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Review Article

The Relationship between Working Memory and Acquisition of Mathematical Strategies in Children with Cerebral Palsy: A Review of Literature

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ABSTRACT

Background: Cerebral Palsy (CP) is defined as non-progressive brain damage attributed to limitation in mobility, learning, language, and communication. The high prevalence of low academic achievement in learning mathematics in CP cases is related, in part, to multifactorial influences; working memory may be one of the factors which can be related to arithmetic attainment. The purpose of this article was to review the relationship of working memory with mathematical performance in children with CP.
Methods: In this Review of literature article, Five English search engines (Pubmed, Scopus, Science direct, EMBASE, and Central) were used with key words, "cerebral palsy, arithmetic, mathematical performance, and working memory". The inclusion criteria were English relevant articles in which participants had CP and both mathematical abilities and working memory were assessed.
Results: A total of 103 articles were screened. Twenty-five potentially relevant titles or abstracts were identified. Based on inclusion criteria, only 7 articles were found.
Conclusion: Given the high risk of mathematical learning difficulties in children with CP, information about mathematical skills and the role of working memory on the different components of mathematical strategies is limited. Further research should be carried out to investigate this issue. The findings in this study showed the relationship between working memory and the difficulties with mathematical and numerical learning of CP cases.

Background

Historically, the term Cerebral Palsy (CP) was defined as non-progressive brain damage attributed to limitation in mobility, learning, language, and communication [1]. Almost 2.11 per 1000 births were affected by CP disorder [2]. CP is the leading neurological damage in the fetal or early infancy period associated with developmental problems [3]. Observation of intellectual disability, attention or memory deficit, language and learning impairments are common clues in the diagnosis of CP [4].

Regarding the type and degree of motor impairment, around 50 % of individuals with CP demonstrated learning difficulties [5]. Observation of learning difficulties in the area of mathematical skill is more common in children with CP [6]. However, impairment in learning mathematics of patients with CP is systematically related, in part, to multifactorial influences such as fine motor skills [7], linguistic skills, and non-verbal intelligence. Working memory may be the other factor which can be

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related to arithmetic attainment [8]. As a result of the high prevalence of numerical learning difficulties and the importance of the key effect of working memory in learning, the purpose of this article is to review important issues and findings in this field.

Mathematical Learning Difficulties (MLD)

Low IQ, impaired social adaptation and developmental problems have been identified as the important predictors of learning disabilities [9]. Given the high prevalence of low academic achievement, levels or types of learning difficulties (reading, maths or comorbid difficulties) have far-reaching negative consequences on daily activities [10].

Mathematics is a hierarchical and multifaceted high level skill that involves a hybrid of cognitive skills [11, 12]. Basic mathematics development impairment refers to difficulties in storing and recalling arithmetic facts [13], for solving single-digit additions and subtractions [14]. Therefore, it is tempting to understand the cognitive origins of mathematical difficulties to compose instructional interventions aimed at remediation of poor arithmetic performance early on.

Working Memory as Supporting General Cognitive Ability

Working memory is the ability where a person can store information temporarily to complete a wide range of cognitive tasks [15]. In addition, working memory refers to a three-factor modal including the central executive, the visuospatial sketchpad, and the phonological loop [16]. Furthermore, the visuospatial sketchpad and the central executive are key components of effective and efficient acquisition of adequate strategies for representation of numbers on the mental number line [17, 18]. Based on many studies, significant unique associations between working memory and various measures of mathematical skill have been observed across time. On the other hand, children with difficulties in mathematics may have low scores on measures of working memory [19-22]. For instance, Swanson [23] documented a correlation between the visual-spatial working memory of students and their arithmetic facts which were stored in their long-term memory. In another study [24], the direction of the relationship between the central executive and arithmetic fact retrieval in children with MLD was clear. On the other hand, poor central executive capacities could result in low fact retrieval performance to solve addition. Following correlational data, dual task studies have indicated that children with weak phonological working memory function showed deficits on keeping track of the operands while solving arithmetic with counting strategies [25, 26]. However, it could be said that the phonological loop may play a crucial role in the process of accurately memorizing basic arithmetic facts [26].

Against this background, other studies have found that there was not a significant association between mathematical performance and each working memory component, i.e. by studying whether visual-spatial [27], phonological processing [24] and executive functions [28, 29] are related to children's performance in general mathematics achievement tests.

Current Review

According to the cognitive domain impairment and abnormal motor development of children with CP, learning disabilities are probably the result of a developmental cascade originating in early development. However, these deficits ultimately might lead to delay in carrying out daily life activities later on besides academic and work success [30]. Moreover, there are multiple published papers on the association between general mathematical skills of children with CP and their working memory in various states of mathematical development. Several authors of these studies argued that there was a clear significant relationship [31-37], while Van Rooijen and colleagues [34] observed no significant correlation between the mentioned items. In view of this, the present review was conducted to review the available literature on the relationship of working memory with general mathematical problems in children with CP wherein so far no reviews specially highlighted whether there is any specific relationship. Given the different findings from prior studies, an important question was addressed: does the working memory of children with CP relate to general mathematical difficulties?

Methods

Data Sources

In this Review of literature article, five electronic search engines including (Pubmed, Scopus, Science direct, EMBASE, and Central) were searched. The search terms "cerebral palsy, arithmetic, mathematical skill, and working memory" were used in the search of computerized databases.

Inclusion/ Exclusion Criteria

The inclusion criteria were: (1) publications had to have been conducted in years 2000-2019; (2) they had to provide evidence of mathematic and working memory measures to examine the relations between working memory and mathematical competence; (3) they had to be English language articles; and (4) subjects included in these papers had to have a confirmed diagnosis of CP.

Additionally, studies were excluded as (1) they were unrelated and repetitive articles and (2) the sample population had neuropsychiatric and mental comorbidities.

Data Extraction

A selection of 103 publications was screened (Figure 1). After review, 25 potentially relevant titles or abstracts were identified. Based on full-text publication and inclusion or exclusion criteria, the final sample comprised only 7 articles. In the next phase, relevant information including names of authors, year of publication, number of participants, the mean age of the participants, the aim of per study, measurements of working memory and

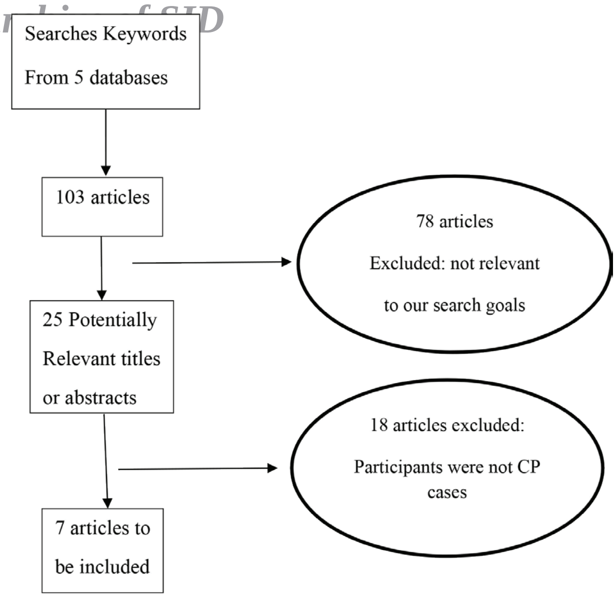

Figure 1: Flow chart of searching result

mathematical performance, and major findings were extracted and charted in Table 1.

Results

Participants and Group Comparison

This search process yielded 7 articles [31-37] which contained a total of 459 participants with CP, with an age ranging from 6-9 years. Three of the included longitudinal studies [31-33] used three groups; one control group (children without CP in mainstream schools), one group of CP-special, and one CP-mainstream group. The other four longitudinal and cross-sectional studies [34-37] used only one CP group in their study design.

Assessment Procedure

Several different tests were used to measure different components of working memory and mathematical performance. Two of the studies used the Digit span forward and backwards test and a subtest of the Wechsler intelligence scale for children-III (WISC-III) to measure working memory ability. The children were required to repeat the numbers in the same or reverse order. Arithmetic performance of the subjects was assessed with a Dutch standardized arithmetic achievement test, The Student Monitoring System for Arithmetic Performance with separate parts for addition, and subtraction [34, 35]. Another two studies [32, 33] used Simple Addition and Simple Subtraction tests. The authors had examined different components of working memory including updating, visuospatial sketchpad, and phonological loop via Backward Digits, Knox Blocks, and Digits Recall and Word Recall, respectively. The tasks designed to measure the child's ability to repeat the digits and tap the blocks in the same order.

In two reports [36, 37], the authors offered to administer Automated Working Memory Assessment (AWMA) to measure verbal working memory in which children are asked to repeat the words after hearing them. Moreover, Corsi Block task was designed to measure visual-spatial working memory of children in recognizing the certain sequences of blocks. They conducted the Early Numeracy Test-Revised (ENT-R), a standard Dutch test, to assess concepts of comparison, classification, one-to-one correspondence and seriation, as well as counting skills. A three-session test of the last study [31] was administered to assess early numeracy and arithmetic skills using the Early Numeracy Test in all three sessions and The Addition or Subtraction test in both the second and third sessions. To control the phonological loop and the central executive of working memory, authors used Digit Recall, Word Recall, and Backward Digits. In addition, Knox Blocks was chosen to measure the visuospatial sketchpad of working memory.

All significant predictors of correlation between mathematical performance and working memory competence are presented in Table 1. Findings from three studies [31-33] with three groups (CP-special, CP-mainstream, and typically developing groups) using different instruments that measure mathematical strategies and working memory components, showed that children with CP in special education showed evidence of working memory deficits and arithmetic difficulties. The investigators also reported statistically significant correlation between working memory components and mathematical achievement. On the other hand, deficits in visuospatial sketchpad resulted in a higher risk of mathematical impairments in children with CP. Likewise, another study [35] demonstrated that working memory was by far the most determining factor in the initial status and growth rate of arithmetic performance in children with CP of 7 to 9 years of age.

Two recent papers [36, 37] provided support for the efficiency of working memory as one potential predictor of early numeracy and arithmetic performance of participations. To put it another way, the authors reported improvement in early numeracy performance of children with CP which could, however, be the result of an increase in cognitive abilities (visual-spatial working memory and updating). In contrast to the result of six of the studies, the last study [34], showed a trend towards significant correlation only in word decoding, fine motor skills, and arithmetic performance. Even so, working memory abilities were not important prerequisites for addition and subtraction performances of primary school children with CP of 7 years of age.

Discussion

The present review was conducted to focus on the relationship of working memory with general mathematical problems in children with CP. Interestingly, based on six studies [31-33; 35-37] although with mixed findings, there is conceivable support for the notion that working memory deficits may relate to difficulties in arithmetic performance in children with CP, while, one study [34], has shown some indication that working memory ability was not strongly related to mathematical problems. Some explanations might account for these inconsistencies.

Table 1: Summary of study details for included papers

Study/ Year	N		Mean age (SD)		Mathematics Measurements	Working memory Measurements	Aim of per study	Major findings
	CP	TD	CP	TD				
Jenks etal (2007) [31]	41 CP- special 16 CP-mainstream	16	7.0 (0.7) 7.0 (0.4)	6.9 (0.4)	ENT; Addition and Subtraction Test	Digit Recall; Word Recall; Backward Digits; Knox Blocks	To examine the mediating of working memory on the development of arithmetic skills among CP children	Significant association between working memory and mathematical skills
Jenks etal. (2009) [32]	41 CP-special 16 CP- mainstream	16	7.0 (0.7) 7.0 (0.4)	6.9 (0.4)	Addition and Subtraction Test	Backward Digits; Knox Blocks; Digit Recall; word Recall	To evaluate whether arithmetic difficulties in CP children are related to working memory	Significant association between working memory and mathematical skills
Jenks etal. (2012) [33]	41 CP-special 16CP - mainstream	16	8.93 (0.79) 8.88 (0.34)	8.94 (0.44)	Addition and Subtraction Test	Backward Digits; Knox Blocks; Digit Recall; Word Recall	To examine the cognitive correlates of maths ability in CP children	Significant association between working memory and mathematical skills
Van Rooijen etal. (2012) [34]	116	-	-	-	The Student Monitoring System for Arithmetic performance	Digit Span Forward and Backwards test; WISC-III	To assess whether cognitive and motor variables are related to arithmetic performance of CP children	No Significant association between working memory and mathematical skills
Van Rooijon etal. (2014) [35]	60	-	7.2 (0.23)	-	The Student Monitoring System for Arithmetic performance; ENT-R	Digit Span Forward and Backwards test; WISC-III; AWMA; Corsi Block task	To examine the development of arithmetic performance and its cognitive precursors in the children with CP	Significant association between working memory and mathematical skills
Van Rooijon etal. (2015) [36]	56	-	6.0 (0.58)	-	ENT-R	AWMA; Corsi Block task	To study whether working memory is predictive of arithmetic performance of CP children	Significant association between working memory and mathematical skills
Van Rooijon etal. (2015) [37]	56	-	6.0 (0.61)	-	ENT-R	AWMA; Corsi Block task	To evaluate whether working memory is positively related to the early numeracy performance	Significant association between working memory and mathematical skills

CP: Cerebral Palsy; TD: Typically developing; ENT: Early Numeracy Test; WISC-III: Wechsler Intelligence Scale for Children-III; ENT-R: Early Numeracy Test-Revised; AWMA: Automated Working Memory Assessment

In three included longitudinal studies [31-33] involving a control group (n=16) and two CP-special (n=41) and CP-mainstream (n=16) groups, the authors used mathematics and working memory measurements. Based on the available details from these three studies, two studies [32, 33] from the same research team had very similar methodological protocols. Addition and Subtraction test was used to assess the accuracy and speed of retrieval of simple and complex addition or subtraction facts. Additionally, Digit Recall, Backwards digits and Knox Blocks were designed to measure the phonological loop, updating and visuospatial sketchpad of working memory, respectively. The participants were asked to repeat the digits in the correct or in reverse order and tap some blocks in the same order in accordance with the test manual.

Another study [31] conducted both the Addition and Subtraction test and Early Numeracy test which can be seen as two components. The number concept component submitted to measure a child's ability to compare objects regarding the quantitative or qualitative properties, a child's ability to group objects on the basis of one or more criteria and a child's ability to compare numbers of simultaneously presented objects as well as a child's ability to order objects. However, the counting component was submitted to measure counting and understanding and applying cardinality accurately.

In the four other longitudinal and cross-sectional studies [34-37] using only one CP group in their study design, The Student Monitoring System for Arithmetic Performance was designed in two articles [34, 35] to measure only addition and subtraction equations not multiplication equations. The components of this scale were presented in an increasing order of difficulty and the children were requested to answer as soon as they can could within 1 min. There were another two studies [36-37] using The Early Numeracy Test Revised [ENT-R] to measure understanding of number and counting skills of children with CP. In addition, working memory abilities were operationalized with measures testing updating and phonological loop in one study [34]. A similar decision was made on another three studies [35-37], while being treated as one entity with the use of Corsi block-tapping and Automated Working Memory Assessment to measure different components of working memory.

With respect to the different measurements of the included studies, we can clarify the validity of the results in an objective manner. First, the authors [34] did not assess the visual-spatial working memory ability of CP children, although visuospatial abilities have been identified to have a positive relationship with mathematical abilities of the normal population [38]. In a study, Critten and colleagues [39] compared the abilities of visuospatial perception and mathematics in CP children with their normal peers. CP children gained lower scores in both skills compared to the normal population. On the other hand, they concluded that visual memory was severely impaired in CP children and that was related to poor mathematical abilities of these children. Also scientists supported the idea that the lower scores of the CP group were due to the problems in recognizing of the shape and position of the blocks and remembering the sequence of the blocks rather than the motor skills [39, 40]. Moreover, CP children showed difficulties in basic components of visual perception such as length (estimate the length of visual stimuli), surface (estimate the surface area occupied by objects), orientation (appreciate orientation of the objects) and position (evaluate the relative position of objects) [41].

Second, the unexpected nonsignificant association between working memory and mathematical skills would probably be an effect of mathematical measurement issue. This might be a bias for the study [34] applying only addition and subtraction equations because the children had not received any education on multiplication to use different strategies in mathematical problem solving. Apart from this methodological argument, a more process-oriented explanation by Geary and colleagues [42] could be that three different type of working memory components affect specific mathematical skills to different degrees. In other words, general measures of mathematics are more validated measurements to examine their association with working memory [43].

Third, the correlation reported in a large sample of seven-year-old children with CP [34] may be partially confounded by age controlling which could cause correlation coefficient to drop [44]; because variation in the strength of association between mathematical performance and working memory may be the result of involvement of younger children more in visuospatial processing [45] which was not evaluated in the mentioned study.

Beside the visuospatial aspect of working memory, the phonological awareness is another element which is a necessary but not sufficient prerequisite for mathematical development. Some aspects of phonological awareness are found to be related to mathematical development such as: sound categorization, rhyme detection, initial consonant detection, initial sound mentioning, phoneme elision and blending phonemes [46].

There is very close relationship between literacy development and math development [46]. Also, there is very strong relationship between phonological awareness and the visuospatial aspect of working memory [46]. Therefore, we suggest speech therapists and other learning specialists to consider these related aspects together when they want to diagnose, assess and treat the mathematical problems of children and specially CP children.

According to our search strategy and aim of our article, we found very limited articles which were related to the topic. Some gaps exist especially in investigating the relationship between phonological loop and mathematical development. So, there is a need for further studies in this domain.

Conclusion

Overall, the articles identified in this review were conducted in the measurements of working memory and mathematics among CP children. In reviewing this sample of studies, we came across some general insights demonstrating the importance of working memory as an important factor to improve the mathematical performance of children with CP.

Due to the dearth of studies on this topic, all the available evidence shows the need for review of the link between working memory capacities and mathematics performance of CP children to train their working memory deficit or ameliorate their mathematical performance. In conclusion, this information about such links would be useful and relevant for developing effective early interventions for these children. As such, more work is needed to fractionate different aspects of the working memory and mathematical skills in order to disentangle their differential relationship and to determine the types of relation (specific or general) between all components of working memory abilities and mathematics skills.

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