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Impact of working memory on arithmetic problem solving in primary school pupils with mathematical learning difficulties

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Abstract
Learning arithmetic operations is fundamental for social and professional emancipation, where counting and solving numerical operations is part of everyday behavior; this reflects the more or less serious difficulties that pupils with mathematics learning difficulties (MLD) may encounter. The interest of this work is to underline the importance of the cognitive deficit at the memory level in these subjects. In this sense we selected 30 pupils aged 7 to 8 years old, educated from 2nd to3rd year of the primary cycle with MLD on whom we applied tests of arithmetic problem solving and working memory (WM). Analysis of the results indicates a significant correlation between the difficulties recorded in arithmetic and WM. These results lead us to a systematic evaluation of WM in subjects with MLD, in any therapeutic diagnostic approach.
Keywords: Mathematics learning difficulties; Solving arithmetic problems; Working memory.

1- Introduction

Mathematics represents a part of our cultural heritage, a human characteristic without which this science cannot exist (Golding, 2018). It is a fundamental science, provided to students from the elementary stages, which contributes to the training of the learner in this direction; this construction takes place on the level of critical reflection, the resolution of problems ranging from the simplest to the most complex by adopting logical approaches which will even impact the subject in their daily life (Obradovic & Mishra, 2020; Vintere, 2021) , one's professional future (Parsons & Bynner, 2005) and even one's health (Reyna et al, 2009) and constitutes one of the foundations of the modern economy and technology (Ernest, 2015). This is not limited to the acquisition of logical problem-solving approaches but of an appropriate mental attitude.
Arithmetic represents the most basic level of mathematics to which a majority of subjects can access, in fact Ernest (2015), uses the term functional calculation, to distinguish this elementary learning essential for social and professional integration, which represents the minimum acquired at the end of schooling, excluding those who present particular difficulties. Despite its importance, mathematics overall remains an unloved subject in school, according to Maslow (1987) many students or pupils develop negative attitudes towards mathematics and their own abilities fueled by their failure in this subject.
Beyers (2011), defines mathematics as a mental aptitude, which calls upon cognitive, affective and conative functions, the latter underlines the mental effort that the learner must make to express himself in this discipline which requires language and a specific vocabulary (Riccomini et al, 2015). The cognitive aspect of the study of mathematics alone represents a research theme widely addressed in psychology and neuropsychology.
According to Karagiannakis et al (2014), the term Mathematical Learning Difficulty or disability (MLD) is used broadly to describe a wide variety of deficits in mathematical skills, generally belonging to the domains of arithmetic and arithmetic problem solving, this term from the field of research in cognitive psychology, underlines a cognitive deficit in the processing of numerical data, the D in the abbreviation MLD is relative in the literature to difficulty, disability or disorder (Baccaglini-Frank & Di Martino, 2020) , for other authors (Devine et al, 2013), the term arithmetic learning difficulties (ALD) is also used. The proportion of subjects varies between 11 and 16%, compared to 6% for severe or dyscalculic forms (Mah Jabeen et al, 2021; Morsanyi et al, 2018).
Lin et al (2021), limit the difficulty threshold between scores below the 35th percentile and above the 10th percentile, we find an approximately close limitation in Dirks et al (2008) with scores below the 25th and 10th percentiles, For Geary (2011) there is a consensus on the delimitation of subjects with MLD with scores

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below the 25th percentile, which includes low-performing students (25th to 11th percentile), and those with developmental dyscalculia (lower at the 10th percentile). As a precautionary measure and based on the observations of Mazeau and Pouhet (2014) as well as the DSMV-TR (2022), we will retain the term Mathematical Learning Difficulty for subjects with moderate difficulties, limited to between -1 and -2 difference type of the average, while the term Mathematical Learning Disability, will be reserved for subjects with severe difficulties, limited to -2 standard deviation (Dyscalculia).

Gallistel and Gelman (2005), suggest that mathematical cognition relies on deep structures independent of language that recall is our means of thinking, since the ability to estimate quantities and reason arithmetically exists in animals and young children at the stage pre-linguistic, although the use of language becomes very important in mathematical representation at a more advanced stage (Dehaene, & Cohen, 2000; MC closkey, & Caramazza, 1985). Mathematical cognition involves metacognitive functions commonly called executive functions, the three main components of which are inhibition, mental flexibility and working memory, the latter studied on the basis of Baddeley's model (Cragg & Gilmore, 2014) ; in fact, numerical representation and arithmetic processing in the context of mathematical reasoning require a conscious and active retention capacity, which is ensured by working memory (WM), which according to Baddeley and Logie (Demir, 2021), allows the store and process information while performing higher order cognitive tasks such as understanding, learning and reasoning such as solving an arithmetic operation;

In the standard Baddeley model (Coolidge & Wynn, 2020, 2022), working memory is a complex structure which consists of a central administrator, which represents the conscious control unit, the slave subsystems which allow the entry of visual and phonological information, provided by the notebook Visuospatial and the phonological loop with an intermediate component, the episodic buffer, an intermediate link between external stimuli and internal cognitive processing, in this vision working memory represents a real buffer zone between the perceptual input and the information stored in long-term memory under conscious attentional control (Hitch et al., 2020). It is necessary to distinguish between WM and short-term memory (STM), the first multi-component stores and processes data while the second consists of a simple register which is limited to momentary saving (Alloway et al., 2006).

Different studies establish a direct link between the deficit observed in working memory and arithmetic resolution in subjects who have difficulty learning mathematics (Kroesbergen & van Dijk, 2015; Friso-van den Bos et al., 2013), since this operation involves a momentary storage capacity associated with metacognitive processing (Garcia et al, 2016).

With a view to better understanding the difficulties in learning arithmetic among primary school students in Algerian schools, we assume that there is a significant correlation between the decline in working memory capacity and the deficit. recorded in the resolution of arithmetic operations and vice versa.

2- Methodology

2-1- Method

The purpose of this descriptive study is to evaluate the correlation between working memory and the ability of pupils with MLD to perform arithmetic operations, based on the idea that the manipulation of numbers and their active storage involves the intervention of working memory.

2-2 - Working framework

According to our research resources, we limited our field investigation to six primary schools, located in the department of Tizi ouzou, Algeria: Siaci Amar1et2, Abarane, Snaoui Ali, Hadjadj Boussad, Yahia Ali. Data collection took place during the year 2023.

3- Sample

Our population is made up of 321 pupils aged 7 to 8 years old, educated from 2nd to3rd year of the primary cycle; Based on the diagnostic criteria established by the DSM 5, we eliminated subjects with all types of deficits, auditory, visual, intellectual, unfavorable economic situation and psychological state in consultation with the clinical psychologists, educationalists, teachers of these establishments; we undertook continuous monitoring over 6 months, which corresponds to the 1st and 2nd quarter of schooling, where we collected the academic results relating to the quarterly calculation exams; These scores were entered into the IBM SPSS Statistics 20 software, in order to calculate the distribution of scores in terms of quartiles and percentiles, this allowed us to identify pupils who present MLD, which are included in the standard deviation [- 1,-2], and limited according to Geary (2011), between the 25th and 11th percentiles, not to be confused here with potentially dyscalculic students with a standard deviation < -2 or at the 10th percentile, as shown in table 1 of the distribution scores relative to the average of the scores of the 1st and 2nd quarter, for the 310 students.

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Table 1: *Ranking of averages in percentiles*

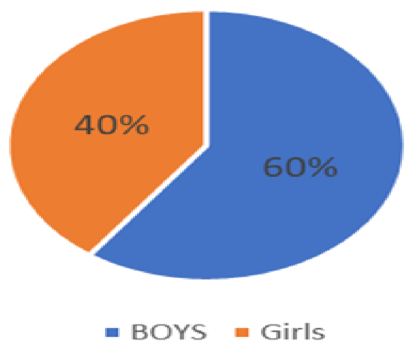
	Percentiles						
	5	10	25	50	75	90	95
Average of quarterly results 1 and 2	1.2875	2.8700	5.6875	8.4350	9.2500	9.8340	10.0000
Tukey hinge values			5.7500	8.4350	9.2500		

From Table 1, we retain pupils whose arithmetic scores are between 5 and 2 as students with MLD, which corresponds to the ranking of the 1st to 25th percentile, with a total of 30 pupils as detailed in Table 2 and Figure 1.

Table 2 : *Sample characteristics*

	Boys	Girls	7 years	8 years	2nd year	3rd year
Number	18	12	10	20	9	21
Percentage	60%	40%	33.33%	66.66%	30%	70%

Figure 1. *Indicates the proportion of the sample by gender*



Note that the proportion of MLD boys is greater than girls as noted in previous studies (Badian, 1999; Barbaresi, 2005), although other studies indicate a superiority of boys in arithmetic and mathematics in general (Stoet & Geary, 2012), due to a biological disposition for the conscious manipulation of spatial thinking (Penner, 2008).

4- Work tools

The evaluation of the correlation between arithmetic scores and working memory involves the use of two evaluation tools:

4-1- Evaluation of the resolution of arithmetic operations

We used the battery for the evaluation of number processing and calculation in children - Algerian adaptation ZAREKI-RA, (Hacene, & Belkheir, 2018). The overall battery life is between 30 and 47 minutes.

The battery consists of 12 tests, for the present study we limited ourselves to two tests:

- Test number four: Oral mental arithmetic.
- Test number eleven: Arithmetic problems presented orally.
  - Test number 4: Oral mental arithmetic.

We can detail the content of test number 4 in table 3

Table3: *Details of test number 4*

Operation	Number of items	Example	Rating
Addition	8	5+8 = ; 6=12 =	0-1-2 total out of 8
Substraction	8	17-5 = ; 14-6 =	0-1-2 total out of 8
Multiplication	6	2×3 = ; 6×2 =	0-1-2total out of 6

For test scoring 4, 0 if no answer or incorrect answer, 1 if correct answer but after repetition of the question, 2 if the answer is correct without repetition.

- Test number eleven: Arithmetic problems presented orally.

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Test number 11 includes six arithmetic problems, presented orally, e.g.:
"Laila has 8 balls, she gives some to Amine. Now she has 3 balls left. How much did she give to Amine?"
For the scoring of test 11, 0 if no answer or incorrect answer, 1 if correct answer but after repetition of the question, 2 if the answer is correct without repetition. Total scores out of 12.
The application of the two tests is done orally without any written support, individually.

4-2- Working memory assessment

For the assessment of WM we used the Miller test (1956); this test has two parts:

- Digit span forward (DSF): Relating to the STM.

Seven series of numbers ranging from 3 to 9 digits, preceded by training of two series of 3 then 4 digits.

- Digit span backward (DSB): Relative to WM

Seven series of numbers ranging from 2 to 9 digits, preceded by training with two series of 3 digits.
For the administration and grading of Part 1, the subject must correctly repeat the proposed series, with the possibility of a second attempt. The rating is relative to the number of digits reproduced correctly for the last series before failure in two successive trials for the same series. For the second part he must be able to repeat the series in the opposite direction of his presentation, with the possibility of three attempts. The notation is relative to the number of digits reproduced correctly for the last series before failure in three successive trials for the same series minus 1, that is to say N= number of digits last successful series -1= Phonological memory span of digits.
The speed of verbal presentation of each digit for each series is one digit per second.

4-3- Data transmission and collection

The administration was carried out individually, isolated for each student, for both tests.

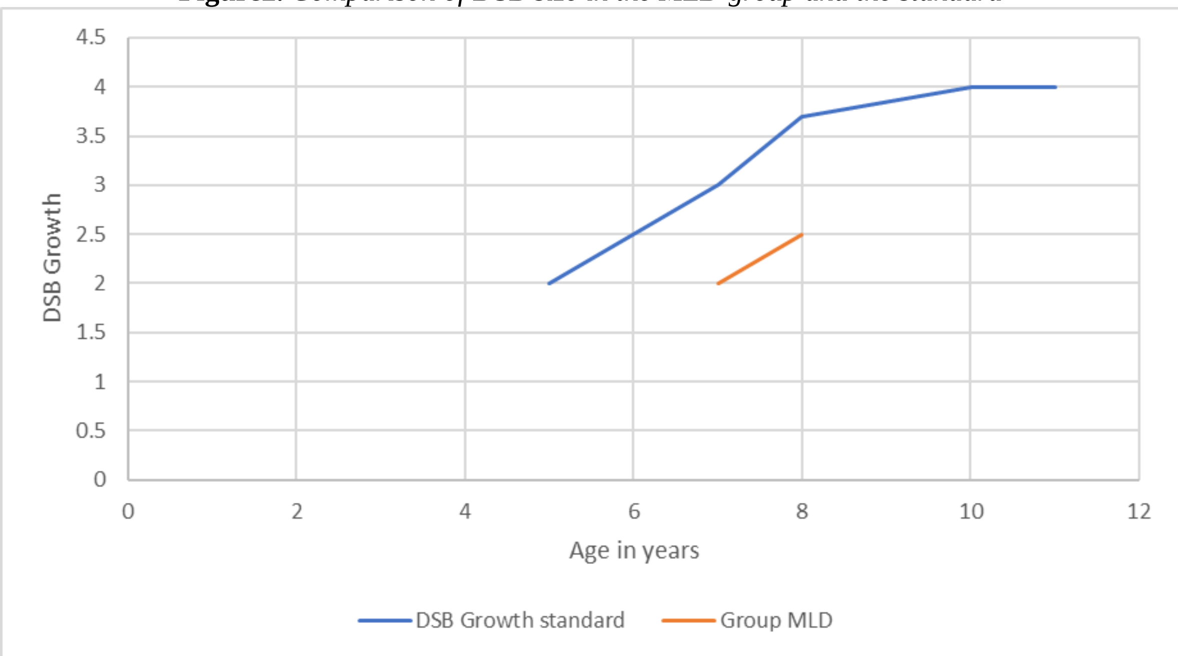
5- Results

We will carry out a comparison of the DSB scores with the standard, in order to see if our MLD group presents a deficit at this level, subsequently we will seek to understand the order of difficulties recorded between tests 1 and 2 relating to tests 4 and 11 of ZAREKI-RA. Subsequently we will carry out a correlation study between the DSF and DSB scores with those of tests 1 and 2.

5-1- Comparison of DSB scores with the standard

The aim of this comparison is to understand whether the selected pupils have a deficit in reverse recall (DSB). We based ourselves on the study by (Reynolds et al, 2022), carried out on a cohort of 18,000 American students aged between 5 and 11.5. As shown in the lower curve in blue (Figure 2). We placed the average score obtained in our group in comparison with the evolving curve of the DSB by age (orange curve).

Figure2. *Comparison of DSB size in the MLD group and the standard*



As shown in Figure 2, the DSB value in the MLD group aged 7-8 years with an average value of 2-2.5 is much lower than the standard value.

5-2- Comparison of test 1 and test2 arithmetic scores

The interest of this approach is to assess the degree of difficulty according to the type of operation required, distributed between four groups: group1 (addition), group2 (subtraction), group3 (multiplication), group4 (problem solving), in for this purpose we carried out an ANOVA analysis, followed by Tukey's test for comparison of means, as explained in table 4.

Table4 : *Intergroup differences*

(I) groups	(J) groups	Difference of means (IJ)	Standard error	Meaning
1.00	2.00	4.40000*	.85744	,000
	3.00	3.30000*	.85744	.001
	4.00	5.63333*	.85744	,000
2.00	1.00	-4.40000*	.85744	,000
	3.00	-1.10000	.85744	.576
	4.00	1.23333	.85744	.478
3.00	1.00	-3.30000*	.85744	.001
	2.00	1.10000	.85744	.576
	4.00	2.33333*	.85744	.037
4.00	1.00	-5.63333*	.85744	,000
	2.00	-1.23333	.85744	.478
	3.00	-2.33333*	.85744	.037

* The mean difference is significant at the 0.05 level.

The comparison of the scores clearly indicates an order of correct answers going in the direction of addition, multiplication, subtraction, problem solving, on the other hand the value of p, for groups 2 and 3 as well as 2 and 4 indicates that the students experience the same degree of difficulty in subtraction and multiplication as well as subtraction and problem solving.

5-3- Correlation of arithmetic test 1 and test2 scores and working memory

In order to calculate the assumed correlation between these variables. We obtained the results shown in Table 5.

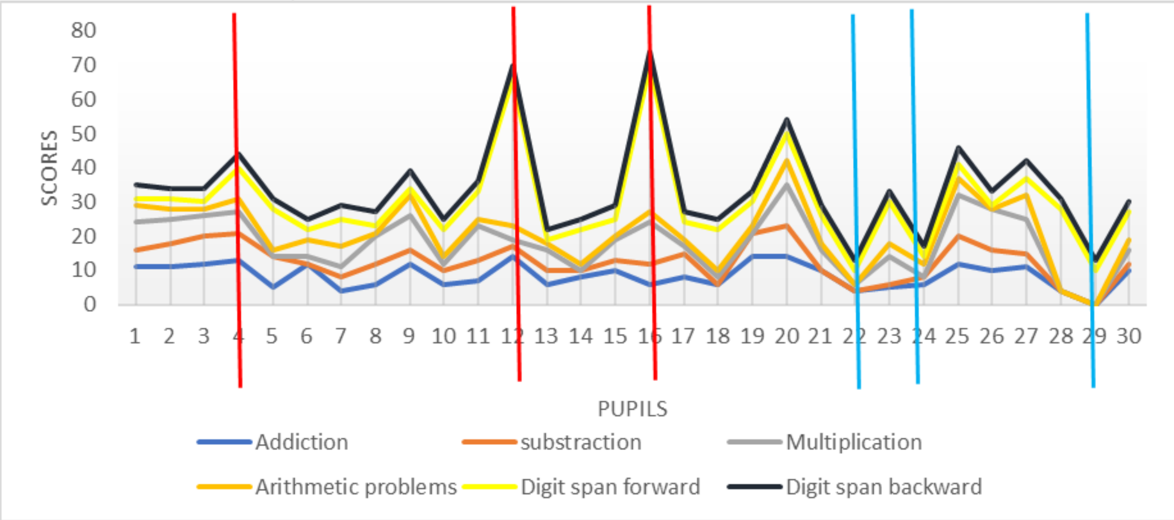
Table 5: *Results of the correlation analysis between arithmetic tests and working memory*

		Arithmetic problems	Addition	Substraction	Multiplication
DSF*	Pearson correlation	.495**	.457*	.404*	.658**
	Sig. (bilateral)	.005	.011	.027	,000
	NOT	30	30	30	30
DSB*	Pearson correlation	.429*	.415*	.366*	.406*
	Sig. (bilateral)	.018	.023	.047	.026
	NOT	30	30	30	30

* Digit span forward; ** Digit span backward

It is possible to represent these results through figure 3, which allows us to judge the points of convergence and divergence between the 30 MLD pupils.

Figure3. *Correlation points between different variables*



We notice from Figure 3 that there is a strong correlation between the arithmetic tests and those of working memory, the vertical lines in red make it possible to visualize the increase in scores for all the variables and vice versa in the case of reduction in scores, visualized here in vertical lines in blue.

6- Analysis and discussion

The results of the statistical analysis show that there is a significant correlation between arithmetic tests 1 and 2 as well as those of working memory, as we have seen through graph1, plus the storage capacity of the information is important in its passive form (STM), relating to DSF scores, or active (WM) for DSB scores, plus the results relating to the resolution of arithmetic operations (addition, subtraction, multiplication), or the resolution of problems arithmetic presented verbatim is important;

Working memory seems, in view of the results recorded, to play an important role in solving arithmetic problems and operations; solving a problem in general, and in the present study calculation, involves conscious processing at a metacognitive level (Top-down), it is not a question here of saving digits or numbers randomly, but good to keep them in an orderly manner in order to execute a set of logical steps or rules that allow you to find the results. It must be said that WM plays an important role in cognitive processing, moreover Diamond (2013), defines it as the conscious space which allows the various executive functions to be carried out, including WM, such as mental flexibility, inhibition, programming and problem solving.

In all arithmetic operations the pupil must save the digital data, in order to carry out processing based on the recall of the rules or strategies stored in long-term memory, or the Buffer seems the point of correspondence between the two memory systems (Nobre & al, 2013). Note that Table 4 indicates greater difficulties in subtraction and multiplication. Working memory seems more required in subtraction than in addition where the degree of difficulty is greater. For multiplication, the strategy adopted is to directly recall pre-recorded scores in LMT, on the basis of multiplication tables, errors of confusion between close scores (e.g. 5x4=25 instead of 20) can be explained by the use of a purely verbal recall at the WM level, a strategy widely used for learning multiplication from the 2nd to the 3rd year of primary school, while a pupil from the 4th year onwards must resort to visual recall strategies, and a written manipulation of operations (Soltanlou et al, 2015). Higher scores in multiplication compared to subtraction imply a facilitative effect of the immediate recall effect in the latter compared to subtraction (Campbell, 2008) which integrates solution strategies that involve WM and other executive functions. Note here the greater involvement of the STM in multiplication with $r = 0.60$ compared to $r = 0.40$ for the WM, that is to say that the pupils examined rely much more on the STM in multiplication with the use of a more automated verbal reminder but with a risk of confusion as we have seen.

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Note also that the lowest scores were recorded in problem solving, in this situation the subject must save a long verbal instruction, composed of words, numbers and assembled syntactically, which requires a greater memory load. important on the phonological loop, with tasks of comparison, deduction, in addition to the morphosyntactic analysis of the instructions. While in a simple arithmetic operation, such as addition, the pupil must proceed with a single step to find a score based on a direct strategy, in solving a multi-step word problem, he must construct a treatment plan with several procedures adapted to the specificity of the problem which involves more in-depth cognitive processing;

Indeed, multi-step word problems are more complex and their solutions require children to formulate a plan and coordinate procedures rather than simply applying an overlearned operation. This requires that they monitor their thinking and transfer and apply previously learned strategies to new problems (Agostino et al, 2010). Thus, different underlying cognitive processes can be identified depending on whether children use shortened or more meaningful strategies to solve a set of mathematical problems.

Note also that this type of problem integrates semantic representation by change and combination which allows you to move from a formal representation to a more abstract treatment, in this sense the involvement of WM seems much more important in terms of saving capacity but also active processing which makes it possible to predict the direction of change, for example decreasing, if situation A =3, situation B = 3-2, therefore situation C =1.

As we have just seen, language is a key element in solving arithmetic problems, it is involved in the semantic representation of the values of numbers in terms of cardinality and ordinality (Dehaene & Cohen, 2000; Mc closkey & Caramazza, 1985), the understanding of the mathematical instructions on the verbal level and its abstraction is very important in mathematical performance (Singer & Strasser, 2017), therefore comprehension problems relating to language could seriously hamper mathematical performance in subjects MLD.

Working memory alone cannot explain these difficulties, executive functions and logical processing (Bull & Lee, 2014; Cantin et al, 2016; Stolte et al, 2020) are involved, to a large extent, in the resolution of arithmetic problems and must be taken into consideration.

Conclusion

Learning arithmetic is a fundamental operation in the construction of knowledge in humans. This high-level cognitive operation requires the ability to actively retain encrypted data; the learner must save this information in short-term memory (STM), but also actively manipulate it on the basis of processing and prediction strategies learned subsequently. but adapted to the specificity of the arithmetic situation, as we have seen for example for the resolution of problems presented verbally. This metacognitive processing directly involves the WM, which plays a central role in this operation, on the one hand it allows a momentary saving of data thanks to its STM component, it allows the strategies saved in MLT to be recovered thanks to the Buffer, as well as the treatment of the semantic meaning of the problem. The results of the present study indicate a strong correlation between arithmetic processing, whether basic operations like addition or more advanced and complex ones as we saw for the arithmetic problems in the test11. The difficulties recorded in pupils who present mathematics learning difficulties (MLD), would be seen in the correlation scores with those of the phonological memory span of the WM, the lower this span, the more the calculation scores are low with more errors, particularly omission or confusion, as shown in figure3. Although WM seems to clearly contribute to mathematical processing, particularly in our arithmetic situation, other functions intervene and must be the subject of studies in this sense such as executive functions and language comprehension, which alone can be a real obstacle to the abstraction which is the basis of mathematical representation.

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