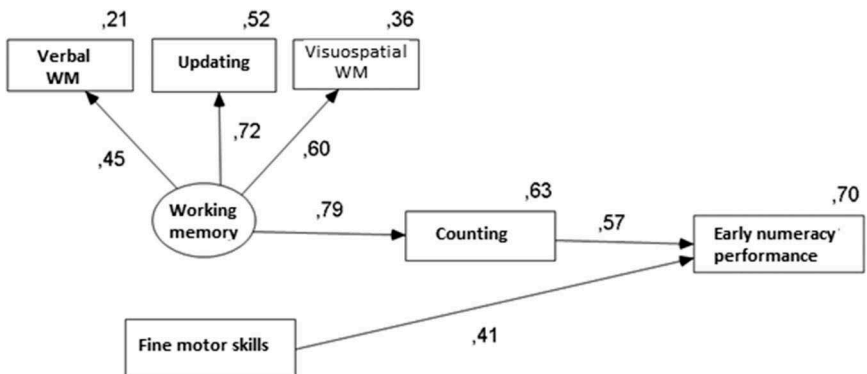
factors in this model (Figure 2). Specifically, the latent factor working memory related most strongly to early numeracy performance in the children ( $\beta = .73, p < .001$ ). However, fine motor skills were also positively and significantly related to early numeracy ( $\beta = .28, p = .01$ ).

Based on the theory as well as the substantial correlation between counting and early numeracy, counting was added as a mediating variable between working memory and early numeracy performance (Figure 3). The fit indices indicated that the model still fitted the data sufficiently. The  $\chi^2$  had a non-significant value ( $\chi^2 = 11.60, p > .05$ ). The comparative fit indices were sufficient (TLI = .89, CFI = .96). Moreover, the AIC index had the lowest value (AIC = 45.59). However, the RMSEA was above the preferred value of .08 (RMSEA = .09). In this model, 70% of the variance in early numeracy performance was explained by the predictors in the model. Fine motor skills were still positively related to the early numeracy





**Figure 2** Working memory and fine motor skills are significantly related to early numeracy performance (the numbers above or next to the arrows are standardized regression coefficients and the numbers above the variables represent the explained variance by the model).



**Figure 3** Final model: counting is added as a mediating variable between working memory and early numeracy performance (the numbers above or next to the arrows are standardized regression coefficients and the numbers above the variables represent the explained variance by the model).

performance in 6-year-old children with CP ( $\beta = .41, p < .001$ ). This implies that the better children perform in a manual dexterity task, the higher they will score in the early numeracy task. Moreover, working memory was positively and significantly related to counting ( $\beta = .79, p < .001$ ). Counting, on the other hand, was significantly related to early numeracy performance ( $\beta = .57, p < .001$ ). Thus, high performance in the working memory measures is related to high performance in counting, which in turn is positively associated with early numeracy performance.

## DISCUSSION

To our knowledge, the present study is the first to integrate various factors which have previously been shown to affect early numeracy in typically developing children and

apply this to children with CP. We examined whether working memory, non-verbal intelligence, linguistic skills, counting and fine motor skills were related to the early numeracy performance of 6-year-old children with CP. Working memory and fine motor skills were positively and significantly related to early numeracy performance in these children. In addition, basic counting skills were a mediating variable between working memory and early numeracy performance. In the following paragraphs, we will discuss our findings in the light of previous studies on the cognitive performance of children with CP. If comparison with existing studies is not possible, we will refer to research on typically developing children.

The eminent role of working memory on early numeracy performance corresponds to the outcomes of earlier studies on the relation between working memory and arithmetic performance in children with CP (Jenks et al., 2007). Children with CP have repeatedly been shown to have difficulties with working memory (Bottcher, Flachs, & Uldall, 2010). Toll and Van Luit (2013) found that remedial education could accelerate the numeracy performance of children with limited working memory skills. Consequently, children with CP might benefit from this type of intervention.

Our finding of the positive relation between fine motor skills and early numeracy performance is fully commensurate with a previous study, in which we found that fine motor skills were related to the ability to solve addition and subtraction tasks in primary school children with CP (van Rooijen et al., 2012). In typically developing children, gesturing was shown to help children to count correctly by keeping track of and coordinating the counted items and their verbal representations (Alibali & DiRusso, 1999). Finally, our results showed that counting mediated the relation between working memory and early numeracy, which supports the hierarchical development of arithmetic (Butterworth, 2005). This is further corroborated by the finding that counting is not a significant predictor of early numeracy by itself, but that it does mediate the relation between working memory and early numeracy performance.

In our study, non-verbal intelligence was not statistically significantly related to the early numeracy performance of children with CP, which is in contrast to previous research on the arithmetic performance of children with CP (Jenks et al., 2007). A possible explanation for the non-significant relation between non-verbal intelligence and early numeracy could be the differences in the assessment and construction of non-verbal intelligence and working memory. Working memory was constructed as a latent factor consisting of verbal, visuospatial and updating skills, and was as such measured more comprehensively than non-verbal intelligence, which was assessed with Raven's CPM. Moreover, working memory and intelligence are theoretically closely related because they both entail executive attention (Engle, 2002). Consequently, working memory could have suppressed the influence of non-verbal intelligence on numeracy performance in the current model.

The non-significant relation of linguistic skills with early numeracy performance also contradicts previous studies in typically developing children (Purpura et al., 2011). This could be explained by the relatively small sample size for this type of analysis (Kline, 2005). An alternative explanation is that children with CP show a delay in linguistic skills, such as word decoding, compared to typically developing children (Peeters, Verhoeven, De Moor, & Van Balkom, 2009). However, they may have the language skills required for performing the currently used early numeracy task. As a result, other factors might be more strongly related to numeracy performance compared to linguistic skills.

Fine motor skills and early numeracy skills were found to be significantly related, but the results should be interpreted with caution considering that all variables were measured at the same time. Children with CP who have more severe motor difficulties also have more cognitive problems (Smits et al., 2011). It may well be that the manual restrictions of these children prevent them from obtaining relevant learning opportunities (Campos et al., 2000). Therefore, this interrelation between cognitive and motor activities warrants further study.

An important theoretical issue to be considered is whether children with CP are impaired or delayed in the development of numeracy performance. Children with CP often show additional cognitive impairments, which could result in different developmental trajectories compared to their peers. Jenks et al. (2007) propose that early brain impairments influence cognitive factors such as intelligence and working memory, which in turn influence arithmetic accuracy. Based on our cross-sectional study, we cannot draw definite conclusions on the impaired versus delayed development issue, but our data pattern suggests that children with CP follow a developmental trajectory similar to that of typically developing children. Future research is warranted on this issue as it informs the feasibility and content of remediation programs for these children. That is, if they merely lag behind their peers, training of basic numeracy skills is a promising and feasible course of action. However, if the accompanying cognitive disturbances lead to a different developmental trajectory in terms of numeracy performance then remediation programs developed for typically developing children might be less effective.

Children with CP generally lag behind their peers in the development of numeracy and arithmetic (van Rooijen et al., 2011). The difficulty that children with CP encounter with subitizing has been attributed to impairments in visuospatial skills which defer their perception and memorization of spatial shapes (Arp & Fagard, 2005). More recently, visual disabilities, and especially cerebral visual impairment (CVI), have been regarded as a core symptom of CP. Around 60 to 70% of people with CP are estimated to have some form of CVI, presumably because the same cerebral networks are involved (Fazzi et al., 2012). Possible compromised visual functioning was not explicitly tested in the present study. However, as this may indirectly affect cognitive development, and has a direct impact on the performance of cognitive measures and scholastic performance, it is suggested that future studies incorporate this into their assessments. Furthermore, a limitation of the present study is the lack of information on the etiology of the diagnosis of the participants and the relation with neuropsychological functioning. The increasing use of neuroimaging data could provide us with a more detailed understanding of the etiology and pathogenesis of the disorder (Korzeniewski, Birbeck, DeLano, Potchen, & Paneth, 2008). That is, abnormalities in neuroanatomical findings have been reported in approximately 80 to 90% of children with CP. By the same token, the effects of the type of CP, gross motor functioning and affected body side are factors that warrant more detailed study in order to develop tailored intervention programs.

Taken together, our findings highlight the importance of working memory for the early numeracy performance of children with CP. Including several cognitive factors related to the early numeracy performance of typically developing children, working memory was by far the most determining factor. Interestingly, fine motor skills were also influential. Although cognitive and motor development is obviously interrelated in children with CP, manual dexterity could still explain a part of the

variance in early numeracy performance. Finally, basic numeracy skill, such as counting, might function as a prerequisite for the development of more complex numeracy performance.

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