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## **Working memory, number sense and arithmetical performance: Relations between these domains.**

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*Studies correlating working memory, number sense and arithmetical performance show controversial results which create the need for further investigation. This research aims to verify the relationship between two working memory components (central executive and phonological loop) and numerical competence assessed through two different tasks: the Number Knowledge Test and the School Achievement Test. It involved 79 Brazilian students from 4<sup>th</sup> to 7<sup>th</sup> year of elementary school. The results suggest a significant correlation between the central executive and number sense. The same relationship was observed for the arithmetical performance. The phonological component showed no significant correlation with number sense nor arithmetical performance. The educational implications of the study are pointed out.*

*Keywords: Working memory, number sense, arithmetical performance.*

### **Background**

Both number sense and working memory are fundamental skills for arithmetical learning (Geary, 2011; Jordan et al, 2013). Studies investigating the relationship between working memory and arithmetical performance have been widely discussed in the literature (Anderson & Lyxell, 2007; Geary et al., 2007; Passolunghi & Siegel, 2004). However, the research that deals with the relationship between working memory and number sense is recent. Number sense is considered the basis of arithmetical learning and, consequently, it is assumed to be associated with working memory (Friso-Van Den Bos, Van Der Ven, Kroesbergen & Van Luit, 2013).

Working memory is a cognitive system that supports the development of various learning processes. It is a limited capacity system which allows the temporary storage and manipulation of verbal or visual information required for dealing with complex tasks. During learning the student constantly uses the resources of working memory to perform a series of activities, from the simplest tasks, such as remembering instructions, to the more complex ones, such as solving problems, that require the storage and processing of information and the control of learning progress. In the case of arithmetic, for example, a multidigit calculation ( $23 + 48$ ) requires several subprocesses (retrieval of arithmetic rules and arithmetic facts from long-term memory, calculation and storage of intermediate results, arithmetic procedures that involve carrying and borrowing operations) that must be coordinated and executed by the working memory system. Students with deficits in this ability would face problems. Thus, a difficulty especially related to the coordination of simultaneous operations of processing and storage can interfere in the execution of arithmetic tasks, resulting in slower performance and more errors in computation (Andersson & Lyxell, 2007).

Considering the tripartite model proposed by Baddeley and Hitch (1974), the working memory system is formed by three components: two storage systems (visuospatial component and the phonological loop) and the central executive, the nuclear component of working memory, responsible for the processing of cognitive tasks, coordinating the information stored within the other two components. It is generally agreed

that arithmetical achievement is associated with working memory performance (Alloway & Alloway, 2010; Andersson & Lyxell, 2007; Geary, Hoard, Byrd-Craven, Nugent, & Numtee, 2007). However, there is a lack of consensus regarding the relative importance of the central executive (Andersson, 2008; Geary et al., 2007; Passolunghi & Siegel, 2004), the phonological loop (Andersson & Lyxell, 2007; Passolunghi, Mammarella & Altoè, 2008) and the visuospatial component (Geary, Hamson & Hoard, 2000; Mclean & Hitch, 1999) in relation to arithmetical performance.

Some studies found that the central executive is the most affected working memory component (Corso & Dorneles, 2012; Geary, Hamson & Hoard, 2000; Geary, Hoard & Hamson, 1999). The central executive has three main functions: inhibition (prevent irrelevant information from entering or remaining in working memory), shifting (shifting between pieces of information and response sets) and updating (active processing and refreshing of information in working memory). There is no consensus regarding the role that each specific executive function plays in number sense. Some studies point out that inhibition is central to number sense development (Kroesbergen, Van Luit, Van Lieshout, Van Loosbroek & Van De Rijt, 2009), but such a result was not found by others (Lee et al., 2012; Navarro et al., 2011). Updating is usually seen as the most important predictor of number sense (Kroesbergen et al., 2009; Lee et al., 2012), but, it is important to emphasize that research focusing on the relation between number sense and executive function is still limited (Friso-Van Den Bos et al., 2013).

Concerning number sense, the literature shows consensus related to the important role that this construct plays to mathematical development, but there is a lack of consensus regarding the best way to define, assess and intervene in number sense (Gersten, Jordan & Flojo, 2005). Considering studies in the areas of mathematical education and cognitive development, Berch (2005) compiled a list of 30 characteristics presumed to compose the number sense concept. According to the author, number sense means awareness, intuition, recognition, knowledge, ability, desire, feeling, expectation, process, conceptual structure or mental number line. When defining number sense, some authors point out the conceptual, abstract aspect of numerical processing. For example, Dehaene (2001) emphasizes that number sense refers to the ability to mentally represent and manipulate numbers and quantities. Gersten and Chard (1999) define number sense as the flexibility with numbers and the understanding of the meaning of numbers and ideas related to them. Other researchers use definitions emphasizing the performance that is facilitated by that conceptual understanding of number, such as counting ability, number identification, number awareness, estimation, measurement, mental operations with numbers (Jordan, Glutting & Ramineni, 2010). We believe that both definitions of number sense are complementary: In order to succeed in the comprehension and execution of tasks involving numbers, relations and quantity, an abstract understanding of numerical processing is necessary. Therefore, the conception of number sense that characterizes this paper is that it is a general construct, which encompasses a very broad set of concepts, which the student develops gradually from his interactions with the social environment. Number sense is a way of interacting with numbers with its various uses and interpretations, enabling the individual to deal with daily situations that include quantification and the development of efficient strategies (including mental calculation and estimation) to deal with numerical problems (Corso & Dorneles, 2010).

Recently, researchers are interested in the association between the different components of working memory system, especially the central executive and the number sense. Children are expected to employ working memory capacity while experiencing number sense tasks such as counting, understanding magnitude, doing basic arithmetic calculation, using mental number line (Gersten, Jordan & Flojo, 2005).

However, there is a small body of literature targeting the association between working memory and number sense.

## The current study

The literature presented above suggests that working memory plays an important role for the development of numerical competence. However, the importance of each working memory component is not well defined. In order to contribute to this discussion, the present study aims to verify the relationship between two working memory components (central executive and phonological loop) and numerical competence assessed through two different tasks: the Number Knowledge Test and the School Achievement Test.

## Method

This is a cross-sectional study involving 79 (10- to 14- year-old) Brazilian students (36 girls and 43 boys) from the 4<sup>th</sup> to the 7<sup>th</sup> year of five public elementary schools. Mean age was 11.9 years. Students were indicated by their teachers considering the students' performance (average and low average) in the math curriculum according to each school year.

## Instruments

### 1) Working Memory

1.1 The central executive component of working memory was measured using two different tasks: a non numerical - processing of verbal information (adapted from Hecht et al., 2001) and a numerical task - processing of numerical information (Yuill, Oakhill & Parkin, 1989). In the first task the students were required to answer yes or no to sets of two to four questions and then say the last word in each of the sentences, for example, in the two-question set, "Do tables walk?" and "Do lamps run?", a correct response would be "no" to each question and then "walk" and "run". For the numerical task, the students read aloud a growing sequence of three-digit sets and, at the end of each set, should remember, in order, the last digit of each set. For example, for the sets (2 5 7) and (1 8 6), the digits "7" and "8" must be remembered.

1.2 The phonological component of working memory was assessed through the Memory of Digits, Sentences and Short Stories task (Golbert, 1998). It consists of a growing sequence of digits, sentences and short stories to be repeated by the student.

### 2) Numerical Competence

2.1 Number Knowledge Test (Okamoto & Case, 1996): This task is designed to assess the students' knowledge and comprehension about counting, numerical concepts and basic arithmetic calculation. The instrument is divided into four levels of complexity, being presented from the simplest (level 1) to the most complex (level 4). Although this instrument was designed for assessing students up to 10 years of age, we decided to use it, even having few students in the sample older than this age group. The students who were 13 and 14 years old were repeating students who were facing difficulties in some foundational components of numerical proficiency. The sample of this study was formed by average and low average arithmetic learners, but no ceiling effect in this task was observed.

2.2 School Achievement Test (Stein, 1994): This is a Brazilian standardized psychometric instrument designed to verify the students' arithmetical achievement. It presents 38 items (3 word problems and 35 written calculations). The word problems involve magnitude comparison and simple addition and

subtraction calculation. The written computations involve basic operations, operations with decimals, fractions, operations with integers and potentiation.

Data were analyzed using the correlation analysis between number sense and arithmetical achievement measures with the working memory tasks (central executive and phonological tasks), using the analysis of Pearson correlation at the significance level of  $p < .05$ .

## Results

Considering the central executive component of working memory, a significant correlation was found between the two working memory tasks and the tests that measured both number sense (WM1  $r = 0,449$ ,  $p = 0,000$ ; WM2  $r = 0,316$ ,  $p = 0,005$ ) and arithmetical achievement (WM1  $r = 0,303$ ,  $p = 0,007$ ; WM2  $r = 0,344$ ,  $p = 0,002$ ). The phonological component of working memory, though, did not reveal a significant correlation between the three tasks designed to assess the phonological loop neither with the number sense task nor with the arithmetical measure. Only a weak correlation was found between number sense and the task that assessed the recalling of short stories ( $r = 0,226$ ,  $p = 0,045$ ). Correlations among the measures are reported in Table 1.

**Table 1** - Pearson correlation coefficient ( $r$ ) and the significance level ( $p$ ) between the number sense test and the mathematical subtest of the TDE with the different components of working memory (central executive and phonological loop)

	<u>WM1</u>		<u>WM2</u>		<u>MD</u>		<u>MS</u>		<u>MSS</u>	
	<u>r</u>	<u>p</u>	<u>r</u>	<u>p</u>	<u>r</u>	<u>p</u>	<u>r</u>	<u>p</u>	<u>r</u>	<u>p</u>
<b>NKT</b>	0,44	0,000*	0,316	0,005*	0,153	0,177	0,169	0,137	0,226	0,45*
<b>SAT</b>	0,303	0,007*	0,344	0,002*	0,189	0,096	0,12	0,915	0,069	0,547

NKT = Number Knowledge Test; SAT= School Achievement Test; WM1 = Working Memory 1 (non numerical task); WM2 = Working Memory 2 (numerical task); MD = Memory of Digits; MS = Memory of Sentences; MSS = Memory of Short Stories.

\*  $p$ -value  $< 0,05$

## Discussion

The results of the study presented a significant correlation between the two central executive tasks and the number sense test. This point emphasizes the fact that dealing with number sense activities requires working memory involvement, in this case, specially through the central executive system, since it was not found a positive relation between the phonological component of working memory and the number sense measure. This outcome reinforces what research has shown in relation to the strong association between the central executive (updating function) and number sense in children (Lee et al., 2012). Results in the same line are presented by Friso-van den Bos et al. (2013) who found that updating has the highest correlation with number sense, when compared to the shifting and inhibition functions of the central executive. As pointed out earlier, a small number of investigation has targeted the association between number sense and the central executive component of working memory and, therefore, more investigation is needed considering that research of this kind will bring contributions to preventing and remediating arithmetical difficulties.

The results of this research are in line with those that emphasize the positive association between working memory and arithmetical achievement (Geary, Hoard, Byrd-Craven & Desoto, 2004; Passolunghi, Mammarella & Altoè, 2008) reinforcing that the working memory is critically involved in a variety of numerical and arithmetical skills. In this study, this positive association refers to the executive component of working memory, but not to the phonological one. As mentioned before, there is a controversy in the literature regarding the role of each component of the working memory system in arithmetical achievement (Meyer, Salimpoor, Wu, Geary & Menon, 2010). Studies that include students with difficulties in mathematics in its sample indicate problems with the three components of the working memory system, but the central executive seems to be specially affected.

The non-conclusive results related to the contribution of each working memory component to numerical competence can be related to the following aspects: the large variability in the tasks used to assess the different components of working memory, the different kind of arithmetical tests being used and the ages of the subjects being assessed. We know that different cognitive demands require distinct working memory resources and these resources, in turn, can vary according to the age of the subject (Andersson & Lyxell, 2007). Therefore, although there have been advances in this area of study, more investigation is needed.

## Conclusion

The study showed a significant correlation between the central executive component of working memory (updating) and number sense. It contributed with more investigation with regard to the association between working memory and number sense, as studies linking these two domains are still scarce and present controversial results. The next steps for future investigation will involve more detailed analysis aiming to identify how the different tasks that compose the Number Knowledge Test (counting, numerical magnitude, mental number line, estimation, arithmetic calculation) are associated with the central executive, including in this analysis not only the updating component of the central executive, but also shifting and inhibition. This sort of analysis can give us a better view of the intensity of the involvement of the central executive function in different number sense tasks.

The outcomes of this investigation are in agreement with previous studies highlighting the significant correlation between working memory and arithmetical skills. The educational implication of such a finding deserves our attention. It is crucial to know the cognitive abilities that are impaired in the learner since the way the teaching process is conducted, will directly influence the effect that the cognitive deficit has on learning. For instance, students who are very slow to calculate, need the teaching of more efficient counting strategies and procedures in order to avoid being based overmuch on their working memory (when the counting all procedure is being used, for example), overloading it and increasing the chance of error in the calculation. Problems in working memory end up affecting the set of everyday situations in which mathematical tasks are involved. Those difficulties lead the students to present some characteristics that make the learning of mathematics more difficult, for example: counting on the fingers for a longer time, not performing mental calculation, forgetting the result of calculation they just made, not remembering the sequence of steps of an operation (Geary et al., 2007).

Studies are being designed focusing on the development of interventions to improve the working memory capacity by asking children to engage in tasks that require simultaneous processing and manipulation of information (Klingberg, 2010). However, the results of these studies are still controversial (Melby-Lervag & Hulme, 2013). Recent intervention research emphasizes the importance of combining working memory interventions with interventions that target the specific mathematical areas in which the student is showing

delay (Sperafico, 2016). This type of work has brought promising results to help students with working memory difficulties to learn mathematics.

Finally, this study contributed to the field of arithmetical learning by bringing some evidence of the positive associations between working memory and numerical competence (number sense and arithmetical achievement). Knowing the cognitive abilities underling arithmetical learning is fundamental to guide curriculum planning considering the working memory demands of the tasks, their level of difficulty and the characteristics of the learners. Further studies in this area will offer advances in the processes of preventing and remediating learning difficulties in mathematics. By identifying which components of working memory are weak, it is possible to avoid that at-risk students develop future problems. In the same way, research of this kind will support our understanding of possible cognitive obstacles that interfere in learning mathematics, so that we can face them trough the selection of adequate teaching resources and content as well as good teaching strategies. Maybe this is the most important contribution that the constructs of working memory and number sense can make to mathematical education.

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