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PhD THESIS

PSYCHOLOGICAL AND EDUCATIONAL ASSESSMENT OF CHILDREN WITH SPECIFIC LEARNING DIFFICULTIES IN MATHEMATICS FOR A SUCCESSFUL INCLUSION

- SUMMARY -

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TABLE OF CONTENTS

Chapter III
Methodology of assessment in Mathematical learning difficulties

Chapter IV
Reasearch objectives and methodology

Chapter V
Original research

The Research Topic and its Relevance

When doing a complex assessment of the students with mathematics learning difficulties for their school inclusion and recommendation of appropriate support services, we are faced with the lack of a proper conceptual and procedural framework. This is largely due to a controversy that exists in the field regarding the development of mathematical skills and etiopathogenic mechanisms of such disorders.

Number and calculation processing models, as well as the explanatory ones for learning difficulties in Math are different for children and adults. Although adult neurophysiology has made great strides towards explaining and characterizing acquired dyscalculias, this is not the case with learning difficulties in the field of Mathematics. In the latter case, we face the issues of the difficulties in learning a complex subject, learning which is done on the basis of several psychological factors, that develop unevenly and that get involved differently at different moments of the individual development. Mathematics is a complex object due to least two reasons: it includes a rich family of mathematical disciplines and it puts into work a wide range of psychological factors.

The concentric organization of teaching mathematics, conducted by the math curriculum, expects that the student builds new knowledge and skills on existing ones. Thus, learning problems can occur at any level. In this context, it explains the heterogeneity that exists in the field regarding the diagnosis of math learning difficulties, existing classifications, disorder explanatory models and models of intervention in their case. Moreover, at present, new directions in addressing learning difficulties are emerging, such as the "response to intervention" model, cutoff point model, and the discrepancy model, which proved ineffective, was given up.

We are interested in how to integrate into these new models, the screening, evaluation and diagnosis of specific math learning difficulties at an early stage of formal learning of mathematics, through the cognitive approach to evaluation. Specifically, starting from the current theories on the development of mathematical skills and the processes that are the basis of learning difficulties, we propose to investigate, through a methodological variety the nature of the relationship between general cognitive abilities (such as working memory), numerical-specific skills and Math performance. The research addressing the relationship between cognitive abilities and the number-specific ones that affect math learning are just *getting started, but are essential for building an explanatory model of skills development in the field of mathematics and math difficulties (Raghubar et al., 2010).*

Studying this relationship in first grade students, at a time in math education when there is an important qualitative leap, is relevant not only to build an explanatory model of math learning difficulties, but also to identify those aspects of the relationship relevant in screening children at risk of developing learning difficulties in mathematics.

Thus, we are interested not only in finding the psychological factors that support performance in mathematical tasks, but also the psychological factors that are relevant for developing mathematical skills during first grade, whose impairment would lead to expressing learning difficulties in mathematics.

Chapter I.
Current theories on math learning difficulties

The psychological and educational assessment of children with learning difficulties in mathematics can not be achieved without a thorough knowledge of the object of assessment. For this reason, in Chapter I we considered necessary to take stock of current legislative and operational definitions, terminology used (with the existing partial synonym), specific explanatory theories that existent in the field. Out of these theories, two are of interest to the present research in that the research bases part of its methodological approach on them. Consequently, out of all the explanatory theories in the field of mat learning difficulties, our approach is strongly anchored in the theories of cognitive skills deficiencies in math learning difficulties. Among them, Geary's theory (2004) argues that learning difficulties in mathematics are based on deficits in the cognitive systems that support the conceptual and procedural skills in math. Out of these systems, an important role is assigned to the central executive component (or working memory, according to the unitary models) which is responsible for allocating attention resources, for the inhibition of information that is irrelevant to the mathematical task or for maintaining activated the information needed for the task. The representation of the information in the cognitive system and the manipulation of these representations are allegedly supported by verbal and spatial-visual systems.

This model can explain three of the learning difficulties subtypes detected by Geary (1993). Geary (2004) formulates or synthesizes several different assumptions about the deficient cognitive functions that would be responsible for math learning difficulties. Of these, we mention the involvement of working memory, specifically of the central executive component, through some of its functions (inhibition of irrelevant information, updating information from long-term memory, maintaining activated the information needed for the task). Within the original conceptual scheme for identifying math learning difficulties, Geary has not introduced, but only mentioned as an alternative to the systems of representation and manipulation of information, a separate specialized modular arithmetic system (Geary and Hoard, 2005). On the opposite side and in agreement with this alternative representation we find the theories explaining the learning difficulties through the deficits in mental representation and manipulation of numerical quantities.

Therefore, in Chapter I, we review the three hypotheses which are currently intensively investigated: the numeric sense deficit hypothesis (Dehaene, 1997), the access deficit hypothesis (Roussel and Noel, 2007) and numerical module deficit hypothesis (or accurate processing of magnitude) (Butterworth, 2005). Therefore, according to Dehaene (1997), children with math learning difficulties present damage in the representation system of quantity approximation. According to access deficit hypothesis (Roussel and Noel, 2007), the link between symbolic numeric representation and the non-symbolic one would be affected.

According to the third hypothesis, learning difficulties would be based on a deficit in exact processing of numerical size (Butterworth, 2005). Talking about the heterogeneity of learning difficulties manifestations, we also reviewed the classifications of different forms, in chronological order, in order to also reflect the theoretical developments that have occurred in this area especially in the last two decades. The new classifications attempt to solve the problem of heterogeneity through the existence of different causal factors and in relation to different forms. In this regard, we mention Wilson and Dehaene's typology (2007).

Learning difficulties in mathematics are found both isolated and associated with other disorders, so their knowledge is required in terms of differential diagnosis. Knowing the frequency with which these difficulties are manifested in the population is, from the evaluation perspective, in a reference point on which to report accurate identification. This knowledge about math learning difficulties are the result of a long process conducted over several decades by researchers and research groups or interested practitioners and professional and parent associations. Research and knowledge of math performance and cognitive profile of children with learning difficulties is important both for grouping into types and to find bridges between the biological, psychological and behavioral levels.

Chapter II.

Psychological factors implicated in the development of mathematical abilities in sustaining mathematical performance.

The approach of evaluation in the field of math learning difficulties has certain peculiarities, among which the most important is given by the key element that distinguishes them from acquired dyscalculias, namely that math learning difficulties are installed in the process of development of mathematical skills. It is important to gather data on the theories of developmental psychology that discusses the development of mathematical skills.

Currently, out of the developmental psychology field, two major perspectives that address the issue of developing mathematical skills are active. One is drawn from Piaget and continued by piagetian descent, in which the development of mathematical skills runs parallel and based on the development of logical structures. Formation of the concept of number would make the foundation of conceptual and operational tools.

The forming of the number concept would be made based on operational and conceptual instruments. Counting, in their design, would have no operational value. At the other side, we find the theories that show the presence of mathematical skills in infants, long before the milestones that Piaget gave (supported by data from the developmental psychology ,of ethology, but also from the field of neurophysiology) (Wynn, 1992;, Dehaene, Piazza, Pinel, Cohen, 2005) and which support the hypothesis of specific innate numerical abilities. Controversy exists in the second category as well, on how arithmetic skills develop from these basal quantity processing systems. Some researchers (Gallistel and Gelman, 1992, Fuson, 1988) place high importance to counting, in the transition from approximate non-symbolic math processing to the exact symbolic and approximate one.

Depending on the direction that we embark on, we opt to search either general cognitive skills that support math performance, or specific numerical skills. Controversy is maintained in the theories of number processing and calculation, in the types of representations that support such processing. However, we can not overlook the fact that the existing models explain dissociations occurring in mathematical task performance in adults with acquired dyscalculia, but learning difficulties are installed somewhere in the process of development of arithmetic skills. For this reason, we have described the model of cognitive development of the representation of the number (von Aster and Shalev, 2007). This model allows the formulation of causal hypotheses on possible neurophysiologic dysfunction of development dyscalculia, as it establishes links between the mathematical and pre-mathematical skills, development of working memory capacity, type of representation involved in processing and the neurophysiologic substrate that would support them. Of course that the relations among these cognitive abilities and mathematical performance are not fully clarified. Mathematics is a complex field which requires a large number of cognitive and non-cognitive abilities. Out of the most frequently discussed cognitive abilities in the literature are intelligence, working memory, verbal abilities, and visual spatial abilities.

The relation between these and mathematical performance is a complex one mediated by multiple factors (of which we mention chronological age, gender, level of schooling, social economic status, mathematical sub-domains etc.). In this chapter we review results of current studies that address these relations. Therefore we address the relation between phonological abilities and developing arithmetical abilities, between visuo spatial abilities and mathematical abilities, and with general cognitive abilities (such as fluid intelligence and working memory).

Our qualitative theoretical synthesis encompasses studies in which the mentioned relations are analyzed from several perspectives (componential, based on type of processing and on types of mathematical tasks).

Chapter III.

Methodology of assessment of math learning difficulties.

In the last decade the field of assessment of learning difficulties has been substantially transformed as a consequence to the numerous critiques to the discrepancy model. New model have appeared of which we described response to intervention model, cut off point model and neuropsychological models. Based on the discrepancy between the level of performance and the ability level, achievement tests and general cognitive abilities tests were widely used. Currently, achievement tests are used in diagnosis, but a cutoff point is applied to mark the limit from where a significantly low performance starts, which is indicative of deficits in cognitive abilities that sustain mathematical abilities.

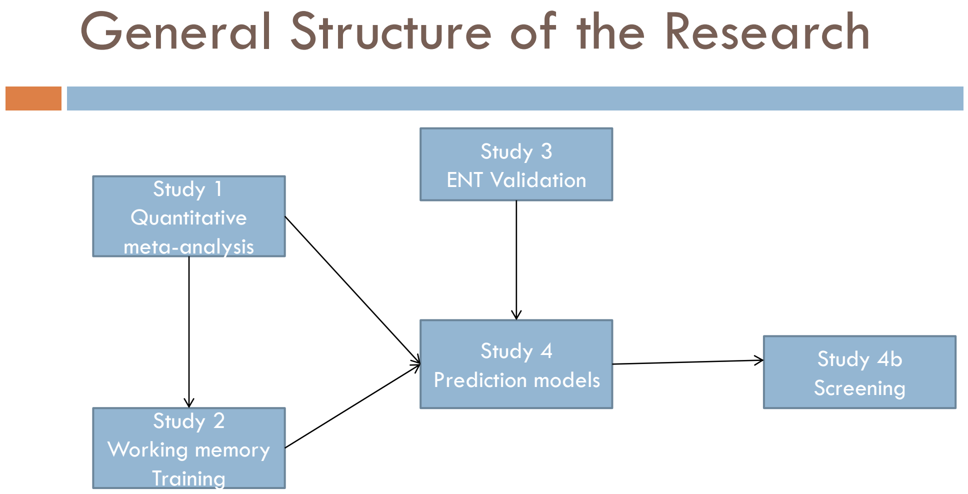
If we consider arbitrary and relative such a cutoff point and we option for response to intervention, then we would put greater emphasis on curriculum based instruments. For a detailed analysis of performance profiles and for causal interpretations, it would be recommended to use instruments built on neuropsychological models or theories on number and calculation processing or other components of mathematical abilities. Regardless of the chosen model, it remains extremely important the early identification of learning difficulties or of children with high risk to develop such difficulties.

However, unlike in the field of reading difficulties, in mathematical difficulties there is no agreement upon a single combination of abilities that would represent a strong predictive model of math learning difficulties (Seethaler and Fuchs, 2010). In the literature, two types of screening instruments are described: screening on the basis of cognitive variables and screening based on assessment of early mathematical competencies.

Chapter IV.
Research objectives and methodology

A first general research objective is to emphasize the role of working memory in mathematical performance in children with such learning difficulties. In order to achieve this objective, we have employed three distinct methodological approaches with specific objectives: synthesizing studies that analyze individual differences in working memory in children with Math learning difficulties and normally achieving through a meta- analytical study. The second approach aims at emphasizing the predictive role of working memory over mathematical performance. The third approach indexes the impact of modifiability of working memory abilities over arithmetical performance of students with low achievement in Mathematics. Mathematics is a complex object, and learning supported by the combined action of several factors. Even if working memory plays an important role in sustaining performance and development of mathematical abilities, it needs to be seen not in isolation, but in interaction with the other factors.

Therefore, the second objective addresses the development and validation of predictive models for the development of mathematical abilities of primary students. We illustrate underneath, the general structure of the research.



Study 1 represents a quantitative meta-analysis of the research literature comparing working memory abilities in persons with Math learning disabilities/difficulties and the normally achieving, based on the multi-componential working memory model of Baddeley and Hitch (1974). We will investigate separately effect sizes in the case of all three working memory components. Given that numerical measures of working memory are more frequently associated with math learning difficulties, in our study we will include a supplementary analysis to address the effect size on numerical and non-numerical working memory tasks.

After addressing the hypothesis of a numerical specific working memory deficit in math learning difficulties, in study 2 we investigated the effect of numerical specific working memory training on the arithmetical performance of third graders with low achievement in Mathematics. Training the capacity to store numerical material concomitantly with performing a processing task should lead to better calculation abilities, given the important role of working memory in Mathematics.

Based on results of previous studies, we aimed at further analyzing if and in what way general cognitive abilities (fluid intelligence, working memory), numerical abilities (counting and approximate processing of quantity) relate to performance in tasks of calculation and knowledge of numbers and number system. In order to achieve this objective, first, we have adapted and validated in study 3, an instrument for the assessment of early mathematical competency, given the lack of such instruments in Romania.

In order to better analyze the role of working memory in the development of mathematical abilities, working memory was introduced along with other general and specific numeric abilities in prediction models, for a better isolation of its specific role. The development of such models and their theoretical and practical implications are described in study 4.

Chapter V.
Original research

This chapter encompasses four research studies that represent author's original contribution to the research topic.

Study I. Working Memory Deficits in Math Learning Difficulties: A meta-analysis

Introduction

Given that a large number of studies address the role of working memory in Math cognition using various methodologies (for a review, see *LeFevre et al.*, *2005*), and the variety of the psychological instruments for the assessment of working memory and mathematical abilities, in the present study, we conducted a quantitative synthesis of the literature comparing children with Math Learning Difficulties to average-achieving, age-matched children on measures of working memory, in view of Baddeley's multi-componential working memory model (*Baddeley and Hitch*, 1974).

Given the fact that Mathematics is a complex subject, which requires multiple cognitive abilities, we hypothesized that all three components of Baddeley's working memory model should display deficits in children with Math learning difficulties as compared to average-achieving, age-matched children. We will separately investigate the correlation between age and size effects on all three working memory components. We hypothesize that working memory deficits are a function of age. If there are any working memory differences in children with Math learning difficulties as compared to average-achieving, age-matched children, are they much greater for numerical information than for non-numerical information? We hypothesize that children with Math learning difficulties would present more accentuated working memory deficits for numerical material and/or processing than for non-numerical.

Method.

Identification of studies

For the identification of studies we proceeded to search in electronic databases (Ebsco, Sage, Proquest, Science Direct, PsychInfo), using key- words related with the topic and selecting the studies based on inclusion criteria: a. to compare at least one group with Math learning difficulties and one average- achieving, age- matched group on measures of working memory; b. to clearly state the diagnosis criteria for Math learning disabilities; c. to use norm-referenced standardized measures of Math performance and Reading performance; d. to use specific measures of working memory; e. Math learning difficulties not to be associated with Reading disabilities (mention at least one measure of Reading skills and an average performance in Reading of the MLD group). f. to offer enough quantitative data for the computation of effect sizes (means, standard deviations for working memory measures; IQ, Reading and Math scores). Based on these inclusion criteria 18 studies of the total 40 studies were retained for further analysis.

The tasks were then coded for Phonological loop, Visual spatial sketchpad, and Central executive component, according to their descriptions. The tasks were also coded for numerical and non- numerical information, based on whether they involved the processing and manipulation of numerical information, such as numbers delivered in any format. Measures of the visual-spatial sketchpad are only non-numerical and therefore are not included in this type of analysis. Calculation of effect sizes was done according to published procedures (*Hunter & Schmidt, 2004*).

Results

Cohen’s criterion was used in order to interpret the magnitude of the effect sizes (small effect: 0.2 - 0.5; moderate effect: 0.5-0.8; large effect: > 0.8). In interpreting the results, we also considered the above mentioned confidence intervals. If the confidence interval for the computed effect size included 0, then the effect size was considered non-significant. Effect sizes were corrected for sampling errors.

Based on the correction formula in the case of Central Executive Component we obtained D= -0.93, Var D= 1.58, 95% CI= (-1.53; -0.33). A large effect size on measures of Central executive component is a strong indicator of an existing difference between Math learning disabled and average achieving, age- matched counterparts on this dimension. The mean of effect sizes on measures of visual- spatial sketchpad is in the moderate range of Cohen’s criteria (D= -0.51, Var D = 0.12, 95% CI= (-0.87; -0.31). Again, a negative result indicates an effect size in favor of the average achieving, age-matched group. For the Phonological loop, a mean of D=-0.36, var D = 0.14, 95% CI= (-0.57; -0.15) situates the effect size in the lower range.

A mean effect size was computed on each of the three working memory components for numerical and non-numerical measures. One mean effect size was situated in Cohen's large effect range (D= - 1.29), for comparisons on Central executive component measures of numerical nature. A moderate effect size was obtained for comparison on Phonological loop numerical measures (D=-0.52). The effect size for Central executive non-numerical measures is situated in the moderate range (D=-0.56). Corrected mean effect size for Phonological loop non-numerical is situated in the weak-to- moderate range (D=-0.43). Among verbal working memory measures, the largest effects sizes on comparisons of Math learning disabled to average- achieving, age- matched controls were for measures of numerical nature.

In order to investigate whether there is a linear relationship between effect sizes and age, we conducted a regression analysis as described by DeCoster (2009), where we considered age as a continuous moderator. In the case of PL the results showed no relation between effect size and age (Z= 0.77), while, for both VSSP and CE, we obtained significant results (for CE Z = -13.37 while for VSSP Z = -10.12), which revealed a significant linear relationship between age and effect sizes. It is a reverse relationship between size effect and age. Differences in performance of MLD as compared to average-achieving, age-matched children are greater at younger ages than at older ones, but only on measures of Visual spatial sketchpad and Central executive component.

Discussion:

The results indicate a strong effect size (D= -0.93) in favor of the age- matched, average- achieving groups on measures of Central executive component, but only a moderate effect for the Visual spatial sketchpad, and a weak effect for the Phonological loop. A strong effect size for group comparisons on Central executive component is consistent with previous findings (*LeFevre et al, 2005; Geary, 2010*). Most of the Central executive tasks included in our study were concurrent span tasks that required the participants to concomitantly manipulate and store predominantly verbal information.

These types of tasks may tap the switching function of the Central executive component. McLean and Hitch (1999) introduced variations in the type of information and designed specific tasks for Central executive functions. Their findings were significant in Making Trails and Missing Item, indicating a Central executive deficit responsible for faulty retrieval of task- relevant information from long- term memory, and for difficulties in switching between tasks. Most of these studies (see *LeFevre et al., 2005* for a review) subscribed for a domain- general deficit in Central executive component, but in our study a stronger effect size emerged for Central executive measures of numerical nature (D=-1.29). Such measures included digit span backwards, counting spans, making trails tasks etc. An example of a non- numerical Central executive task is Daneman and Carpenter's listening span task (1980). Phonological loop tasks typically required for the active storage and repetition of a verbally provided material.

The mean effect size on numerical Phonological loop measures indicates a moderate effect (D= -0.52). These differences indicate that some other functions of the Central executive component (such as simultaneous coordination of two operations, inhibition of distracters, and switching between tasks) were affected rather than the storage component of working memory. A weak-to-moderate effect size was obtained on non-numerical measures of Phonological loop (D= -0. 43) still in favor of the age- matched average achievers. By corroborating these results with a previous meta- analytical study (*Swanson and Jerman, 2006*), we can identify a consistency in results on visual- spatial working memory (M= -0.63), but not on verbal working memory (M= -0. 70). Based on our findings, we conclude that Phonological loop deficits do not underlie Math difficulties. At the same time, a stronger emphasis should be given to the Visual-spatial sketchpad memory deficits.

A visual- spatial working memory deficit seems to moderately differentiate between poor mathematicians and average- achievers, especially at younger ages. Schuchardt et al. (2008) McLean and Hitch (1999), van der Sluis et al. (2005), Geary et al. (2007) found significant differences between the two groups on measures of Visual- spatial sketchpad. Moreover, certain measures, such as backward digit span, considered to tap the Central executive component, may involve a visual-spatial type of representation and processing (*Raghubar et al., 2010*).

Therefore poor performance on such tasks could be more indicative of a Visual-spatial memory deficit, rather than Central executive. Larger effect sizes on numerical measures for Central executive, together with a moderate effect size for numerical measures of the Phonological loop, as compared to the non-numerical ones, come in support of domain-specific working memory deficit hypotheses. Moderate effect sizes emerged for the non-numerical measures of Central executive and weak for Phonological loop non-numerical measures.

These findings support the idea of a working memory deficit in numerical stimuli processing, and are consistent with Passolunghi and Cornoldi (2008). Raghubar (2010) interprets such findings as consistent with studies demonstrating importance of domain specific knowledge (i.e. numerical knowledge) to performance on more general cognitive abilities (memory). Such an interpretation can be more plausible given a moderate effect size for the non-numerical Central executive measures.

In other words, Math learning disabled (MLD) have a poorer performance on CE measures as compared to average-achieving, age- matched children, but these CE deficits are even more accentuated for numerical measures. This is not unusual since it is acknowledged that this numerical domain is impaired in MLD children (*Raghubar, 2010*). The results indicate that Math learning disabled are moderately impaired in Visual- spatial working memory tasks which are non- numerical in nature.

The two subsidiary systems of Baddeley and Hitch’s working memory model are not equally impaired in persons with Math learning difficulties as compared to average achievers in Mathematics. This could indicate that not the coordination function of the Central executive component is affected, but other functions. On the other hand, this finding can be explained also by a stronger relation between Visual- spatial sketchpad and Central executive component, such as that a classical Visual spatial sketchpad span task imposes stronger loads on the Central executive than a Phonological loop span task does (*Miyake et al., 2001*). In other words, the observed moderate effect size of the Visual- spatial sketchpad may be due to its heavier load on the Central executive component.

The coexistence of a spatial working memory deficit with numerical Central executive deficits in the large group of Math learning difficulties can be reconciled with the existence of different impaired mathematical profiles in this category.

Fourth, we investigated to see whether age moderates variations in effect sizes per working memory component. It is documented that the relationship between working memory and Math skills varies as a function of age (*Alloway, 2006*). Indeed, age mediates the effect size for the difference in performance on Central executive and the Visual spatial sketchpad tasks, when comparing MLD to average-achieving, age-matched individuals. In the case of Phonological loop this effect was not significant, which can also be explained by the lack of variation in age in our data collection for PL measures. Most studies that had Phonological memory measures had groups with mean ages between 8 and 10 years.

Overall, the deficit or delay in the Central executive component is persistent, probably domain-general, still more accentuated in younger ages, when it acts as a bottleneck for academic learning. Moreover, this delay or deficit in the Central executive component can explain the specific pattern of procedural competence of children with MLD and low achievers (LA), with more procedural errors in computation and with immature strategies kept for longer periods of time (*Geary, 2004; Geary, 2010*). The fact retrieval deficit, which is rather persistent in MLD and a certain group of LA, can be explained in at least the case of the former, as difficulties in one of the Central executive functions, that of inhibition of irrelevant information.

Also, some researchers indicate that there may be differences in academic and cognitive performance between MLD children with Math performance under the 11th percentile (MLD), and those, now considered LA, with performance between 11th and 25th percentile (*Geary, 2010; Murphy et al., 2007*). When reviewing evidence for differences in working memory involvement in Mathematical domains for MLD and LA, Geary (2010) states that MLD have pervasive working memory deficits in all three components, while LA may have some subtle deficits of Central executive, such as in switching between tasks and in inhibiting irrelevant information. Only few studies that corresponded to our inclusion criteria investigated distinctively the relationship between working memory and poor Math performance in these two groups. Most of the studies classified MLD based on a performance below the 25th percentile on a Math standardized measure, including also what is currently called low-achievers. Moreover, researchers have indicated that there may be differences in working memory performance in these two groups (*Murphy et al. 2007*) at least on measures of Central executive. Due to the small number of studies we were not able to emphasize any involvement of severity of Math learning difficulties over variations in working memory performance.

Practical applications:

An important implication of these findings for practice is in the area of identification and diagnosis of learning disabilities. It seems that working memory deficits are greatly related to Math learning difficulties, especially in the functioning of Central executive component and only moderately for the visual- spatial sketchpad. Our findings cannot indicate whether these working memory deficits are specific to Math Learning Difficulties, but they come in support of Geary's conceptual schema (1993) for identification and study of potential Math Learning difficulties. He used this framework to explain procedural deficits, visual spatial deficits, and some of the semantic memory deficits by faulty working memory mechanisms. Another implication for practice, still in the field of identification and study of Math learning difficulties, is the finding of a more accentuated effect size of the comparisons on numerical measures of working memory, in favor of age- matched individuals with average performance in Mathematics.

These Central executive numerical tasks seem to be indicative of Math learning difficulties. Such findings may indicate the need for more specific interventions in training working memory (training specific functions of the Central executive component), concomitantly with interventions designed to form and/ or consolidate correct representations of numbers and their relationships. Also, given that MLD encounter more difficulties in tasks of Central executive component, and CE is much needed for problem solving, instructional adaptations may be introduced through reducing the load on the CE component.

Study 2. The effect of numerical specific working memory training on mathematical performance of student with low achievement in Mathematics.

Our hypothesis is that, if the MLD students show a lower attention control because of numerical material and / or numerical processing, than training this function in specific mathematical situations will improve Math performance in arithmetical problems, especially in additions and subtractions (not so often in multiplications), where arithmetical facts are not automatic and therefore an active manipulation with numerical material is needed, together with a temporary storage of partial results and intermediate steps. Intervention will not aim at improving working memory capacity as measured by memory span, but will focus on improving performance in simultaneously managing the storage and the processing with numerical material.

Method

Participants

Participants were third graders from a school in Cluj-Napoca. Those were administered the pre-test assessment, after obtaining parent consent in proportion of 94% of the cases. All students are enrolled in regular programs; none had a clinical diagnostic. Pretest was administered to a number of 72 children of the three grades, all third graders. Based on pre-test results, participants with low scores (N = 20) were selected and assigned to two groups (experimental (N = 10) and control (N = 10)). We only considered low achievers in Mathematics, based on whether their performance was at least one standard deviation under the mean of the group. Each group consisted of an equal number of students from each grade, in order to avoid any influences of the teaching style and pace of teaching. Given the small size of experimental and control group, in baseline we used paired sampling instead of randomization.

Procedure

One week before the training, participants were tested with a calculation fluency task and a working memory task. One week after the training, post-test measures were administered and participants were rewarded.

Measures

Calculation fluency measures consisted of a sheet with 81 single-digit arithmetical problems. Children had to solve as many as possible in 90 seconds per each sheet. One sheet contained simple single-digit additions, one single-digit subtractions, and one single-digit multiplications.

Working memory measures: Digit span subscale from Wechsler Intelligence Scale for Children (Wechsler, 2003) was also administered to measure working memory abilities with numerical material.

The training program was conducted over a 3 week period, with 2 weekly sessions of 50 minutes each. Sessions were conducted in small groups of 4-5 children to facilitate group discussions and to reduce the demands on the working memory group tasks. This type of training addressed the enhancement of working memory abilities specifically in the numerical domain and it contained not only numerical material, but also numerical processing. All activities were designed in order to contain concomitantly temporary storage of numerical information and processing, according to current definitions of working memory (Engle et al., 1999).

Results

In pretest there were no differences between groups on calculation tests and working memory performance. Comparison between pre and post test measures using Wilcoxon statistical test, showed significant differences between the two moments in the case of the experimental group (except for subtraction), but non-significant in the case of the control group.

Table 1. Pretest - posttest comparisons - Wilcoxon

	experimental group Z values	control group Z values
Addition	2.8^{**}	0.7
Subtraction	1.4	0.82
Multiplication	2.31^{*}	0.71
Digit span forward	2.52^{**}	0.27
Digit span backward	2.04^{*}	1.69

Note: ** significant at $p < .01$; * significant at $p < .05$

Table 2.

Mann Whitney – posttest comparisons (U)

Addition	9	$p < .01$
Subtraction	31	$p > .05$
Multiplication	14.5	$p < .01$
Digit span forward	1.5	$p < .01$
Digit span backward	27	$p < .05$

Posttest comparisons between groups based on Mann Whitney statistical test, showed significant differences in favor of the experimental group, therefore in favor of the intervention. Numerical specific working memory training effect is expressed through an increase in speed and accuracy of addition and subtraction as well as an increase in working memory capacity.

Discussions

Based on the results we can conclude that students with poor performance in Math benefit from such a program aimed at the training of working memory through tasks with numeric content. However, the hypothesis was partially confirmed in the sense that there were improvements in working memory capacity and in the performance in computing with addition, but not with subtraction. The gain has been the increase in computing speed of addition and multiplication tasks. It is possible that other mechanisms are involved in subtraction, except for working memory loading on the phonological loop.

Within the training the attention control ability was trained by asking the participants to simultaneously manage a storage operation (of numerical material offered verbally) and a processing operation. At the same time, by training the attention control ability, we succeeded to also develop the phonological loop capacity, as evidenced by a significant difference between the two groups (experimental and control). The improvement of the phonological loop is also supported by significant differences between the two groups obtained in the case of the operation of multiplication. These results are consistent with those presented in the specialized literature, indicating that the phonological loop (corecteaza forma in romana) plays an important role in supporting performance in the case of the operations of multiplication (given the phonological coding of arithmetic facts).

The results indicate that working memory can be trained specifically to children in primary education cycle, which is consistent with other results from the literature (Holmes et al., 2009). The activities selected for inclusion in the training program have a higher ecological validity than the traditional working memory tasks, in that they model situations in which working memory for the numeric field has applications in everyday life (nominal values of the number in phone number sequence, solving Sudoku, etc.).. We can assume that this will also facilitate the transfer of working memory skills from the specific tasks proposed to other types of mathematical tasks that the student must perform in order to achieve success in school and in which the working memory is involved.

The obtained results indicate that working memory is trainable and that its specific training on the numeric field leads to positive impact on Math performance. However, these results should be viewed with caution. Due to the small number of participants that was available, it is not possible to calculate the effect size, so it is difficult to extract a definitive conclusion in this regard. Also, the mediator role of its growth in improving calculation performance could not be investigated given the small volume of the sample included in the study. Based on these preliminary results, future studies will attempt to overcome these limitations by including a larger number of participants to provide us with greater statistical power.

Regarding the general issue of this paper, we mention as the conclusion of this study the fact that working memory is trainable with a positive effect on improving performance in addition and multiplication tasks by improving phonological loop capacity and central executive component functions.

Study 3. Adaptation and validation of the Early Numeracy Test (ENT) for Romanian

This study proposes to investigate the psychometric properties of a tool for assessing early mathematical competence, adapted for preschool and early school-age population in Romania. I opted for (Utrecht) Early Numeracy Test (early math proficiency test), because it is built on a hybrid model that combines the Piaget theory on the formation of the concept of number with the new theories that places the counting skills at the basis for building the concept of number. Thus, the test allows both the assessment of pre-logic operations involved in the formation of the number concept and the knowledge of numerical sequences and their applications on sets of concrete objects.

Early Numeracy test (ENT) - Van Luit and van de Rijt (1994, 2005).

General description

The early numeracy test was built by members of the Special Education Department of Utrecht University, Netherlands within a research project. The test was designed to evaluate early mathematical competence in preschoolers from the second and third year of kindergarten, respectively schoolchildren in first grade (children aged 4 to 7 years). These issues covered by the test would follow, according to research, a multi-linear development, that is they would develop around the same time and would interact with each other (Van de Rijt et al., 1999). This observation, together with the results of the validation study (Van de Rijt et al., 1999) (which showed through Item Response Model and based on factorial analysis that a single factor can explain 60% of the variance), support the relevance of measuring early mathematical competence as a one-dimensional construct.

Van de Rijt (1996) has selected for evaluation through the ENT eight aspects of early mathematical competence. We present below a brief description of the sub-tests with the definition of the eight aspects, from the original description of the test (Van Luit and van de Rijt, 2005):

(1).Comparison notions,

(2).Classification,

(3). One-to-one correspondence,

(4).Serierea,

(5). Verbal counting,

(6).Structured counting,

(7). Principiul cardinalului mulţimii de elemente în numărat,

(8). General knowledge of numbers.

The validation process of Form B of the test

The adaptation process steps are in accordance with the adaptation norms of psychological assessment instruments (Hambleton, 1994).

Data collection, analysis and interpretation of results

Data collection procedure

The sample used in adapting the ENT test included a number of 287 children aged 4 to 8 years. The assessments were conducted in November-December of 2010. Test administration was made by students (2) and MA (3) in Psychology, who previously attended a training session to meet the standard administration instructions.

The analysis of measurements fidelity

To check the precision of the measurement of early mathematical competence through this instrument, we used two methods: the analysis of internal consistency and test-retest method. Thus, we obtained a coefficient α Cronbach = 0.83, considered satisfactory. To assess the degree in which scores obtained by a subject are constant between 2 administrations of the test, we used the test-retest method (with re-administration at 3 months). Linear correlation coefficient was calculated between the 2 test scores. Thus, we obtained a correlation coefficient r (100) = 0.75, significant at $p < 0.01$. The value obtained indicates a strong correlation between the two test scores, which entitles us to say that the test shows a good stability over time.

Norms for the general population

Based on the age groups in the original form of the ENT test, we divided our sample in the same way, adding a seventh group to include children aged over 7 years and 7 months, present in the first grade in large numbers.

Based on raw scores, we obtained the proficiency scores (linear transformation). These scores were used in the calibration process. Thus, rules were made both by age and by level of schooling.

Analysis of measurement validity.

For the Romanian language version of form B of the Early Numeracy Test, we analyzed the extent to which test scores estimate current positions of participants based on scores from a fluid intelligence test (Raven Progressive Matrices, parallel form). Thus, based on the Pearson correlation between IQ and ENT gross total score, we obtained a validity coefficient of $r = 0.51$, significant at $p < 0.01$, which indicates a good validity of the ENT test. The predictive validity was investigated by simple regression analysis, using as criteria a test of mathematical knowledge built on first grade curriculum, and an arithmetic test with time limit. The non-standardized regression coefficient obtained is 0.613.

The 95% confidence interval for these coefficients is (0.5 to 0.72). The standardized regression coefficient obtained is $\beta = 0.65$. The coefficient of determination (R2) obtained is 0.43 with a standard estimate error of $\varepsilon = 3.17557$, which indicates the variation percentage from the dependent variable caused by the variation of the independent variable. In other words 43% of the scores variance in the mathematical knowledge test is due to the early mathematical competence test scores. In the case of the predictive relationship with the criterion variable, the mathematical regression coefficient obtained is 0.72 (calcul matematic coeficientul de regresie nestandardizat obținut este 0,72). The confidence interval of 95% for these coefficients is (0.4, 0.10).

The standardized regression coefficient obtained is β = 0.47. The coefficient of determination (R2) obtained is 0.22, with a standard error of estimation ε = 0.56, which indicates the variation percentage from the dependent variable caused by the variation of the independent variable. In other words 22% of the variance in calculation test scores can be explained based on early mathematics proficiency scores.

Analysis of competency development by age

To see if the early math proficiency test scores are different in relation to the subject's age, we tested the differences between raw scores for the 7 age groups. We opted for a one-way ANOVA test, in which age was treated as independent variables (categorical), and raw scores from ENT as dependent variable. The effect of age showed as significant (F6, 280 = 23.806, p <0.01).

Discussions and conclusions

The form B of the test has good internal consistency (α Cronbach = 0.83) and good stability over time of measurements (test-retest correlation = 0.75, p <0.01). The relative validity to the criterion of the test was investigated by calculating concurrent validity (by correlating the ENT scores with the Progressive Color matrix ones, the parallel form) and predictive validity. Thus, the Pearson correlation obtained (r = 0.51, p <0.01) shows a good concurrent validity, a significant relationship between ENT test scores and the independent criterion (here a test of intellectual skills assessment). The predictive validity of the test was investigated on the basis of simple linear regression analysis, observing the relationship between ENT test scores and performance on a Math knowledge test and a calculation test, given at the end of first grade. The results obtained (R^2 = 0, 43, R^2 = 0.22) indicate that a large proportion of the math performance variance at the end of first grade can be explained by the variance in performance in the ENT test.

A higher proportion of the performance variance in the knowledge test is explained by that of the performance in ENT, form B. Also, the competence score obtained allows us to establish the level of mathematics proficiency by correlating it to the rules by age or level of schooling. In setting these levels we used sectioning scores in accordance to the ones currently used in the specialized literature to differentiate those with mathematics learning difficulties of those with low results. Based on the results obtained we can conclude that the Early Numeracy Test (Test of early mathematical competence), form B is a valid instrument that can be used to assess the level of early mathematical competence, but also in predicting mathematical performance in first grade.

Study 4. General and specific numerical cognitive abilities as predictors of math performance in first grade

General objectives:

1. Describing the relations between cognitive, phonological and specific numerical skills in the prediction of Math performance in first grade.
2. Identifying those powerful predictors that can later be used in screening learning difficulties in mathematics.
3. Verification of existing theoretical models on skills supporting the development of numeracy and calculation skills.

Specific objectives:

1. Investigating the causal relationship between working memory skills, fluid intelligence, phonological processing and visual-spatial skills, and math performance in first grade
2. Investigating the unique contribution of working memory in predicting math performance at the end of first grade, by isolating other cognitive variables
3. Determining the efficient combination of Math performance predictors in first grade
4. Investigating the relationship between working memory skills and the numeric-specific ones (such as ANS acuity) in predicting mathematical performance
5. Analysis of the different role of the components of working memory performance in numeracy and computing tasks, in the initiation stage of the student in systematic math education
6. Replication of results on the importance of counting skills for the in first grade math performance.

Method

Participants

A total of 165 first grade children in two different counties (Cluj and Dolj) were tested at the beginning of first grade and 7 months later. Child participation was voluntary, with written parental consent.

Procedure

Participants were tested in two stages. The first phase lasted throughout October and November and the second in April-May.

In the first stage measures of cognitive variables included in the study were administered. This time, the math knowledge and computing tests were administered collectively. The ANS test was administered individually in a room other than the classroom.

Instruments

Fluid intelligence assessment was performed using Color Progressive matrices (Raven, Raven and Court, 2005), parallel form. The Romanian edition has an internal consistency α Cronbach = 0.90, test-retest reliability r = 0.67.

Spatial processing skills, which refer to mental manipulation ability of bi-and tri-dimensional figures, were measured using cubes construction subtest (Block Design) of the Wechesler Intelligence Scale for Children-IV (Romanian edition). Reliability coefficients are appropriate and have values over 0.9.

Assessment of **executive functions** was based on the Tower subtest (part of the Nepsy battery). The test measures the executive functions of planning, steps monitoring and error and problem solving. This subtest has a reliability coefficient α = 0.90 for the 6 years age group, α = 0, 83 for the 7 years age group and α = 0.77 for the 8 years age group.

Working memory skills were measured by means of several tasks. Thus, the **phonological loop** function was assessed through digit span forward subtest (Wechsler Intelligence Scale for Children-IV). This is considered a measure of **short-term verbal memory**. Reliability coefficients are appropriate and have values over 0.9.

To have **a non-numeric measure** as well, we built, based on descriptions in the literature (Noel, 2009) a direct memory of monosyllabic words test. The internal consistency of the sample, measured by split-half method, is good (Guttman split-half coefficient = 0, 74, Spearman-Brown r = 0.74).

The central executive component was evaluated by the digit span backward subtest of the Wechsler Intelligence Scale for Children-IV (Romanian edition, 2011). The internal consistency is adequate, the α Cronbach coefficient has a value greater than 0.9. The measurement of the visual-spatial memory was achieved through a Corsi blocks type of task, the computerized version, built based on descriptions in the specialized literature.

The phonological awareness test was adapted from phonological awareness samples, source: Reeducation orthophonique no. 197 / 1999; secondary source "Set of instruments, samples and tests for evaluating education of children with disabilities". The internal consistency of the sample is acceptable (Cronbach α = 0.67).

The mathematical knowledge test is an informal educational tool, built based on the first grade Math curriculum in place (2003) and related performance benchmarks, but also by consulting an alternative first grade Math textbook (Pacearcă and Mogoş, 2004). The final version of the test comprised 23 items, grouped into the following dimensions: number, ordering, reading and writing numbers, numerical comparison, number composition, calculation. The raw data obtained were the basis for calculating the internal consistency of the instrument. A 0.84 α Cronbach coefficient was obtained, which corresponds to a good internal consistency.

The calculation fluency test

This test is an informal educational tool. The test contains operations of addition and subtraction of two terms. The test includes 4 subtests, two for each operation that is studied in first grade: 2 addition subtests and two subtraction ones. The subtests also differ by the size of the numerical material. Thus, the first 2 addition and subtraction subtests contain 81 operations each, with and without passing over order, whose result is contained in the 0-20 concentru. The following 2 subtests include 54 additions, respectively subtraction operations each in concentrul 10-100, but without passing the order. For each subtest, children were given five minutes to solve. Calculation (corecteaza in rom) exercises were organized on columns of 27 each, and the children had to go through them in order.

The score was the total number of tasks correctly solved. A performance index was also calculated, representing the sum of the accuracy reports for each of the 4 subtests. The accuracy report represents the value resulting from dividing the number of correctly performed calculations to the total number of calculations of the subtest. The **ANS** is assessed by comparison tasks performed on large sets of objects.

The approximate comparison task used was developed based on tasks designed by Barth et al. (2005). In order to obtain an indicator of the accuracy of the approximate number representation system, we chose to calculate the Weber fraction corresponding to the hardest ratio. We recorded the frequency of correct answers and we calculated a probability score of the correct response in the case of the report claiming the level of acuity of 0.2, corresponding to the age range of the participants (Halberda et al., 2008). The calculation of the Weber fraction was made according to the formula $w = (n1-n2) / n2$, if $n2 < n1$ and $(n2-n1) / n1$, if $n1 < n2$. For each participant the Weber fractions were calculated for each of the 24 comparisons.

Design

In order to investigate predictors of math performance we employed a multivariate procedure that would allow us for considering several predictors for our criterion variable. Duet o the fact that we have many predictor variables, some of them overlapping partially, we proceeded first at investigating their predictive values inside categories and only afterwards at combining the significant ones into prediction models. This model will be tested for validation using split half method. We chose to use multiple hierarchical regression that allows us to introduce independent variables in a specific order. Therefore we used a forced entry method.

Results

First we analyzed the usefulness of including several measures of working memory components into the prediction model.

Table 3. Correlation matrix among measures of working memory and mathematics

	Test of mathematical knowledge	DSF	DSB	MVSSP	word span

Test of mathematical knowledge	-	$.377^{**}$	$.376^{**}$	$.283^{**}$	.179
DSF	$.377^{**}$	-	$.323^{**}$	$.223^{*}$	$.527^{**}$
DSB	$.376^{**}$	$.323^{**}$	-	$.294^{**}$	$.303^{*}$
MVSSP	$.283^{**}$	$.223^{*}$	$.294^{**}$	-	.253
word span	.179	$.527^{**}$	$.303^{*}$	.253	-

Note: ** $p < .01$; * $p < .05$ / DSF – digit span forward; DSB – digit span backward; MVSSP –visual spatial sketchpad;

As illustrated by the correlation matrix, the strongest relationships between measures of working memory and mathematical performance emerged in the case of DSF and DSB. Both correlate positively with mathematical performance. Positive correlation, weaker, though significant is between MVSSP and mathematical performance. Significance threshold for r values was subjected to Bonferroni corrections.

The non-numerical measures of phonological loop did note correlate significantly with the criterion and therefore was not considered into the prediction model. Analyzing the relations between the predictive variables, one can observe that these are significant except for the correlation between MVSSP and Word Span. There is a strong correlation between the two numerical measures of working memory and a weaker, positive and significant correlation between MVSSP and DSB. Based on these results, we eliminated Word Span and we established the order for the first entry of prediction blocks. We introduced the variables in the model in the following order: backward digit span, forward digit span and last visual spatial sketchpad.

Analysis of results indicates that two of the three models have similar prediction power (R= 0.54 and R = 0.55). R^2 change indicates that eliminating the last predictor from the model would have a small effect over R^2. The first model explains most of the predicted values, $R^2 = 0.234$, F(1, 102) = 31,158, $p < 0.001$. In other words 23% of the variance in the mathematics test results is due to the variability of this predictor (measure of the Central Executive component). R^2 value for the second model indicates that by introducing Phonological Loop into prediction model will explain an additional 5.8% of the variance for predicted values ($R^2 = 0.29$, F(2,101) = 20.77, $p < 0.001$).

In the third model we introduced MVSSP which explained an additional 1% of the variance for predicted values ($R^2 = 0.30$, F(3,100) = 14.81, $p < 0.001$). Multiple regression coefficients for all three models are statistically significant ($p < 0.001$) which invalidates null hypothesis and supports that prediction based on the model is better than random prediction.

Based on sum of squares residual analysis we can conclude that by adding more predictors to the backward digit span would increase prediction power but it won't modify the significance level.

In the case of the first model, where we introduced only the Central Executive measure, $\beta=0,484$, $t\ (102)=5.58$, $p<0.001$. For the second model both coefficients were statistically significant ($\beta_{dsb}= 0,38$, $t=4,22$, $p<0.001$; $\beta_{dsf}= 0,26$, $t=2,86$, $p<0.01$). For the third model the coefficients corresponding to VSSP was not significant ($\beta= 0,13$, $t=1,52$, $p>0.10$).

Based on these results, we can conclude that the best prediction model with working memory measures is the second model presented above comprised of the first and the second block. The third block will be excluded from further analysis.

Based on the previous regression analysis we isolated those measures of working memory components that proved to have strong predictive power for performance on the mathematical knowledge test. Therefore, we will include only digit span forward and digit span backward, as measures of short term verbal memory and central executive component.

Further, we proceeded at identifying those variables that are relevant for the prediction of computation performance in first grade. First, we have analyzed the usefulness of including an ANS measure. Scores obtained by the participant on our ANS task ranged from 0.10 to 1, and were normally distributed. Given that ANS task is an experimental task derived from existing descriptions in the literature, we had to compare participant's performance to the chance.

The displayed performance was above chance (as indicated by $t = -521,08$; $p < .01$), and indicates that the task had an adequate level of difficulty as compared to the level of cognitive development and chronological age. Second, we correlated performance on the Mathematical knowledge test, with the computation task and the ANS task. ANS task did not correlate significantly with any of the Math performance measures (the correlation with the Math knowledge test was $r\ (73)= -0,4$, p= ns.;while for the computation test a $r\ (73)=-0,7$, p=ns was obtained). Based on these results, we chose to exclude ANS measures from the prediction model. By analyzing the correlation matrix among several cognitive, phonological abilities and computation, we retained only those variables that presented strong and significant associations with arithmetic performance.

Therefore, initially we have considered measures of phonological abilities (phonological awareness and phonological memory), visual- spatial abilities (visual- spatial processing and visual spatial sketchpad), general cognitive abilities (executive functions measures, such as the Tower and digit span backward). The only variables that emerged as significantly correlated with performance on the computation test in first grade, were phonological loop (r(76)=0,40 , p<0,001) and the central executive component (r (76)=0,23, p=0.05) as measured by backward digit span. We used the same forced entry procedure to conduct the regression analysis, in the case of prediction of computation performance.

First, we introduced the phonological loop, and secondary the central executive component. The determination coefficients indicate that these abilities of working memory explain a significant proportion of the variance in the computation performance scores, of first graders. In the case of phonological loop, we have obtained a R^2=0,16, while for the central executive R^2=0,18. By adding a second predictor into the model, the modification in the determination coefficient is statistically not significant.

Beta values for each of the variables have a different statistical significance. In the case of phonological loop, we obtained a beta= 0,40, t=3,85, p<0.001, while for the central executive as operationalized through digit span backward, a beta= 0,14, t= 1,29, p>0.10, considered not significant. The last does not represent a good predictor of computation performance. Further, we proceeded at considering other independent variables from other categories: intellectual ability, early math competency, non-symbolic quantification abilities. Along with these variables we introduced , in the same block, general performance on working memory (operationalized by the general score that combines the two subtests). Dependent variable was operationalized by performance on the Math knowledge test. We randomly selected a group of participants on which to perform the regression analysis, and another group for the validation of regression model. Therefore, from the total of 165 participants, by sorting the name alphabetically, we selected the first 85 data for the regression analysis, and we left the rest of 80 for the validation procedure. Regression analysis was performed using a hierarchical model with forced entry. The volume of the group is adequate, considering the number of independent variables (Green, 1991; apud Popa, 2010). We analysed the correlation matrix in order to determine the relevant linear relations, as well as the presence of multicoliniarity between considered variables. Tabel 4 dispays the correlation matrix and the p-values for the Pearson coefficients. Significance threshold for r values was subjected to Bonferroni corrections.

Table 4. Correlation matrix

	Math knowledge test	ENT	Raven	Digit span	ANS

Math knowledge test	-	.513**	.588**	.399**	.006
ENT	.513**	-	.510**	.367**	.017
Raven	.588**	.510**	-	.390**	.203
Digit span	.399**	.367**	.390**	-	-.032
ANS	.006	.017	.203	-.032	-

The matrix indicates that the measure of the approximate number system does not correlate significantly with any of the other variables and consequenlty; it will not be considered into the prediction model. Strong correlations emerged among predictor variables. Multicolinarity will be further analyzed based on indices of VIF and tolerance. Based on the correlation matrix, we were able to introduce into the hierarchical regression, first the measure of early Math competency (given that it presented the strongest correlation with our criterion), second the intellectual ability, and third working memory.

The following determination coefficients were obtained. For the first block of variables, represented by early numeracy competence, a R^2=0,26 emerged (SE=3,35, F (1, 78)= 27,87, p<0,001) and an adjusted R^2=0,25. These values indicate that a significant proportion of the variability in the Math knowledge test is due to variance on scores of early numeracy test (26%). By introducing a second block, that entails also the intellectual ability, 41.7% can be explained (R^2=0,41, Adjusted R^2= 0,40, SE=3,00, F (2,77)= 27,52, p<0,001). The third model that contains additionally working memory explains 45% of the variance (R^2=0,45, adjusted R^2 =0,43, SE= 2,92, F(3,76)= 21,15, p<0,001). In all three models, multiple regression coefficient is statistically significant, indicating that prediction on the basis of the model is above chance. Including additional variables to early numeracy competency increases the precision of prediction (as the total sum of residuals is decreased), but it does not chance the level of significance.

Table 5 displays the standardized and unstandardized coefficients for the regression equation, in the case of all three models.

Table 5.

Model		Unstandardized coefficients		Standardized coefficients			Confidence interval for B (95%)		Collinearity indices	
		B	SE	Beta	t	Sig.	Min	Max	Tolerance	VIF
1	(Constant)	-.055	3.084		-.018	.986	-6.194	6.085		
	ENT	.498	.094	.513	5.279	.000	.310	.686	1.000	1.000
2	(Constant)	-10.677	3.632		2.940	.004	17.908	3.445		
	ENT	.294	.096	.302	3.061	.003	.103	.484	.776	1.289

	Raven	.165	.037	.445	4.503	.000	.092	.238	.776	1.289
3	(Constant)	-11.433	3.549		3.221	.002	18.501	4.364		
	ENT	.278	.094	.286	2.966	.004	.091	.464	.772	1.296
	Raven	.142	.037	.383	3.839	.000	.068	.216	.720	1.389
	Digit span (DS)	.349	.151	.208	2.307	.024	.048	.651	.883	1.132

The values of the coefficients and their statistical significance, allowed us to keep them into the regression equation. On the basis of B and a values, we determined the regression equation for the prediction model. Therefore, our equation is y=-11,433+ (0,278*ENT)+ (0,142*Raven)+ (0,349* DS).

Validation of prediction model

In order to validate the obtained regression equation, we computed predicted values for a second group and correlate these values with the actual performance on the Math knowledge test. In the case of the correlation between predicted values on the basis of the regression equation and the actual performance of the control group, a Pearson r= r(74)= 0,78, p<0,001, was obtained. This value indicates a strong correlation between the two sets of data (the predicted performance and the actual performance), and confirms the stability of the prediction model in the case of another group of participants.

Results

In the current study, first we have investigated the predictive relation between working memory and mathematical performance in first grade. We analyzed separately the relation among several measures of working memory and Mathematical knowledge, respectively Math calculation. Therefore, we assessed the three working memory components, based on Baddeley and Hitch’s model (1974), in the beginning of first grade. Seven months later, we administered the measures of Mathematical knowledge and Math computation. Analyses showed that all three components of working memory were significantly correlated with the Math knowledge test. The relation between the non- numerical measure of the phonological loop and mathematical performance was not significant, whereas the numerical measure of the phonological loop correlated significantly with Math performance. On the other hand, the correlation between the two measures of the phonological loop is a strong one (r=0,52, p<0.001), which comes as a strong support for the criterion validity of the word span task, which is an experimental task in our study.

First, we identified the relevant cognitive predictor variables from the literature and based on the linear correlations with the Math measures, we kept the significant ones from independent or partially independent categories. Therefore, we selected to introduce in the first prediction block the central executive component. The second block contained additionally the phonological loop. In the third block, we introduced additionally the visual-spatial memory.

The results of the regression analysis indicate that central executive component can uniquely explain 23% of the variability in the scores on the Math knowledge test. In other words, the central executive component represents a good predictor of Math performance. By adding a second predictor, represented by the phonological loop, a greater proportion was explained (29%). Whereas, by introducing visual-spatial working memory in the third block, only a small percentage change occurs (1%). By analyzing values of the unstandardized and standardized coefficients of the regression analysis, one can observe that the coefficient for the visual spatial working memory was not statistically significant. Consequently, it was not introduced further into the regression model.

Therefore, Math performance on a curriculum based informal test, can be predicted by the central executive and the phonological loop performance, as measured at the beginning of first grade. It needs to be pointed out that both measures were numerical. Visual spatial working memory explains only a small proportion, as compared to the central executive component and the phonological loop. One possible explanation comes from the correlation between its measure and the central executive measure (r= 0,29, p< 0.001).

This correlation comes in support of the hypothesis that visual spatial memory tasks load heavier on the central executive component, as compared to phonological loop task (Miyake et al., 2001). Also, some researchers argue that visual spatial tasks require more attention resources from the central executive component, especially in younger ages (Alloway et al., 2006, apud De Smedt et al., 2009). However, DeSmedt et al.(2009) showed that in first grade, visual spatial working memory and the central executive component, but not phonological loop contributed each uniquely to the prediction of Mathematical performance.

Moreover, by separately analyzing the contribution of the spatial and the visual components, the above mentioned authors argue that prediction power is mostly conferred rather by the Corsi block type of tasks. In our study, phonological loop explains, in addition to the central executive component a considerable proportion in the variability of scores on the Math knowledge test. It is possible that this switch from visual to phonological representations to occur earlier in the case of Romanian children, as a consequence of the combined action of several factors, including the facilitation offered by a phonetic language, but also by a transparent numeration system, and an early contact with abstract symbolic representations since kindergarten.

Computation performance correlated most significantly with the phonological loop ($r = 0.40$, $p < 0.001$). Correlation with the central executive component is statistically significant but has less power than the phonological loop($r = 0.23$, $p < 0.05$). Correlations with visual-spatial and phonological skills had values close to this, but have not reached the threshold of significance. In predicting computing performance in first grade, the phonological loop alone can explain 16%, and with the central executive component, 18%. These results are consistent with previous studies which showed that phonological memory skills measured at the beginning of first grade were significant predictors of addition performance four months later (Noel et al., 2004).

Phonological awareness did not correlate significantly with performance on the computation task and therefore was not included in the prediction model. Previous studies have shown that the two are related rather when Math facts from long-term memory are automatically updated. In our case, the computation test consisted of simple calculations, but with regrouping, and of more complex calculations, but without regrouping. In both cases, addition and subtraction results were not automatically retrieved, children being forced to employ computation strategies, such as counting or decomposition.

Thus, children used more short-term phonological memory and central executive resources. Another interesting finding is the absence of any correlation between the measure of ANS acuity and Math performance in numeracy and calculation tasks. The two instruments employed in the assessment of Math performance were comprised of exact numerical and arithmetical tasks. Therefore, based on these results, we argue that the approximate number system does not seem to play a major role in the development of exact arithmetical skills. This finding is in accord with other studies (Iuculano et al., 2008). Therefore, in first grade, this approximate number system does not represent a precursor of exact arithmetical abilities. The lack of a correlation between the measure of the ANS and the other cognitive and phonological abilities can be explained in terms of ANS as an independent and specialized system, which is put in use only in approximate Math tasks.

Further, after emphasizing the predictive value of working memory for performance on the Math knowledge test and the computation test, we added new cognitive and numerical factors into the model, such as intellectual ability and counting abilities as measured by Early Numeracy test. By introducing intellectual ability into the prediction model, prediction power of working memory decreased, which indicates that the variability explained by working memory in performance on the Math knowledge test overlapped partially with the one explained by the intellectual ability.

This result was expected given that working memory abilities are strongly correlated with intellectual ability (Conway, Kane and Engle, 2003; apud De Smedt et al., 2009). As well, we expected to find a partial overlapping in the explained variability on the Math knowledge test, between counting abilities and phonological memory, given that counting is based on phonological representations. Due to that fact that these are not identical abilities, and overlapping is not total, we chose to include working memory along with intellectual ability and counting ability in the prediction model. The model is comprised of early numerical competency, intellectual ability, and working memory.

Regression analysis emphasized that this model comprised of three predictors explains a considerable proportion of the variability of scores on the Mathematical knowledge test (R^2=0,45, adjusted R^2=0,43, SE= 2,92, F(3,76)= 21,15, p<0,001). Counting abilities uniquely explained 26% (R^2=0,26 ; ES=3,35; F (1, 78)= 27,87, p<0,001). Nonetheless, intellectual abilities added significant contribution to the explanation power (R^2change=0,154, F change(1,77)= 20,279, p<0.001). By introducing working memory in the third block, an additional 3,8% of the variability in scores on the Math knowledge test was explained (R^2change=0,38, F(1, 76)= 5,324, p=0,024). The regression equation obtained on the basis of these findings was further validated. Validation was supported by a strong and significant correlation between predicted scores on the Math knowledge test and the actual performance of a group different from the one on which we conducted the regression analysis. Therefore, the prediction model based on counting abilities, intellectual ability, and working memory is a stable one.

Based on the results, we can conclude that in predicting Math performance in first grade, a strong role is played along intellectual ability (already known as a strong predictor of academic performance) by counting abilities. Early numeracy test which was used as a measure of such ability was built on new theories of arithmetical skills development (Fuson, 1988), which put a great emphasis on counting as a precursor of arithmetic. Four of the eight subtests index knowledge of numbers, counting abilities and their application in simple mathematical situations. The remaining four subtests, though built to index operations considered by Piaget as essential in the formation of number concept, contain items with numbers and counting knowledge (Van de Rijt and van Luit, 1999). Following a certain sequence in the development of counting, by the age of seven children know to count (some can count long numbers sequences), master most of the counting principles and employ strategies of regrouping and counting on in the case of large sets of objects. Mastering these abilities would represent a strong fundament for the formation and development of computation and for solving other mathematical tasks such as comparison and ordering, according to several researchers (Butterworth, 1999; Geary, 1993).

First counting strategies are based strongly on counting. First, children would count distinctly the two sets to be added. In a more advanced stage, they would count on from one of the sets. In order to be able to employ counting on strategies starting with the greatest number, children need to understand commutative property of addition (and consequently conservation of quantity and reversibility) and to be able to compare numbers.

By age seven, counting and computation abilities improve qualitatively, in what concerns the economy of the strategies employed in solving problems. Children will use regrouping and counting on, comparison and counting on from the greatest. Knowledge about number sequence, correct retrieval of number sequence, fluent counting without breaking the counting principles are necessary for the development of computation skills, though only for a short period of time. After the first semester of first grade, children are expected to master addition and subtraction without regrouping, with numbers between 0 and 30.

Calculation with small results up to ten should be mastered. Calculations with regrouping, even in the case of small numbers are difficult for the majority of first graders. They know several ways in which to form a ten, but were not taught the calculation algorithm and do not have a conceptual understanding of regrouping, as illustrated by frequent errors they make in such problems. Moreover, seven year olds have a limited representation capacity in the case of large sets, which makes them use skills that are already mastered (such as counting) or to use external supports on which to represent and maintain the necessary information (e.g.using fingers to compute).

Therefore, by analyzing the results of the regression analysis, we can conclude that, in first grade, specific numeric abilities, such as those of approximate representation and processing of quantity do not play an important role in the development of exact Mathematics. Cognitive abilities are important, and variability in the working memory capacity and intellectual ability explains a considerable amount of the individual differences in Mathematical learning. Other cognitive abilities, such as visual spatial ones, do not represent good predictors of mathematical performance in first grade, supposedly because along with the switch to formal Mathematics learning and the increase in working memory capacity, there was also a switch of the solving process towards the support of phonological representations. However, the consolidation of phonological representations associated with simple calculations has not been achieved yet, therefore, in the case of our study, the phonological awareness abilities did not correlate significantly with either performance on the Math knowledge test or computation test. The prerequisite knowledge, such as seriation, classification etc. and counting abilities, seems to represent a strong predictor of Math performance 7 months later. The fact that the variability of scores on the early numeracy test explains a considerable proportion of the variability in scores on the Math knowledge test, indicates that ENT could be used as a predictive instrument, along with the largely used intelligence assessment.

Therefore, based on the results we can make recommendations with regard to instruments used in prediction of Math performance in first grade. Of course, in order to use ENT in the identification of children with risk to develop learning disabilities in Mathematics, further analyses would be needed.

Study 4b. Investigation of ENT utility as a screening tool of children with high risc in developing Math learning difficulties

Based on the strong predictive value of the Early Numeracy Test for predicting Math performance in first grade, we further investigated its usefulness as a screening tool for identification of children with a high risk in developing Math learning difficulties. Therefore, using a cutoff point frequently employed lately in the literature together with the performance of a group of first graders on the Math knowledge test, we have investigated how well ENT can discriminate between two categories of results: extremely low (equal or less than 10th perentile), corresponding to performance of learning disabled; performance over 10th percentile (which is comprised by low achievers and normal achievers).

In order to investigate its discrimination power, we chose Receiver operating curves analysis. Performance was converted into a dichotomic variable, with a value of 1 corresponding to extrememly low, and 0 for performance situated over the 10th percentile. A group of 165 participants was included in the study. Participants were administered also, at the beginning of first grade, the measure of early math competency (Early Numeracy Test). Using MedCalc, we conducted ROC curves analysis, introducing a frequency of Math learning disabilities of 5 %. Z test indicates a significant difference between the area under the ROC curve corresponding to ENT, and the area of a test chosen randomly. AUC=0,952, which indicates a good discrimination power (Streiner and Cairney, 2007, apud Pintea and Moldovan, 2009). This result indicates that ENT can be used with high accuracy as a screening tool for the identification of children with extremely low Math achievement. Based on criterion values and coordinates of ROC curves, the most discriminative score of ENT is a score of 30, for which sensitivity of the tool is 93,33 and specificity is 85,61. Based on these results, we can conclude that ENT can be used as a screening tool for the identification of children with high risk to develop Math learning difficulties.

Chapter VI.

General discussions and conclusions

Through the present research, we aimed to clarify the role of working memory in mathematics performance in children with such specific learning.

Another objective was, based on current theories on the development of mathematical skills and processes underlying the learning difficulties, to investigate through a methodological variety the nature of the relationship between general cognitive skills (such as working memory), number-specific skills and math performance. The goal was to highlight the psychological factors relevant to express and / or indicate the presence of learning difficulties in mathematics. Another goal was to understand their mechanism of interaction in the development of mathematical skills. Identifying those factors that prepare and support the learning of mathematics is firstly relevant to the identification and intervention / prevention in children at risk of developing learning difficulties in math.

In this chapter we compare and summarize the results of the studies in relation to how the results provide answers to the research issues raised initially. We will highlight the limits but also the theoretical and methodological contributions, as well as suggesting new research directions. Starting from a rich literature in math learning difficulties, we isolated those psychological factors that have proven relevant and we analyzed the legitimacy of an identification and evaluation approach based on them. First, we investigated whether working memory, whose role in supporting learning is well documented, is affected in children with learning difficulties in mathematics.

The hypothesis of such shortages or delays was first formulated by Geary (1993) and recently revised (2010). The research results on this subject are contradictory, and evaluation methods and models of working memory are varied. Thus, we aimed to achieve a systematization of the results to date, with the purpose of drawing a conclusion as to the presence or absence of such shortfall in working memory. In the first study we conducted a quantitative synthesis of the results that examine individual differences in the working memory and mathematical performance.

The most recent meta-analysis in the field (Swanson and Jerman, 2006) included studies by the year 2002 and approached working memory from the perspective of the unit model of attention control. Thus, through a meta-analytic approach we conducted a synthesis of studies by 2010, from the perspective of Baddley and Hitch’s multi-components model (1974), opting for this model due to its popularity in the studies on the theme. Through study no.1, we managed highlight the presence of deficits or delays in the central executive component of working memory, emphasized in material processing or numerical tasks at the expense of the group with learning difficulties.

Children with math learning difficulties performed significantly lower in tasks related to the central executive component, that require simultaneous processing and storage of information necessary for solving tasks. But their performance was even lower than that of those with average results, but the same chronological age, when working memory tasks have required storage or processing of numeric material (counting points). In the visual-spatial component of working memory the effect was moderate to significant. We also revealed that individual differences in children's performance on working memory tasks are more pronounced at lower ages.

These results, integrated into the whole research on learning difficulties issues, open new research directions. It would be interesting to watch the effect of introducing numeric material or numeric processors on the working memory capacity in children with math learning difficulties. Also, by reviewing the hypothesis on the differences in working memory, among those with difficulties and those with no difficulties, Geary (2010) gives a new hypothesis on the delayed development of working memory capacity in those with learning difficulties in mathematics.

The result that the difference in performance of working memory tasks attenuates with age supports the new hypothesis recently advanced. A practical implication of the results of this study concerns the identification of learning difficulties in mathematics. Thus we emphasized those components of working memory that distinguish between those with learning difficulties and those with no difficulties. Through synthesizing the studies that have examined individual differences in the abilities of working memory, we found that the three components of working memory are affected equally in the case of those with learning difficulties. If the meta-analytic study demonstrated that the differences between those with learning difficulties in mathematics and those without are more pronounced in working memory tasks with numeric material, in study no. 2 we investigated the effect of a specific numeric working memory training in children with low results in arithmetic.

Training the storage capacity in the case of numeric material while performing a task in children from third grade with low results in mathematics led to improved computing skills (in addition and multiplication operations). This effect indicates the role of working memory in supporting performance in arithmetic. The fact that the discrepancy in performance of working memory tasks (central-executive and visual-spatial) was more pronounced at lower ages, against the group with learning difficulties raised a new research issue. Thus, if we have to deal with a delayed development of these skills in children with learning difficulties, isn't the variation in working memory capacity at the inception of math learning responsible for individual differences in mathematics performance? In other words, we wanted to exclude the idea that there is an effect of the specific mathematical knowledge onto general cognitive performance, such as performance in a working memory task. Also, we wanted to see to what extent the relationship between working memory and math acquisitions is affected when we consider the contribution of other factors.

Thus, in Study no. 4, we aimed to analyze if and how the working memory skills are related, measured in first grade with math performance (both numeracy and computing tasks), but also how they interact with other factors such as specific numerical skills and fluid intelligence, as a measure of general learning capacity, relevant to the development and disability theories. We analyzed separately the role of working memory components (in numeric and non-numerical tasks) in predicting mathematical performance. Correlation analysis showed that all three components of working memory are significantly related to scores in the math knowledge test.

The correlation between non-numerical measure of phonological memory and mathematical performance was not significant. Instead, the numerical measure of phonological loop correlated strongly with the performance on the math knowledge test. In other words, those with less capacity to temporarily store and update a series of numbers have had lower performance in math knowledge and computing tests. These results enable us to reconsider the hypothesis of a specific -numerical deficit in working memory. In study no. 3 we present the approach and results of a validation tool for assessing early math skills in kindergarten and first grade, but its usefulness in predicting math performance in first grade.

The practical relevance of the prediction in the context of the absence of such an instrument in Romania is obvious, especially since this tool is built from a hybrid model of the piagetiene theory and of cognitive theories from the developmental psychology on numerical skills. This way the articulation of the curriculum (strongly influenced by constructivist theories in terms of content selection and organization of goals in first grade) and evaluation for screening purposes is ensured.

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