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THE EFFECTS OF WORKING MEMORY TRAINING VS. METACOGNITIVE TRAINING ON MATH PERFORMANCE OF LOW ACHIEVING STUDENTS

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ABSTRACT. In the current study we investigated the efficiency of two different types of training on the mathematical performance of students with low achievement in Mathematics. We chose to select a direct training of domain-specific working memory and a training of metacognitive skills as applied to Mathematics. It seems that domain-specific working memory deficits are encountered in children with Math learning difficulties. Moreover, it seems also reasonable to consider a program that is based on metacognition, as many mathematical activities are approached in a systematic and algorithmic manner. Both programs were efficient in enhancing operation fluency in simple and complex math problems. Results can be used in the direction of adding to the behavioral profile of children with Math learning disabilities, but also in designing efficient intervention programs for poor Mathematicians.

Key words: *math low achievers, domain-specific working memory, metacognition, training, prediction strategy, evaluation strategy.*

ZUSAMMENFASSUNG. In der vorliegenden Studie habe ich die Wirksamkeit zweier Trainigmethoden bezüglich der mathematischen Leistungen von Schülern mit schlechten Ergebnissen im Fach Mathematik untersucht. Ich habe ein direktes Trainingprogramm für das spezifische numerische Arbeitsgedächtnis ausgewählt und ein Training der metakognitiven Fähigkeiten mit Anwendung im Bereich des Faches Mathematik. Auch ein Interventionsprogramm basierend auf metakognitiven Techniken ist angebracht, da viele mathematische Tätigkeiten in einer systematischen und algorithmischen Weise angegangen werden. Beide Programme waren wirksam, was die Aufbesserung der Rechnungsfähigkeit bei einfachen Rechenübungen angeht, aber auch bei Operationen mit hohen Zahlenwerten. Die Ergebnisse können vewendet werden, sowohl als Ergänzung des kognitiven Profils der Kinder mit Lernprobleme im Bereich der Mathematik, als auch für das Planen von effektiven Interventionsprogrammen für Schüler mit schlechten Ergebnissen im Fach Mathematik.

Schlüsselbegriffe: *Schüler mit schlechten Ergebnissen im Fach Mathematik, spezifisches numersiches Arbeitsgedächtnis, Metakognition, Training, Voraussagestrategie, Bewerrtungsstrategie.*

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1. Introduction

Learning mathematics is becoming imperious in modern societies. Even though, the tendency in Romania is towards simplifying the Math curricula and to expend the content over several school years, the societal expectancies, reflected in curricular objectives and selected Math content, increased. In this context, Math learning problems that appear in the formal learning are obvious, and the interest in designing and investigating efficiency of remedial interventions continues to increase. Even so, the number of studies that investigate the efficiency of this kind of interventions for improving Math performance is low as compared with the number of studies on other topics in the literature on Mathematical education and cognition. Scientifically validated interventions are only at the beginning, and treatment protocols on the current cognitive theories (Geary, 2010) are to be developed. Meanwhile, such a low number of studies on this topic can be explained by high costs and implementation difficulties (Wilson & Räsänen, 2008). Interventions for students with Math learning difficulties can also be categorized based on the psychological approach in constructivist interventions (tin which the student builds math knowledge step by step), behaviorist interventions (model the algorithm and practice the procedure until it becomes automatic) cognitive interventions (students achieve learning strategies and also metacognitive strategies, to use when solving math problems), interventions that develop internal representations of math concepts, interventions based on situated learning (Wilson & Räsänen, 2008). A different direction in intervention goes towards improving working memory abilities of students with math learning difficulties, based on cognitive theories of working memory deficits as responsible for poor Math performance (Geary, 1993; 2004). In a comprehensive synthesis, Geary (2010) mentions such studies that address the efficiency of working memory interventions in stimulating attention control (Holmes, Gathercole and Dunning, 2009), and inhibitory control (Diamond et al., 2007; Thorell et al., 2009). Results on stability in time and generalization of trained skills are mixt (Geary, 2010).

Our objective is to investigate the efficiency of two types of interventions built on different theoretical models, over fluency and accuracy in solving arithmetic problems. These programs are considered cognitive interventions, not explicit interventions.

Without a doubt working memory plays an important role in school achievement (Gathercole and Pickering, 2001). However, it is not clear how to interpret the relation between low math abilities and the performance profile in working memory tasks of Math learning disabled. Some researchers sustain that learning disabled students have a working memory deficit (Geary, 1993, 2004) that will result in difficulties in making associations between the arithmetic operation and the result as a rapid decay of the memory trace occurs. Others sustain the idea of selective working memory deficits such as domain specific deficits of numerical nature (Sigel and Ryan, 1989) or selective deficits in working memory components, such as the central executive component. Hitch and McAuley (1991) obtained important differences between the Math learning disabled students and the average achieving in working memory tasks that involved counting but not comparison. Also, on working memory span, counting on concrete materials and verbal counting, those children had poorer performances that the typical achievers. Siegel and Ryan (1989) compared the Math learning disabled students with a control group on two working memory tasks: listening span and counting span. 9-10 years old and 11-13 years old students with math learning disabilities (MLD) had a lower counting span, but not listening span which led them to hypothesize a deficit in a domain specific working memory that is involved in arithmetical tasks. Also, Passolunghi and Siegel (2004) found important differences between MLD and the control group in counting span tasks. These findings come in support of the idea of a working memory deficit in numerical domain. However, a similar performance could be explained by means of low attention control as a result of higher demands raised by numerical tasks in which children with MLD perform poorly. (Raghubar, 2010). 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.

Metacognition influences the use and hold of cognitive strategies in learning, and also in learning Mathematics. Most of the studies underline two major components of metacognition: metacognitive knowledge and metacognitive strategies. The most efficient approaches in developing metacognition involve the developing of knowledge about cognitive strategies and processes, and offering opportunities for practicing cognitive strategies and metacognitive ones. Neither seems to be efficient when applied separately. Rourke (1993), Geary (2004), Montague (1992) indicated metacognition as an important area for students with learning disabilities. The low metacognitive ability students don't have knowledge about their own cognitive processes, their products or anything that connects with them (Flavell, 1976, apud Garrett, Mazzocco, Baker, 2006); they can't judge what kind of problem they are able to solve. They experience failure in planning the operations they need to make to solve the math tasks, show difficulties in monitoring of procedures they use, most of the time they fail in identifying the errors they make (Lucangeli, Cornoldi & Tellarini, 1997, apud Garrett, Mazzocco, Baker, 2006). Prediction abilities allow them to distinguish between the simple problems and the difficult ones, to identify those that need more time, more effort, and more skills to be solved. The students with better prediction abilities are capable to distinguish between real difficulties and apparent ones, when they predict the performance they will have. The evaluation abilities help them reflect on the solutions and to identify the possible errors they made. If they have low evaluation abilities, their monitoring abilities will be low, too. They won't be able to judge if the solving plan is the right one or if the solution is right (Garrett, Mazzocco, Baker, 2006). Several studies found positive effects of metacognitive training on Math performance (Pennequin et al., 2010; Ozsoy and Ataman, 2009; Gillies et al., 1995). However most of them investigate the effects of such training on performance in word problems and not in arithmetical problems. So, knowing that metacognition supports learning, we can assume that it is equally important in arithmetical problems that also involves planning, steps monitoring, estimation of task difficulty. A metacognitive training will increase Math performance by developing metacognitive knowledge and strategies necessary in performing complex algorithms. No effect is hypothesized for simple single digit calculation.

2. Method

Participants

Participants were third graders from a school in Cluj-Napoca. Of the four third grades in the school, three had a teaching program in Romanian language and one in Hungarian. Since the training programs were in Romanian, we selected only the grades with native speakers of Romanian language. 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 were selected and assigned to the three groups, of which two were administered the training conditions. One was the control group. 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. Appendix one displays descriptive statistics for the three groups for the calculation fluency task. An ANOVA between groups test was administered. No significant differences were found between groups in the pre-test condition (addition, $F(2, 33) = 1, 34$, $p<.20$; subtraction, $F(2, 33) = .20$, $p<.80$; multiplication, $F(2, 33) = .70$, $p<.50$). No differences were in between groups based on scores of the other measures (see table 2).

Procedure

One week before the training, participants were tested with a calculation fluency task, a working memory task, and a metacognitive instrument. 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.

Third grade mathematical knowledge test is an informal instrument developed together with the Resource teacher, based on third grade Math curriculum and long range plans. It contains several arithmetical problems: multiple digit additions and subtractions, multiplication by 10s, simple division and order of operations with all four operations and round parenthesis.

Metacognitive measures

The Evaluation and Prediction Assessment (Desoete, 2001) is an instrument that allows for the assessment of mathematical knowledge and metacognitive skills of prediction and evaluation. In order to assess predictive strategies in students they are required to mark on a Likert scale (1- no, I don't know the right answer, 2- I don't know whether I am able to solve it correctly, 3- yes, I know the right answer) whether they know the right answer for each of the arithmetical problems, without solving them. Second phase consists of giving the students a page with the same arithmetical problems with the instruction to solve them. In the third phase, the evaluation instrument is given. Students need to appreciate whether they were able to solve the problems correctly (1- no, I did not give a right answer; 2- I don't know; 3- yes, I gave the correct answer). Metacognitive questionnaire assesses declarative, procedural, and strategic metacognitive knowledge, as well as prediction, planning, monitoring, and evaluation metacognitive strategies. 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.

3. Description of the training programs

Duration: both trainings were 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. All sessions were conducted in school, in the Resource room, apart from their classrooms.

The metacognitive training was created to improve the metacognitive knowledge and metacognitive strategies of students with low performance in Math. It was designed on Dolly model. The first training session was introductory and consisted of a short presentation of the training and of the Dolly model (Glava, 2009), with its four stages: modeling stage, the practice stage with teacher's support, the cooperation stage, and the individual practice stage. In the second session we discussed the importance of metacognitive questions in each of the stages. Semantically similar questions were formulated by the group and written down on colored cards (What do we know and what do we need to find out? What is the given data?; What strategies are more appropriate to solve this arithmetical problem?; What is similar to/ different from other problems solved before?; Am I able to solve it independently?; What were the difficulties that I encountered when solving the problem? ; How can I check the answer?; Is there another way to solve it?; Which one is the more efficient way to solve it?).

In the third session we discussed the first two stages: the modeling stage and the practice stage with teacher's help; their importance, the way of developing the stage, working on a specific arithmetic problem. The fourth session we discussed the other two stages: the cooperation stage and the individual practice stage. During the fifth session, students in this training condition practiced this model on different arithmetic problems. The last meeting consisted of underlying the importance of this model and the way it could influence school performance. Several guidelines based on previous studies were considered when implementing the program (for more details, see Glava, 2009).

Domain-specific working memory training

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). All training sessions were presented as games for motivational purpose. In the first session, children played the numbers game which consisted of filling in an incomplete number chart with numbers from 0-100. Each child received only a fourth of the chart to complete. After completion, they were asked to recall the numbers they wrote. In the calculation game, they were asked to solve multi-digit vertical additions. After completion, they were asked to recall the numerical material. The calculation results were not corrected. In the second session, we used a well-known working memory task, such as counting span (Case et al., 1982) and we adapted it to be applicable simultaneously to groups of 4 children. Children were given cards with dots. Dots were green and yellow on blue background and were randomly distributed on the card. Dots were the same size. The set size varied from 6 yellow dots to 14. The task consisted of counting the yellow dots and recalling in order of presentation all the counted amounts on four cards. The processing task was to decide who among them had the card with greatest number of dots and in each counting trial. The child with the greatest number had to raise his/her hand to signalize it.

In the "One meter of numbers" game, children were given numbers from zero to nine written in words on a single row on a long paper strip (seven to eight number words). They had to read them silently, memorize them and make the sum of the last two. When recalling the numbers, a piece from the strip was cut containing the numbers recalled correctly. At the end, all the pieces were put together and measured to see if the group has managed to add up to a meter of strip.

In session three, three activities were included. In the "Where does the phone ring" game, children received small cards with phone numbers of six to seven digits with the first three digits identical and in the same order and the last four digits were randomized. Children had to memorize the digits in the given sequence and make the sum of the last two. Afterwards, the trainer "dials" a phone number and the children have to recognize the number and say "ring ring"."Sudoku numbers" game required the children to fill in Sudoku charts with numbers from one to four. On a small card there were four Sudoku squares assigned to four children (each child had one square to fill in).The rules were explained and a trial session was run previously. Children were given few seconds to identify the missing numbers according to Sudoku rules. Each child had to name and ask for the two missing numbers on his square after the square was removed. "Geographical superlatives" game was presented as a general knowledge contest. Children had to listen to a statement with geographical superlatives and numerical information that probes them. Afterwards, they were asked a processing question referring to other information from the same statement. After answering the question children are asked to recall the number. In session four, "Chain addition" game developed after a Luria task was played. The children were sitting in a circle. A starting point (a random number) was established by the trainer. The first child had to add six to the given number. The second had to add six to the sum obtained by the first one and so on. When given a wrong answer the child received a penalty card that stopped him for the next trial. The game continued until all children had difficulties with the addition. In session five, we played the classical game of " the Orange". The children had to roll a pair of dice and had to remember the numbers obtained. The trainer starts the game by saying "I would like to eat (e.g. 4)___ oranges". The child that recognizes his number answered "Why 4 and not e.g. 6? The child to recognize the number six will do the same by choosing a different number. In "Alternative addition", children were supposed to make a chain addition (same as the previous game described in session four), this time adding alternatively number six and number five. The same rules were applied.

4. Results

ANOVA statistical procedure was used to analyze the data obtained in pre and post intervention phases for all three groups. Results showed no difference among groups (two experimental and one control) before the training. After the training the results showed significant differences between groups on all measures except on subtraction and evaluation strategy assessment. The detailed results (F values and p) are presented in table 1.

The result sustains the rejection of the null hypothesis showing differences among groups but it doesn't allow us to say where exactly the differences are. For this reason, we run a post hoc analysis (Tukey test). Prior to this analysis a Levene test was run to assess the equality of variances in different samples. The results were not significant allowing us to assume equal variances. Based on this assumption we selected the Post Hoc Tukey test in order to compare the results between each measure. Table 3 presents the mean values of differences and p – values between all three groups.

Table 1.
ANOVA results between groups (pre and post intervention).

	Fpretest			Fpostest		
	Fpretest (2,33)	p	N	Fpostest (2,33)	p	N
Addition	1.34	0.20	36.00	3.30	0.05	36.00
Subtraction	0.20	0.80	36.00	2.04	0.10	36.00
Multiplication	0.70	0.50	36.00	4.90	0.01	36.00
Direct recall	1.70	0.10	36.00	14.70	0.01	36.00
Backward digit span	1.40	0.24	36.00	5.30	0.01	36.00
Total score metacognition	0.33	0.70	36.00	4.00	0.02	36.00
Prediction	0.20	0.80	36.00	3.80	0.03	36.00
Solving	0.50	1.00	36.00	3.32	0.05	36.00
Evaluation	0.1	0.9	36.00	1.67	0.2	36.00

Table 2.
Post Hoc analyses between groups

POST HOC - Tukey				
	WM Training		MC Training	
	MD	p	MD	P
Addition	6.8	0.05	6.33	0.05
Subtraction	-			
Multiplication	7.41	0.01	6.4	0.01
Direct recall	3.9	0.01	2.16	0.01
Backward digit span	1.91	0.01	0.25	1
Total score metacognition	1.6	0.1	2.1	0.03
Prediction	0.66	1	1.91	0.03
Solving	2.6	0.05	2.4	0.05
Evaluation	-			

After the domain specific working memory training children's performance on working memory improved significantly as compared to the control group. Their computation fluency improved but not in the case of subtraction. Also in the case of informal calculation assessment their overall performance increased significantly. The statistical analyses showed that metacognitive training was efficient in increasing Math performance as well as in improving prediction strategy in children with low achievement. Again, no improvement was obtained in the case of subtraction. The other math measurements recorded significant improvements.

5. Discussion

Based on the results we can conclude that students with low mathematical achievement can benefit from a domain specific working memory training as applied to Mathematics. The gain was recorded at the level of enhancing calculation speed of addition and multiplication and also in accuracy of solving complex arithmetical problems. Not only the calculation speed improved, but also the accuracy in calculation. No improvement was obtained in the case of subtraction and this can be explained by the fact that the memory training program involved working memory skills with a load on the phonological loop and that a different mechanism is involved in performing subtraction. Moreover, these results come in support to the idea that working memory can be specifically trained in elementary children which is consistent with the previous data from the literature (Holmes at al., 2009). The activities selected for the training program were designed to have a higher ecological validity than classical working memory task. This was accomplished by modeling real life situations in which Mathematics can be applied. We can presume that this fact will also facilitate the transfer of working memory abilities to other mathematical tasks required from the student for school success. Among metacognitive strategies, predictive strategy skills were enhanced after the metacognitive program. Predictive strategies required the students to anticipate the results of the solving process and to estimate the level of difficulty of a certain arithmetical problem. After the training, children were better at estimating more accurately the difficulty of complex arithmetical problems and to self asses their own solving skills. In the case of the evaluation strategy there was no significant improvement. This can be explained by the fact the training overall addressed less this particular skill. These results should be considered with precaution since a follow up study was necessary to establish the achievements stability in time. Also, even though intensive (in frequency and duration), trainings were conducted over a relatively short period of time.

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Descriptive statistics

	WM Training				MC Training				Control			
	PRE- test		POST - test		PRE- test		POST - test		PRE- test		POST - test	
	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD
Addition	21	4.6	29.83	6.91	22.5	4.23	30.33	7.5	24.17	5.23	24	5.39
Subtraction	22.75	6.89	28.75	8.17	24.33	5.69	27.58	6.09	23.83	5.42	23.33	6.27
Multiplication	14.75	6.46	19.67	6.67	18.5	9.45	23.5	4.85	16.83	7.08	16.08	5.71
Direct recall	7.08	1.31	10.08	2.1	5.75	1.91	8.33	1.87	5.92	1.24	6.17	1.19
Backward digit span	6.17	2.2	7.58	1.88	5.5	1.67	5.92	1.67	6.92	2.15	5.67	0.92
Total score metacognition	6.5	2.06	6.25	1.65	5.67	2.67	6.75	2	6.17	2.75	4.58	2.1
Prediction	6.33	1.96	7	1.8	6.75	1.81	8.25	1.65	6.83	2.36	6.33	1.67
Solving	6.5	2.43	8	1.85	6.5	1.93	8.33	1.61	6.5	2.97	6.33	2.8
Evaluation	7.17	1.89	7.08	1.78	6.92	1.83	8.33	1.82	7.08	2.02	7	2.33