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The Effect of Cerebral Palsy on Arithmetic Accuracy is Mediated by Working Memory, Intelligence, Early Numeracy, and Instruction Time

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The development of addition and subtraction accuracy was assessed in first graders with cerebral palsy (CP) in both mainstream (16) and special education (41) and a control group of first graders in mainstream education (16). The control group out-performed the CP groups in addition and subtraction accuracy and this difference

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could not be fully explained by differences in intelligence. Both CP groups showed evidence of working memory deficits. The three groups exhibited different developmental patterns in the area of early numeracy skills. Children with CP in special education were found to receive less arithmetic instruction and instruction time was positively related to arithmetic accuracy. Structural equation modeling revealed that the effect of CP on arithmetic accuracy is mediated by intelligence, working memory, early numeracy, and instruction time.

The term cerebral palsy (CP) describes a group of disorders that are attributed to a non-progressive injury in the developing fetal or infant brain that affect the development of movement and posture, and cause activity limitation (Bax et al., 2005). The motor disturbances of CP are often accompanied by additional impairments that include seizure disorders and/or disturbances of sensation, perception, communication, behavior, and cognitive functioning (e.g., Ashwal et al., 2004; Bax et al., 2005; Evans, Elliot, Alberman, & Evans, 1985).

LEARNING DIFFICULTIES IN CHILDREN WITH CP

As a result of these additional impairments, children with CP also have an increased risk of learning difficulties. However, a review of the literature reveals that there have been few studies that have addressed this issue and those studies have used a variety of inclusion criteria and a variety of methods, making direct comparisons between studies difficult. Anderson (1973) investigated the school achievement of children with a physical disability associated with neurological damage (including CP and spina bifida) attending mainstream schools. Teachers rated 78% of these children as having mild to profound difficulties in arithmetic, whereas 69% were rated as having reading difficulties. Frampton, Yude, and Goodman (1998) investigated the prevalence of learning difficulties in children with hemiplegic CP with an IQ of 70 or higher attending both special and mainstream schools. A child was considered to have a specific learning difficulty if the discrepancies between their predicted ability and actual achievement placed them in the most extreme 5% of the normal population. These authors found that 36% of these children had at least one specific learning difficulty, with 25% having difficulty in arithmetic, as opposed to 19% having reading difficulties. In a more recent study, occupational therapists and special education teachers examined the educational records of children with CP (including hemiplegia, diplegia, and tetraplegia) attending mainstream schools and concluded that 46% had at least one specific learning difficulty (Schenker, Coster, & Parush, 2005). Arithmetic learning difficulties seem to be somewhat more prevalent in children with CP. Such arithmetic learning difficulties may be attributable to specific neuro-cognitive impairments resulting from the early brain damage inherent to CP. On the other hand, difficulties in arithmetic might also

be attributable to environmental factors such as the amount of arithmetic instruction time the children receive. These two potential causes are not mutually exclusive. Therefore, the question becomes, to what extent do neuro-cognitive and environmental factors influence the development of arithmetic ability in children with CP?

NEURO-COGNITIVE FACTORS RELATED TO THE DEVELOPMENT OF ARITHMETIC ABILITY

What do we know of the specific neuro-cognitive factors in children with CP that could be related to the development of arithmetic ability? A review of the literature again reveals relatively few studies using a variety of inclusion criteria and methods. Carlsson et al. (1994) investigated the cognitive ability of children with slight or moderate hemiplegia and children without CP, all with normal intelligence attending mainstream schools. These authors found that although children with CP did not differ from controls on WISC verbal IQ, they scored significantly lower on WISC performance IQ. Also, children with CP scored lower than controls on a test of visual perception, visual memory, and visuoconstructive abilities. In a later study, Carlsson (1997) compared delayed recall for words and drawings in the same children. Children with left hemiplegic CP were found to have impaired ability to recall drawings, which, the author argued, was caused by a specific deficit of visual-spatial working memory. Sabbadini, Bonanni, Carlesimo, and Caltagirone (2001) investigated the cognitive functioning of children with severe CP and found that, although their scores were comparable to those of control children in the verbal domain, as measured by the Peabody Picture Vocabulary Test, their performance on visual-spatial and visual memory tasks were lower than the control group.

POTENTIAL PRECURSORS OF ARITHMETIC DIFFICULTIES

Many authors investigating arithmetic problems in other populations have cited a direct relationship between arithmetic and working memory on one side (e.g., Adams & Hitch, 1997; Dark & Benbow, 1990) and the development of early numeracy (e.g., Geary, Hamson, & Hoard, 2000) on the other. Working memory has been shown to be related to arithmetic fact fluency (e.g., $2 + 3 = 5$) by allowing the association of the problem with the answer so that long term memory associations can be formed (Geary, 1993). Since previous research, as reported above, indicates that some children with CP have deficits in working memory, it may be that deficits in arithmetic ability in children with CP are related to working memory deficits. The most widely accepted model of working memory is that of Baddeley and Hitch

(1974). These authors described working memory as being comprised of three components: the phonological loop, for the temporary storage of phonological information; the visual-spatial sketch pad (VSSP), for the temporary storage of visual-spatial information; and the central executive, a modality-free supervisory system responsible for a range of regulatory functions including control of both the phonological loop and the VSSP and the incorporation of information from long term memory.

EARLY NUMERACY

Throughout the preschool years children develop early numeracy skills that are precursors to the acquisition of formal mathematical skill (Baroody, 1987; Geary, 1994; Ginsburg, 1977; Van de Rijt, 1996). Early numerical skills include number concept and simple counting skills. Number concept refers to relational concepts such as more, less, and the ability to arrange objects according to size. Difficulties with arithmetic experienced by school-age children could be related to their level of understanding of number concept and simple counting skills.

ARITHMETIC INSTRUCTION TIME

Arithmetic difficulties might also be attributable to environmental mediators. For example, some authors have identified a relationship between mathematical ability and the amount of arithmetic instruction time. Jenks, Van Lieshout, and de Moor (2007) investigated mathematical ability in a combined group of children with CP and children with spina bifida. These authors compared the level of arithmetic ability of these children in special education to a control group of healthy children in mainstream education. The children in special education had a lower level of mathematical ability in comparison to those in mainstream education and this difference was explained in large part by the amount of instruction time spent on mathematics.

THE CURRENT STUDY

To date, no comprehensive studies investigating the development of mathematical ability in children with CP have been reported. The current study represents the first year of a three-year nation-wide longitudinal study into the development of mathematical ability in children with CP in the Netherlands. A longitudinal design was chosen in order to adequately monitor the development of mathematical ability and the potentially changing patterns of neuro-cognitive and environmental factors that may influence its development. The purpose of this first year of the

study was to examine the contributions of verbal and non-verbal intelligence, working memory, early numeracy, and arithmetic instruction time to the development of arithmetic ability in children with CP. First graders with CP in both special and mainstream education were compared to a control group of first graders without CP in mainstream education. We expected the arithmetic ability of children with CP to lag behind that of their peers without CP, even after controlling for the effects of verbal and non-verbal intelligence. We further expected the effect of CP on arithmetic ability to be mediated by differences in verbal and nonverbal intelligence, working memory, early numeracy, and arithmetic instruction time.

Because of the motor impairments inherent to CP, the future independence of children with CP depends in large part on their ability to perform non-physical tasks. The potential impact of learning difficulties in these children seems therefore greater than in many other populations. With an eye toward developing appropriate interventions designed to treat arithmetic learning difficulties in children with CP, the general purpose of the current study was to gauge the contribution of verbal and non-verbal intelligence, working memory, early numeracy, and instruction time on arithmetic development.

METHOD

Participants

Thirty-two of the 33 special schools for children with motor problems in the Netherlands agreed to participate in this study. These schools also provide educational support services to mainstream schools that have pupils with motor problems. School representatives were asked to obtain written informed consent from the parents of any of their students in special or mainstream education who were about to enter first grade, had a diagnosis of CP and a verbal IQ of at least 70. This resulted in 41 children with CP in special education (CP-special) and 16 children with CP in mainstream education (CP-mainstream). A classmate for each CP-mainstream child, matched on age and gender, was chosen to serve as a control. The CP-special group was composed of 28 boys and 13 girls with an average age of 7.0 years. There were 9 boys and 7 girls in both the CP-mainstream as the control group with an average age of 7.0 and 6.9 years, respectively. The groups did not differ significantly on age. The CP-special and CP-mainstream groups did not differ significantly on mean gestational age (33 and 35 weeks respectively; $p = .46$) or birth weight (1891 and 2233 grams, respectively; $p = .27$). However, the groups did differ significantly on verbal IQ, as measured by the Peabody Picture Vocabulary Test-Revised (PPVT-R; Dunn & Dunn, 1981), $F(2, 70) = 4.1$, $p = .020$, $\eta_p^2 = .11$. The mean verbal IQ of the CP-special, CP-mainstream and control groups were 88.9, 93.0, and 101.3, respectively. CP-special scored significantly lower on verbal

IQ than the control group (p = .005) but the two CP groups did not differ (p = .35). The groups also differed significantly on non-verbal IQ, as measured by Raven's Colored Progressive Matrices (RCPM; Raven, 1965), $F(2, 70) = 18.7, p < .001, \eta_p^2 = .35$. The mean RCPM of the CP-special, CP-mainstream, and control groups were 3.1, 4.8 and 6.5, respectively. All pairwise comparisons of non-verbal IQ were significant ($ps < .05$).

CP is often categorized by the type of motor impairment (see Cans, 2000 for a description of the types of CP). The CP-special group was composed of ten children with unilateral CP (four right, six left), twenty-nine children with bilateral CP and two children with ataxic CP. The CP-mainstream group was composed of twelve children with unilateral CP (eight right, four left), three children with bilateral CP, and one child with ataxic CP.

Procedure

Tests were administered in three sessions: in the beginning, middle, and end of first grade. Children were assessed individually in a quiet room in their own school. Each session took a maximum of two hours, including breaks. The same test battery was administered to all children.

The PPVT-R and RCPM were used to measure verbal and non-verbal intelligence, respectively. Digit Recall and Backward Digits (Pickering & Gathercole, 2001) were used to assess the phonological loop and the central executive of working memory, respectively. To control for the possibility that the phonological loop could be selectively impaired for digits or words, the phonological loop was also assessed with Word Recall (Pickering & Gathercole, 2001). Knox Blocks, a subtest of the Snijders-Oomen Non-Verbal Intelligence Test (1970), was chosen to measure the VSSP of working memory. Because the stimulus material consists of a single row of blocks, rather than the more commonly used matrix of blocks (e.g., Corsi Blocks), this test is more appropriate for participants who have limited hand/arm function. Early numeracy skills were assessed with the Early Numeracy Test (Torbeyns, 2002; Van Luit, Van de Rijt, & Pennings, 1994). Arithmetic skill was assessed with an addition test and a subtraction test. Teachers registered the number of minutes of arithmetic instruction time per child per day in a typical school week. Longitudinal measurements were made of the Early Numeracy Test, administered in all three sessions, and the arithmetic tests, administered in both the second and third sessions.

Materials

Intelligence.   The PPVT-R consists of 150 words of increasing difficulty. In each trial, a word is presented verbally and four images are presented, one of which corresponds to the meaning of the word. The task of the participant is to choose the

image that matches the verbally presented word. The RCPM consists of visual patterns presented in increasing difficulty. In each trial, a single pattern with a missing piece is presented and the task of the participant is to choose the correct one of six pieces that will complete the design.

Working memory.   Each trial of Digit Recall consists of a spoken sequence of digits and the task of the participant is to repeat the digits in the presented order (see Gathercole, Pickering, Ambridge, and Wearing, 2004 for a complete description). This test consists of 30 trials that increase in length from two to six digits. The score is equal to the total of correctly answered trials and ranges from 0–30. Backward Digits is the same as Digit Recall except that the task of the participant is to repeat the sequence of digits in reverse order. Word Recall differs from Digit Recall only in that words are presented instead of digits. Dutch stimulus material was created consisting of three-letter monosyllabic words of the form consonant-vowel-consonant. In the Knox Blocks test, a row of four unmarked wooden blocks are placed in a straight line in easy reach of the child. In each trial, the tester taps a given number of blocks in a predetermined order. The task of the participant is to tap those same blocks in the same order. The test consists of five sets of trials, with each set consisting of four trials of a given length (i.e., number of taps). In each trial of the first set, the tester taps two blocks (e.g., 3rd, 1st). If three trials of a given length are performed correctly, the child progresses to the following set. In each progressive set of trials the length of the trials increases by one tap, to a maximum length of six taps (e.g., 1st, 4th, 2nd, 1st, 3rd, and 4th). The total score is equal to the total number of correctly performed trials and ranges from 0–15.

Early numeracy skills.   Early numeracy skills were assessed with the Early Numeracy Test (ENT: Torbeyns et al., 2002; Van Luit, et al., 1994). The ENT consists of two parallel forms: ENT A, which was administered in the beginning and end of first grade and ENT B, which was administered in the middle of the school year. Each form is composed of eight subscales that can be seen as two main components (Aunio, Hautamäki, Heiskari, & van Luit, 2006). The subscales Comparison, Classification, One-to-one Correspondence, and Seriation form the number concept component whereas the subscales Use of Number Words, Structured Counting, Resultative Counting, and General Understanding of Numbers form the counting component. Each subscale consists of five items, resulting in a total of 20 items per component. Comparison focuses on the child's ability to compare objects with regard to quantitative or qualitative properties. In contrast, Classification tests the ability to group objects on the basis of one or more criteria. One-to-one Correspondence measures the child's ability to compare numbers of simultaneously presented objects. Seriation measures the child's ability to order objects. Use of Number Words tests the following counting skills: producing the number words, counting on (i.e., counting, beginning with a number other than 1), and

using cardinal and ordinal numbers. Structured Counting tests the child's ability to use "point counting" (i.e., pointing to the individual items in a set, counting each object exactly once) and "skip counting" (i.e., counting every nth number in a series of numbers). Resultative Counting measures whether the child understands and can apply cardinality accurately. In the subtest General Understanding of Numbers, numeracy is put into use in real life situations, represented in drawings. The score was the number of correctly answered items on each of the two components, number concept and counting (range: 0 to 20 per component).

Arithmetic instruction time.   Each participant's teacher registered the amount of arithmetic instruction time per child. A typical school week (without holidays or other unusual events) was chosen in advance. Teachers registered the number of minutes that were actually spent each day on arithmetic by that child per day in the chosen week. The total score was the total number of minutes spent on arithmetic in one week.

Addition and subtraction tests.   An addition and a subtraction test, both administered in the middle and end of first grade, were made to assess arithmetic accuracy. These tests differed only in the type of problem presented. The addition test consisted of problems in the form of $a + b$, in which "a" and "b" are not equal, both "a" and "b" are larger than 1 and the sum of "a" and "b" does not exceed 10. The subtraction test consisted of problems in the form of $a - b$, in which $3 < a < 11$ and $1 < b < 8$. In both tests, the arithmetic problems were presented one at a time on a computer monitor and remained visible until the child gave a verbal answer. Each test consisted of 28 trials.

Statistical Analyses

Analyses of variance were performed to test the direct effect of CP on arithmetic accuracy, early numeracy, and working memory. Only significant ($p < .05$) and marginally significant ($.05 < p < .1$) main effects will be reported with statistics. Relevant means (M) and standard errors (SE) are reported in the text. Posthoc differences were considered significantly different only when appropriate tests revealed p-values $< .05$. The relationships between each of the independent variables and arithmetic accuracy were tested with correlations.

Structural equation modeling (SEM) was performed, using AMOS 5.0 (Arbuckle & Wothke, 1999), to answer the question of whether the effect of CP on arithmetic accuracy is mediated by intelligence, working memory, early numeracy, and instruction time. Structural equation modeling provides not only the overall fit of the model to be tested, but also the statistical significance of the size of each relationship within the model (Arbuckle & Wothke, 1999). All variables had kurtosis and skewness of < 1.0, suggesting appropriate distributions for

structural equation modeling. Missing data were replaced using the nearest neighbor technique, but there was very little missing data per variable (0 to 4.1% for individual variables).

The starting point was a hypothesized model that assumes that the effect of CP on arithmetic accuracy if fully mediated by intelligence, working memory, early numeracy, and instruction time. The qualitative variable group was transformed into two quantitative dummy variables: CP-special (CP-special = 1, CP-mainstream = 0, control = 0), and control (control = 1, CP-special = 0, CP-mainstream = 0). A path originating from CP-special, therefore, can be interpreted as the effect of CP-special in comparison to both CP-mainstream and control, whereas a path from control can be interpreted as the effect of control in comparison to both CP-special and CP-mainstream. Intelligence was defined by PPVT-R and RCPM as measures of verbal and non-verbal IQ, respectively. Working memory was defined by Digit Recall, Backward Digits, and Knox Blocks, as measures of the central executive and VSSP of working memory, respectively. Because Word Recall and Digit Recall were found to be highly correlated ($r = .73$, $p < .001$, $N = 73$), only Digit Recall was included in the model. Early numeracy was defined by number concept and counting. Instruction time was defined by the teacher report. Arithmetic accuracy was defined by average percent correct for both addition and subtraction. The observed variables, rather than latent constructs, were included in the model. Full mediation was assumed at each step in the hypothesized model. The cognitive variables (i.e., intelligence and working memory) were allowed to correlate with each other and were assumed to be influenced only by CP (i.e., CP-special and control). The early numeracy variables (number concept and counting) were allowed to correlate with each other and were assumed to be directly influenced only the cognitive variables (i.e., the effect of CP on early numeracy is modeled as being fully mediated by the cognitive variables). Instruction time was assumed to be influenced only by the CP variables. The arithmetic variables (addition and subtraction accuracy) were allowed to correlate with each other and were assumed to be directly influenced only by the early numeracy variables (i.e., the effect of CP on arithmetic accuracy is modeled as being fully mediated by the cognitive variables, early numeracy, and instruction time).

Structural equation modeling was used to determine the best model to fit the observed patterns of mediation in the data. Following Hu and Bentler (1999) and Jaccard and Wan (1996), a model fits reasonably well if the chi-square value does not exceed a limited multiple (3) of its degrees of freedom; if GFI, AGFI, and NFI are large (greater then .90; range = 0–1) and RMSEA is small (less than .08). Individual paths were evaluated for significance and independent variables that had no significant path to following variables were eliminated from subsequent models. A given path was only eliminated from subsequent models if the elimination of that path improved the fit of the model. When correlations were found between one variable and the unexplained variance of another variable, a path between these

variables was added. That new path was only included in the subsequent models if the inclusion of the path improved the fit of the model.

RESULTS

Correlations

Similar patterns of correlations were observed between the potentially mediating variables and both addition and subtraction accuracy (Table 1). Significant positive correlations were found between addition and subtraction accuracy on one hand and verbal and non-verbal IQ (PPVT-R and RCPM, respectively), the VSSP (Knox Blocks) and the central executive (Backward Digits). Neither tests of the phonological loop (Digit Recall and Word Recall) correlate with either measure of arithmetic accuracy.

Arithmetic Accuracy

Because a repeated measures ANOVA on addition and subtraction accuracy revealed no effect of time and no time × group interaction, average addition accuracy and subtraction accuracy (percent correct averaged over the middle and end of first grade measurements) were used in all further analyses. CP-special had the lowest average addition accuracy ($M = 54\%$, $SE = 3.7$), followed by CP-mainstream ($M = 85\%$, $SE = 5.9$) and the control group ($M = 94\%$, $SE = 5.9$). CP-special also had the lowest average subtraction accuracy ($M = 33\%$, $SE = 4.0$), followed by CP-mainstream ($M = 76\%$, $SE = 6.4$) and the control group ($M = 90\%$, $SE = 6.4$). To test the direct relationship between CP and arithmetic accuracy, a MANOVA was performed with addition and subtraction accuracy as dependent variables and group (CP-special, CP-mainstream, control) as between-subjects factor. There was a significant effect of group on both addition and subtraction accuracy, $F(2, 70) = 21.4$, $p < .001$, $\eta_p^2 = .38$; $F(2, 70) = 35.7$, $p < .001$, $\eta_p^2 = .51$, respectively. CP-special scored significantly below both CP-mainstream ($p < .001$) and control ($p < .001$) whereas the latter two groups did not differ from each other. Pairwise comparisons for subtraction revealed the same pattern of results. Because the groups were found to differ on IQ, in order to test whether the observed differences in arithmetic accuracy could be attributed to verbal and non-verbal intelligence alone, this analysis was repeated with verbal IQ (PPVT-R) and non-verbal IQ (RCPM) as covariates. The effect of group on addition and subtraction accuracy remained significant after controlling for the effects of intelligence, $F(2, 68) = 6.9$, $p = .002$, $\eta_p^2 = .17$; $F(2, 68) = 15.8$, $p < .001$, $\eta_p^2 = .32$, respectively.

TABLE 1
Mean and Standard Errors for and Correlations Between All Quantitative Dependent and Independent Variables

| | Mean (SE) | | | Control | | | | | | | | | |
	CP-S	CP-M	Control	1	2	3	4	5	6	7	8	9	10
1. Addition Accuracy	54 (4.5)	88 (4.4)	94 (1.5)										
2. Subtraction Accuracy	33(4.8)	76 (5.5)	90 (1.8)	.854**									
3. PPVT-R	90 (2.3)	93 (4.1)	101 (3.2)	.390**	.293*								
4. RCPM	3.1 (0.3)	5 (5.6)	7 (4.4)	.619**	.583**	.386**							
5. Digit Recall	17 (0.7)	16 (7.8)	19 (1.0)	.170	.152	.408**	.217						
6. Word Recall	12 (0.5)	12 (6.0)	14 (0.7)	.130	.133	.395**	.118	.731**					
7. Backward Digits	5 (0.6)	7 (4.4)	9 (0.7)	.648**	.539**	.329**	.533**	.315**	.293*				
8. Knox Blocks	7 (0.3)	9 (0.4)	10 (0.6)	.482**	.483**	.320**	.439**	.141	.072	.466**			
9. Number Concept	14 (0.5)	16 (0.8)	18 (0.4)	.660**	.545**	.465**	.508**	.165	.157	.503**	.407**		
10. Counting	11 (0.6)	15 (0.6)	17 (6.6)	.791**	.698**	.411**	.623**	.299*	.314**	.628**	.525**	.590**	
11. Instruction Time	148 (8.3)	234 (9.4)	252 (6.8)	.449**	.446**	.223	.464**	.097	.022	.496**	.354**	.328**	.361**

Note. CP-S = children with cerebral palsy (CP) in special education; CP-M = children with CP in mainstream education; PPVT-R = Peabody Picture Vocabulary Test-Revised; RCPM = Raven's Colored Progressive Matrices; *p < .05; **p < .01.

Working Memory

The direct effect of CP on working memory was tested via a MANOVA with the four tests of working memory as dependent variables and group as between-subjects factor.

Central executive.   CP-special had the lowest average Backward Digits score ($M = 4.7$, $SE = 0.5$), followed by CP-mainstream ($M = 6.8$, $SE = 0.8$) and the control group ($M = 9.0$, $SE = 0.8$). The effect of group was significant on this test of the central executive of working memory, $F(2, 70) = 11.2$, $p < .001$, $\eta_p^2 = .24$. The three groups differed significantly from each other in the expected direction (CP-special < CP-mainstream: $p < .03$; CP-mainstream < control: $p = .05$).

Visual spatial sketch pad.   CP-special also had the lowest average Knox Blocks score ($M = 7.2$, $SE = 0.3$), followed by CP-mainstream ($M = 8.9$, $SE = 0.5$) and the control group ($M = 9.8$, $SE = 0.5$). The groups differed significantly on this test of the VSSP of working memory, $F(2, 70) = 10.00$, $p < .001$, $\eta_p^2 = .22$. CP-special scored significantly lower than both CP-mainstream and control on Knox Blocks ($ps < .01$), but the latter groups did not differ significantly from each other.

Phonological loop.   CP-mainstream had the lowest average Digit Recall and Word Recall scores ($M = 16.3$, $SE = 1.0$; $M = 11.6$, $SE = 0.7$, respectively), followed by CP-special ($M = 16.8$, $SE = 0.6$; $M = 11.9$, $SE = 0.4$, respectively) and the control group ($M = 19.2$, $SE = 1.0$; $M = 13.8$, $SE = 0.7$, respectively). The effect of group on the tests reflecting the phonological loop of working memory, Digit and Word Recall, were only marginally significant, $F(2, 70) = 2.5$, $p = .09$, $\eta_p^2 = .07$, and, $F(2, 70) = 3.0$, $p = .06$, $\eta_p^2 = .08$, respectively. Further investigation of the marginally significant effect of group on Digit Recall revealed that although the CP groups did not differ significantly from each other ($p = .68$), both scored significantly lower than the control group ($ps < .05$). A similar pattern of results was observed in the Word Recall data.

Early Numeracy

The effect of CP on early numeracy was tested via repeated measures MANOVA with the two components of early numeracy (number concept and counting) as dependent variables, time (beginning, middle, end of first grade) as within-subject factor and group as between-subjects factor. Means and standard errors on the two components of early numeracy, are shown per group and per session in Table 2. There were significant effects of time, $F(2, 51) = 17.8$, $p < .001$, $\eta_p^2 = .41$, component, $F(1, 52) = 44.8$, $p < .001$, $\eta_p^2 = .46$, and group, $F(2, 52) = 24.1$, $p < .001$, $\eta_p^2 = .48$. These effects were qualified by the significant Time × Group, $F(4,104) = 3.7$,

TABLE 2
Early Numeracy Test Component Scores: Number Concept and Counting
Throughout First Grade

	Mean			Standard Error		
Session	Cp-special	Cp-mainstream	Control	Cp-special	Cp-mainstream	Control
Number concept						
Beginning	12.6	15.5	18.0	.44	.74	.85
Middle	14.6	17.3	18.0	.44	.74	.86
End	15.3	18.4	18.3	.47	.79	.91
Counting						
Beginning	8.2	14.0	16.4	.64	1.08	1.2
Middle	11.7	15.4	16.8	.56	.95	1.09
End	11.0	16.1	16.9	.55	.92	1.06

Note. Participants were tested in the beginning, middle and end of first grade

$p < .01$, $\eta_p^2 = .13$, and Component × Group, $F(2, 52) = 6.2$, $p < .01$, $\eta_p^2 = .19$, interactions. Further investigation of the Time × Group interaction revealed that the three groups differed significantly in the beginning and middle of first grade (CP-special < CP-mainstream < control). However, by the end of first grade the CP-mainstream group scored as highly as the control group ($p > .1$) whereas the CP-special group continued to score significantly lower on early numeracy than the other groups ($ps < .001$). The Component × Group interaction was due to the fact that, whereas all groups scored higher on number concept than counting ($ps < .02$), this difference was larger in the CP-special group.

Instruction Time

An ANOVA was performed on instruction time with group (CP-special, CP-mainstream, control) as between-subjects factor. The average arithmetic instruction time in a typical week was 148 min ($SE = 7.5$) for the CP-special group, 234 min ($SE = 12.2$) for the CP-mainstream group, and 251 min ($SE = 12.6$) for the control group. The effect of group was significant, $F(2, 65) = 33.4$, $p < .001$, $\eta_p^2 = .51$. CP-special received significantly less arithmetic instruction per week (approximately 60%) than CP-mainstream and control, whereas the latter groups did not differ from each other.

SEM: Mediating Effects of CP on Arithmetic Accuracy

The effect of CP on arithmetic accuracy was modeled as being mediated by intelligence, working memory, early numeracy, and instruction time. The hypothesized

model, depicting full mediation at each step, did not fit the data well, χ^2 (29) = 52.525, $p = .005$, GFI = .905, AGFI = .743, NFI = .902, RMSEA = .106. The phonological loop, as measured by Digit Recall, did not have any significant paths to any following variables, so this variable was removed from the model. In a stepwise fashion, non-significant paths were removed and other paths were added between variables if a correlation was found between one variable and the unexplained variance of another variable. Each alteration of the model was accepted only if it improved the fit of the model. This process was continued until there were no potential alterations that could improve the fit of the model. The final model (Figure 1) fit the data well χ^2 (24) = 25.169, $p = .397$, GFI = .943, AGFI = .843, NFI = .951, RMSEA = .026. Paths reported in the final model (Figure 1) are in standardized coefficients (beta coefficients), which indicate the strength and direction of the relationships between variables. Only significant ($p < .05$) and marginally significant ($0.1 > p > .05$) paths are depicted (Figure 1).

DISCUSSION

The goal of the current study was to establish whether children with CP show a delay in arithmetic skill and to examine the mediating effects of verbal intelligence, non-verbal intelligence, working memory, early numeracy, and arithmetic instruction time on the development of arithmetic skill throughout first grade. Toward this end, first graders with CP in both special (CP-special) and mainstream education (CP-mainstream), were compared to a control group of first graders without CP in mainstream education.

The distinction between CP-special and CP-mainstream turned out to be worthwhile, since the performance of the CP-mainstream children was found to resemble that of CP-special children on some tasks and control children on others. This was most apparent in the areas of intelligence and working memory. CP-mainstream resembled the CP-special group on verbal IQ, as measured by the PPVT-R and the phonological loop of working memory, as measured by Digit Recall and Word Recall whereas CP-mainstream resembled the control group on the visual-spatial sketch pad (VSSP) of working memory, as measured by Knox Blocks.

The early numeracy results revealed a tendency for the CP-mainstream group to catch up to the control group by the end of the school year, whereas the CP-special group showed no such trend. In the beginning of first grade, prior to formal arithmetic instruction, there were significant differences in early numeracy between the three groups in the expected direction (CP-special < CP-mainstream < control). By the end of first grade, the CP-mainstream children scored as highly as the control group. However, not only did the CP-special group continue to lag behind the other groups, their early numeracy scores did not increase significantly between the middle and end of first grade. This is a disquieting trend, given that the acquisition of
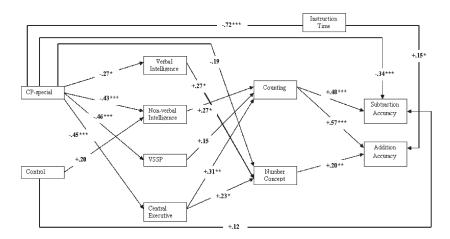
FIGURE 1   Structural equation model showing the mediated effect of CP on arithmetic accuracy. The effect of CP on addition accuracy can be seen as fully mediated by intelligence, working memory, early numeracy and instruction time. The effect of CP on subtraction accuracy can be seen as partially mediated by intelligence, working memory, early numeracy and instruction time. *Note:*   Only significant and marginally significant paths are depicted in the model. Paths are reported in standardized coefficients. Three, two, and one star indicate significance at the .001 level, .01 level, and .05 level, respectively. No star indicates a marginally significant path (0.1 > *p* > .05).

mathematical skill has been described as a developmental process that starts well before formal mathematics instruction with early numeracy skills such as grouping, comparing and counting small numbers of objects (Torbeyns et. al, 2002).

In accordance with the findings of other studies (e.g., Jenks et al., 2007) the results of this study also show a significant positive relationship between instruction time on one hand and addition and subtraction accuracy on the other. Given that schools for children with physical disabilities in the Netherlands provide physical, speech, and other therapies during the school day, it is not surprising that the CP-special group in this study was found to receive an average of only 60% of the amount of arithmetic instruction time that was received by children in mainstream education (both with and without CP). Furthermore, it seems likely that reduced instruction time in special education also occurs in countries other than the Netherlands. For example, Mike (1995) carried out an ethnographic study of literacy instruction in a school for children with cerebral palsy in the United States. He pointed out that there was only little time available for academics due to the various therapies that the students received.

The hypothesized SEM model proposed in this study can be seen as a chronological process. The cognitive impairment in children with CP is a direct result of early non-progressive insult to the developing brain (e.g., Ashwal et al., 2004; Bax

et al., 2005; Evans et al., 1985). Therefore, the mediating effects of the cognitive variables (intelligence and working memory) were assumed to precede the other potential mediating effects. Early numeracy skills start to develop in the preschool years (e.g., Baroody, 1987; Geary, 1994; Ginsburg, 1977; Van de Rijt, 1996), so the potential mediating effects of number concept and counting were assumed to precede the potential mediating effect of instruction time during first grade. Instruction time was assumed to be influenced only by CP (i.e., CP-special and control), because earlier studies found that children in special education receive less instruction time (Jenks et al., 2007; Mike, 1995). The hypothesized model assumed full mediation at each step.

The more parsimonious model that best fit the data (Figure 1) confirms the hypothesized chronological process, although without full mediation at each step. To the extent that there is no direct path between CP-special or control and addition accuracy, the effect of CP on addition accuracy can be described as being fully mediated by verbal and non-verbal intelligence, the VSSP and central executive of working memory, the early numeracy components of number concept and counting, and instruction time. However, there was not full mediation at each step. Whereas the effect of CP on the counting component of early numeracy is fully mediated by non-verbal intelligence, VSSP and central executive, the effect of CP on number concept is only partially mediated by verbal intelligence and the central executive. The direct path from CP-special to number concept, which was added because it improved the fit of the model, indicates that the poorer number concept performance of the CP-special group in comparison to CP-mainstream and control cannot be fully explained by their deficits in verbal intelligence and central executive.

The effect of CP on subtraction accuracy was only partially mediated by non-verbal intelligence, the VSSP and central executive of working memory, and the counting component of early numeracy. The direct paths from both CP-special and control to subtraction, which improved the fit of the model, indicate that the observed mediating effects of working memory and early numeracy are not sufficient to explain the entire effect of CP on subtraction accuracy. This might be an indication that subtraction had not yet been covered in the arithmetic instruction provided in at least some of the special education schools. This would also explain why subtraction accuracy was not influenced by instruction time.

Based on the results of this study it appears that early numeracy skills are strongly influenced by verbal and non-verbal intelligence, the VSSP and the central executive, all of which tend to be impaired in children with CP. The early numeracy skills of number concept and counting were, in turn, found to be important to arithmetic accuracy, which corresponds with earlier studies (Baroody, 1987; Geary, 1994; Ginsburg, 1977; Van de Rijt, 1996). The amount of instruction time children receive in first grade also appeared to influence their addition accuracy. The fact that first graders with CP are less accurate than their unimpaired peers can

be attributed to a higher risk for cognitive impairment that leads to more difficulty in acquiring early numeracy skills which in turn leads to lower arithmetic scores. The reduced instruction time given to children with CP in special education is also related to their lower arithmetic scores.

Taken together, the results of this study have important implications for practitioners. Early numeracy skills appear to be a necessary prerequisite for arithmetic success in first grade. Practitioners might do well to test early numeracy skills prior to the beginning of formal arithmetic instruction. If a deficit of early numeracy skills is found, an effort could be made to teach early numerical skills. This is particularly important for children with CP because their ability to spontaneously acquire these early numeracy skills may be impaired by cognitive challenges. The development of these skills may therefore take longer, as was evidenced by the CP-mainstream group's early numeracy skills catching up to that of their unimpaired peers by the end of first grade. The question of whether the CP-special group's early numeracy skills will eventually catch up to that of the control group will be answered by future measurements of this longitudinal study. Practitioners should also be aware of the possibility that another balance in the school day between time for mathematics instruction and time for other activities could improve the mathematics performance of these children.

Whereas the first grade arithmetic achievement of the CP-mainstream group was on a par with the control group, non-verbal intelligence, and some measures of working memory revealed differences in favor of the control group. The working memory tests intended to measure the phonological loop of working memory revealed no difference between the CP groups, but both scored significantly below the control group. The working memory test intended to measure the central executive of working memory revealed a tendency for the CP-mainstream group to lag behind the control group. Both the phonological loop and the central executive of working memory seem to be of utmost importance for more complicated arithmetic operations than addition and subtraction below ten (Furst & Hitch, 2000). The coming years of this longitudinal study will show whether these working memory problems will influence more complicated mathematical processes in the CP-mainstream group. Another important question for the upcoming longitudinal measurements of this study is whether the CP-special group will continue to lag behind on addition and subtraction accuracy or will catch up with the other groups, as this will be important for the future development of mathematical ability.

As we noted earlier, the future independence of children with CP depends in large part on their ability to perform non-physical tasks. Because of this, an understanding of learning difficulties in these children, with the goal of developing appropriate interventions, is of paramount importance. Based on our results, it would appear that the same processes that lead to arithmetic problems in the general population are at the root of the arithmetic problems in children with CP. The greater difficulty with arithmetic experienced by children with CP appears to be due to

greater deficits in the areas of working memory and early numeracy and, in the case of children with CP in special education, to a smaller amount of instruction time. We hope that the information gained in the current study regarding the contributions of working memory, early numeracy, and instruction time on the development of arithmetic skill will contribute to the goal of developing interventions to treat arithmetic learning difficulties in children with CP.

ACKNOWLEDGMENTS

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