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The role of memory performance on mathematics achievement in primary school 3rd graders

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Abstract

The aim of the study was to determine whether memory performance predicted mathematics achievement in primary school 3rd graders. The sample consisted of 144 3rd grade students selected via convenience sampling method, and drawn from two public and one private schools in Istanbul, Turkey. The three subtests of the Wide Range Assessment of Memory and Learning 2 (WRAML2), namely Symbolic Working Memory subtest, Design Memory subtest, and Finger/Windows subtest were used to assess memory performance. The arithmetic subtest of the Wide Range Achievement Test III (WRAT-III) was used to assess mathematics performance. Prior to conducting a regression analysis measuring the predictive role of memory performance on mathematics achievement, the internal consistency and test-retest reliability of the subtests were computed. Internal consistency measured by Cronbach's alpha and test-retest findings provided evidence for reliability of all subtests. The Symbolic Working Memory subtest and the Design Memory subtests determined mathematical achievement in a linear regression analysis. The results revealed that WM performance measured by the Symbolic Working Memory subtest and visual memory measured by the Design Memory Subtest of WRAML2 determined arithmetic achievement, whereas the Finger/Windows Subtest measuring sequential memory/directed attention didn't predict arithmetic achievement.

Keywords: Wide Range Assessment of Memory and Learning 2 (WRAML2); Wide Range Achievement Test III (WRAT-III); memory; working memory; mathematics achievement

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1. Introduction

1.1. Memory and assessment of memory

Working memory (WM) is defined as a complex cognitive system in which information is temporarily maintained and manipulated in order to complete cognitive tasks, such as learning, planning, decision making, and reasoning (Alloway, 2006; Baddeley, 1999; Bayliss et al., 2007; Leahey & Harris, 1997). WM is a much broader concept than retaining information and serves as an interface where information is temporarily stored and processed, it helps in selecting, integrating, manipulating, and maintaining information during cognitive processing (Baddeley, 1994; Cowan, 2002; Howard, 1995; Oberauer et al., 2003**)**. The fact that incoming information must be briefly held in the mind while simultaneously performing a cognitive task; there are often a limited number of items that are stored and retained within the WM system (Baddeley, 1986; Baddeley, 1994; Cowan, 2001, 2005; Fukuda et al., 2010; Wilhelm et al., 2013).

Given that the definition of short-term memory was insufficient in explaining complex memory processes related to temporary, short-term memory, Baddeley and Hitch (1974) conducted a series of experiments on the role of memory on understanding, learning and reasoning. As a result the authors came up with a model of working memory, according to the model (Baddeley & Hitch,1974; Baddeley, 1986; Baddeley & Logie, 1999; Baddeley, 2000), WM is managed by the central executive system, which acts as a supervisor and is responsible for controlling and managing information flow to WM. It is responsible for self-regulatory functions including learning, control of recall strategies, planning, inhibition, and attentional control (such as shifting attention and switching attention between tasks). The central executive manages two slave systems, namely the phonological loop which is responsible for holding linguistic information, and the visuo-spatial sketchpad responsible for visual and spatial information. Information enters the phonological loop and visuo-spatial sketchpad via sensory routes or through the central executive, in turn they process, update, encode, and store incoming information into working memory (Baddeley, 2000). The episodic buffer which was later proposed by Baddeley (2000, 2003) is a temporary storage system which stores information in a multidimensional code and serves as an interface between the slave systems and long-term memory.

In terms of memory assessment, as far as we know, only one test designed to measure memory performance of children was adapted for the Turkish culture. Özyürek & Ömeroğlu (2013) adapted the Children's Memory Scale (CMS, Cohen, 1997) for 5- 8 year old children.

Also again as far as we know, there are only two memory tests designed for children which are developed in the Turkish culture, and one study in which normative data was collected for a sample of 6-9 year old children. The two tests which are developed are the Working Memory Scale (Çalışma Belleği Ölçeği, Ergül, Yılmaz, & Demir, 2018) designed for 5-10 year old children and the Memory Battery for Preschool Children (Okul Öncesi Çocuklar için Bellek Bataryası) developed by Obalı (2018). The Öktem Verbal Memory Processes Test (Öktem Sözel Bellek Süreçleri Testi, 2016) can be used for 15 years and older individuals, Usta (2016), collected normative data for the Öktem Verbal Memory Processes Test from a sample of children from age 6 to 9.

In the case of attention, when carrying out cognitive tasks, individuals selectively attend to the material at hand, while filtering out irrelevant information (Ashcraft, 2002). It is usually hard to discriminate whether problems in recall are due to a problem in memory or to a problem in attention, and it is well known that when people get distracted, their memory performance is negatively affected (Bunting & Cowan, 2005). In most of the cases, individuals who score low on memory tests, may score low on attention tests, which makes it even harder to discriminate between the two. For example, during the measurement of spatial working memory, when individuals are given a task to search for a certain picture or shape from a list, the probability of being distracted from external stimuli is closely related to the capacity of WM (Lavie & Fockert, 2005). As can be concluded, WM capacity is a major determinant of attention which suggests that the two processes are interwind (Kane, Bleckley, Conway & Engle, 2001).

1.2. Memory and mathematics/arithmetic performance

It is well documented that many children with low WM span have difficulties in mathematics achievement as well as science, and verbal material including reading, and following instructions required in typical classroom settings (Borella & de Ribaupierre, 2014; Gathercole & Pickering, 2000; Jarvis & Gathercole, 2003; Pickering et al., 2004). WM was found to be a predictor of general academic achievement (Grimley & Banner, 2008) including mathematics achievement (Chalmers & Freeman, 2018; Lee et al., 2014). During WM assessment, visuo-spatial working memory was found to be the strongest predictor of mathematical performance (Bresgi et al., 2017; Clearman et al., 2016; Metcalfe et al., 2013). Studies indicate that the effect of especially visuo-spatial memory function on mathematics achievement increases with age (Li & Geary, 2017), STM span measures assessing the phonological loop aspect of WM predicted mathematics achievement in first graders, whereas in second graders more complex working memory span measures and executive processes predicted mathematical performance (Passolunghi et al., 2008).

Studies related to WM and academic performance mainly focus on low achieving children or children with mathematical learning disability. Results show that children with low academic achievement tend to perform lower on the central executive component of working memory (Wu et al., 2008) and their mathematical performance was related to both visuo-spatial and verbal WM (Gathercole et al., 2016; Mammarella et al., 2018). Also these children had more problems in counting and retrieving arithmetic facts from long-term memory (Wu et ai., Menon, 2008). Çakır (2019) found a moderate relationship between verbal short-term memory and verbal working memory and early mathematics achievement, and a low relationship between visual working memory and early mathematics achievement in a study conducted with preschool children.

1.3. The present study

The WRAML2 provides a thorough assessment of multiple areas of memory performance. It also assesses learning through repeated measures of the same material. In addition to administering the whole battery, subtests can be used separately depending on the needs or academic difficulties of the child. The aim of the present was to assess whether memory performance measured by three of the subtest of WRAML2, namely the Symbolic Working Memory subtest, Design Memory Subtest, and Finger/Windows Subtest predicted mathematics performance measured by the arithmetic subtest of the WRAT-III. The Symbolic Working Memory subtest measures working memory; the Design Memory Subtest measures visual memory; and the Finger/Windows Subtest measures sequential memory/directed attention.

These subtests were choosen specifically, given that they are non-verbal and culture free, and in light of the literature, the subtests which were assumed to be the most related with mathematics performance.

Initially, mean scores, standart deviation, standard error of mean, median, score range, minimum and maximum scores and internal consistency and temporal stability were computed for all subtests. Also mean differences of boys and girls were computed.
So far, the present study is the only one conducted in the Turkish culture, investigating memory performance and mathematics achievement in elementary school children.

2. Method

2.1. Sample

The sample consists of 144 3rd grade students aged 9 years, drawn from two private and one public school in Istanbul. Convenient sampling was used. A total of 70 students (31 girls and 39 boys) were selected from the two private schools and 74 students (34 girls and 40 boys) were selected from the public school. In the original standardization study of the WRAML2, 80 individuals were selected from each age group, including 9 year olds (Sheslow & Adams, 2003).

2.2. Instruments

2.2.1.Wide Range Assessment of Memory and Learning 2 (WRAML2)

The WRAML2 developed by Sheslow & Adams (2003) is an individually administered memory battery covering a broad age range, from 5 to 90 years. The battery should be administered by clinicians, counselors or researchers trained in psychological and/or neuropsychological testing. With training, teachers can also administer the battery. The battery includes scaled scores, index/ standard scores, percentile ranks, and age equivalents for ages 5-15. The WRAML2 has a Core Battery composed of the Verbal Memory Index, including the Verbal Learning Subtest and the Story Memory Subtest; the Visual Memory Index, including the Design Memory Subtest and Picture Memory Subtest; and the Attention and Concentration Index, including the Number/Letter Subtest and the Finger/Windows Subtest. These together form the General Memory Index which provides an overview of memory functioning.

The battery also includes a Working Memory Index, which comprises the Symbolic Working Memory and Verbal Working Memory subtests, and two optional subtests, namely Sound Symbol, and Sentence Memory Subtest. There are also Delayed Memory Measures namely, Story Memory Delay Recall, Sound Symbol Delay Recall, and Verbal Learning Delay Recall; and Recognition subtests including the Design Memory Recognition, Picture Memory Recognition, Verbal Learning Recognition, and Story Memory Recognition subtests.

The Design Memory Subtest of the Visual Memory Index, the Finger/Windows Subtest of the Attention/Concentration Index, and the Symbolic Working Memory subtest of the Working Memory Index were included in the present study. The Design Memory Subtest consists of 5 cards with geometrical shapes exposed for 5 seconds, then after 10 seconds of delay the participant is asked to draw what is remembered. The Finger/Windows Subtest measures rote sequential recall and involves directed attention, where a vertically held card with asymmetrically located holes is shown. The examiner places a pencil in the holes in a certain order, then the participant is asked to duplicate the sequence with his/her finger. With each trial, the number of sequences of holes increase. The Symbolic Working Memory subtest consists of two parts. In the first part the participant is presented a card with numbers (1 to 8) in numerical order, the examiner reads aloud a random order of numbers from 1 to 8 and asks the participant to recall the numbers in numerical order. In the second part the participant is presented a card with numbers (1 to 8) in numerical order and letters from B to J, in alphabetical order. The examiner reads aloud a random list of numbers and letters and the participant is required to recall the numbers in numerical order and the letters in alphabetical order.

In the original study, Rasch analysis was computed for person and item separation reliability, in order to test internal consistency and measurement error (Sheslow & Adams, 2003). The person separation reliability was between 0.85 to 0.94 for the core subtests, and between 0.53 to 0.93 for the optional subtests. Specifically person separation reliability is 0.87 for the Symbolic Working Memory subtest, 0.92 for the Design Memory Subtest, and 0.91 for the Finger/Windows Subtest. Item separation reliabilities are extremely high (0.98-1.00), indicating evidence of construct validity.
The Cronbach's coefficient alpha values were between 0.90 to 0.95 for the General Memory Index, and 0.83 to 0.91 for the Attention/Concentration Index. The Cronbach's alpha values were between 0.75 to 0.91 for The Symbolic Working Memory subtest, 0.82 to 0.91 for the Design Memory Subtest, and 0.76 to 0.86 for the Finger/Windows Subtest. For the present study the Cronbach's alphas for the subtests are as follows: 0.81 for the Symbolic Working Memory subtest, 0.88 for the Design Memory subtest, and 0.73 for the Finger/Windows subtest.

The test-retest study was conducted with 142 participants, with an average of 49 days (14-401 days) after the first administration. The correlation coefficient values were between 0.53 to 0.85 for the General Memory Index, and 0.47 to 0.80 for the other subtests. A general increase in scores was observed and was explained as an indicator of learning (Sheslow & Adams, 2003).

The standard error of measurement was 3.4 - 10.9 for all the indexes. The concurrent validity was conducted with the Wechsler Memory Scale-III, Working Memory-III, Children's Memory Scale,(CMS), Test of Memory and Learning (TOMAL), California Verbal Learning Test (CVLT), and California Verbal Learning Test-II (CVLT-II) (Sheslow & Adams, 2003).

2.2.2. The Wide Range Achievement Test – III

The WRAT - III (Wilkinson, 1993) is a screening achievement test for reading, spelling words and arithmetic computation for ages 5-75. The written arithmetic subtest of the WRAT – III was used in the present study. The written arithmetic subtest can be administered in groups and children are given 15 minutes and asked to complete as many problems as they can.

The Cronbach's alpha for the original form is between 0.79-0.89, the test-retest correlation coefficient values are between 0.91-0.98. The standard error of measurement is 6. The Cronbach's alpha for the WRAT III is 0.75 for the present study.

2.3. Procedure

The school principals and vice principals were contacted prior to test administration, information was given related to the purpose of the study and the nature of the tests and their administration. Parents' consent were obtained and test administration was planned with the help and guidance of the principals, vice principals and school guidance counselors. Each administration takes approximately 20 minutes, thus each school was visited multiple times for test administration. Each time a certain number of students were tested.

The tests were individually administered either in a large multi-purpose room, the vice principals office, or an empty classroom, depending on the school. Because WRAT-III can be administered in a group setting, it was administered in the classroom. The rest-retest administrations took place 60 days after the first administration and only in the public school.

2.4. Data analyses

Mean, standart deviation, standard error of mean, median, score range, minimum and maximum scores were computed. Mean difference between girls and boys on the subtests were computed through an independent samples t test. Internal consistency of all subtests was computed with Cronbach's alpha. Pearson correlation coefficient analysis was used to measure temporal stability through test-retest reliability. A linear regression analysis was conducted to assess whether the Symbolic Working Memory Subtest, Design Memory Subtest, and Finger/Windows Subtests predicted mathematics performance.

3. Results

Table 1 shows mean and standard deviation scores, standard error of measurement, median, minimum and maximum scores for the Symbolic Working Memory, Design Memory and Finger/Windows subtests of WRAML2 and the arithmetic subtest of the WRAT- III.

Table 1. Descriptive statistics

		N	Mean	SD	SEM	Median	Score Range	Min	Max
Symbolic Working Memory	Girls	65	11.78	3.82					
	Boys	79	12.11	3.53					
	Total	144	11.97	3.65	3.30	12	0-28	1	21
Design	Girls	65	28.17	8.54					
Memory	Boys	79	30.16	8.65					
	Total	144	29.26	8.63	0.71	30	0-60	6	47
Finger/	Girls	65	9.55	2.67					
Windows	Boys	79	10.25	2.30					
	Total	144	9.94	2.52	0.21	10	0-27	3	17
WRAT-	Girls	65	15.75	3.05					
III	Boys	79	15.56	2.89					
	Total	144	15.65	2.95	0.24	16	0-40	3	23

Independent samples t test showed no subtest mean difference between girls and boys (see table 2).

Table 2. Independent samples t test for mean differences between girls and boys

	t	df	p	Mean Difference	95% Confidence interval of the difference	
					Lower	Upper

Working memory	0.530	142	0.59	0.33	-0.88	1.54
Design memory	1.38	142	0.16	2	-0.85	4.84
Finger windows	1.66	142	0.09	0.70	-0.13	1.52
WRAT III arithmetic subtest	-0.39	142	0.69	-0.20	-1.17	0.78

P* < 0.05

In order to compute test-retest reliability, three subtests of the WRAML2 were administered to 42 children and the WRAT- III arithmetic test was administered to 52 children, 60 days after the first administration. As can be seen in Table 3, the correlation coefficients between the two administrations are significant at $p < 0.01$, indicating temporal stability.

Table 3. Test-retest scores

	N	Symbolic Working Memory	Design Memory	Finger/Windows	WRAT III arithmetic subtest
Symbolic Working Memory retest	42	0.89**			
Design Memory retest	42		0.62**		
Finger/Windows retest	42			0.54**	
WRAT- III arithmetic subtest retest	52				0.72**

P** < 0.01

Linear regression analysis was performed to see whether arithmetic performance measured by the WRAT III was determined by three of the WRAML2 subtests. Results show that the Symbolic Working Memory and Design Memory subtests predicted arithmetic performance. As can be seen in table 4, 22% of the variability in arithmetic performance was accounted for by visual short-term memory and working memory performance.

Table 4. Linear regression

	ß	*SE B*	t	p
Symbolic Working Memory	0.32	0.40	4.82	0.001***
Design Memory	0.07	0.22	2.91	0.001***
Finger/Windows	-0.14	-0.12	-1.47	0.14

Dependent variable: WRAT- III arithmetic test. R= 0.48, R^2= 0.23, Adj. R^2=0.22, F= 14.64
***p<0.001

4. Discussion

Descriptive data for 9-year-old children were provided for the Symbolic Working Memory, Design Memory and Finger/Windows subtests of the WRAML2 and the arithmetic subtest of the WRAT -III. The test-retest findings and the Cronbach's alpha values were found satisfactory for all subtests. The study provides evidence for the reliability of the subtests in a Turkish sample consisting of 9-year-old children.

In the current study, as expected, WM performance measured by the Symbolic Working Memory subtest and visual memory measured by the Design Memory Subtest of WRAML2 determined arithmetic achievement. Interestingly the Finger/Windows Subtest measuring sequential memory/directed attention didn't predict arithmetic achievement. These findings, to some degree may help in explaining problems in arithmetic and math performance. Though WM and visual memory tasks may change across studies, research shows that mathematics achievement is closely related to many areas of memory functioning (Clair-Thompson & Gathercole, 2006). The Finger/Windows Subtest requires rote sequential visual memory, and is very similar to the visuo-spatial memory test Reuhkala (2001) used, in which the experimenter tapped a sequence of squares and asked the participants to recall the sequence. The author found a relationship between math performance and visuo-spatial memory, which we failed to find in the present study.

The findings of the present study are in line with various studies indicating that WM is closely related to mathematics performance, and that troubles in WM may result in problems in mathematics achievement (Bull et al., 2008; Caviola et al., 2012; Geary et al., 2004; Gersten et al., 2005; Hitch & McAuley, 1991; Keeler & Swanson, 2001; McLean

& Hitch, 1999). WM, which is accepted as the working bench of the mind, is continuously active throughout mental processing and serves as a medium for processing information, rather than information storage (Miyake & Shah, 1999). The Symbolic Working Memory subtest requires mental manipulation of information which a child is required to keep in mind, and is similar to requirements of mathematical problem solving involving arithmetic computation while trying to keep in mind the sequences one has to follow in order to solve the problem, while being aware of which step one is currently at, and mental arithmetic including addition with carry. Thus, during mathematical computation, the child integrates information in WM and integrates-links recent input with previous ones, withholds irrelevant information and assimilates it with the problem at hand, which makes WM critical in mathematical computation (Geary, 1990; Geary, Brown & Samaranayake, 1991; Swanson & Beebe-Frankenberger, 2004). As stated, the child must be able to inhibit irrelevant information in order to perform these tasks efficiently, this is crucial given that WM has a limited capacity (Geary, 1995). The Design Memory subtest may predict a child's performance on graphs, diagrams, and spatial problems. Although the arithmetic test in the present study did not include graphical material, its role in defining mathematical performance is striking.

Mathematics also has verbal components, such as reading a problem, following instructions etc. and it is suggested that the reason behind low achievement in mathematics is partly related to the high demand of structured classroom learning activities requiring storage and mental manipulation of information, including following sequenced instructions, identification of stimuli in addition to mathematical computation. These activities overload the WM, thus information may be lost because of distraction, and as a result, children may not be able to complete tasks, give up, or get lost at some point, and eventually these children may have problems completing cognitive tasks (Gathercole et al., 2007; Gathercole & Alloway, 2008; Jaroslawska et al., 2015).

In conclusion, unfortunately problems in WM and other types of memory, may result in decrease in academic achievement. In an attempt to overcome these difficulties, WM training programs for children have been found effective in enhancing WM and visuo-spatial STM scores, and some studies show that positive outcomes continue up to 12 months after training (Dunning et al., 2013; Gathercole et al., 2008; Holmes et al., 2009; Roberts et al., 2016). Although gains in mathematical reasoning and mathematics performance as well as verbal performance were observed 6 months following adaptive training, mixed results suggest that specific aspects of WM should be targeted and training programs should be periodically implemented for long-term positive outcomes. Training programs may also help in increasing self-awareness and must build on cognitive strengths in order to overcome failures.

5. Conclusions

When used in special education and clinical settings, the WRAML2 helps in the assessment stage of children with academic problems, risk for learning disabilities and attention problems, by giving a detailed evaluation of overall performance on memory, attention, and learning. The whole battery can be administered, or specific subtests can be chosen based on the professional opinion of the counselor, special education teacher or clinician, depending on the presenting problem of the child.

Studies confirm that memory functioning, especially visuo-spatial WM is related to mathematics achievement, especially during elementary school years, and because children who have difficulties in these areas will not meet the criteria of learning difficulties, their problems may remain unrecognized (Li & Geary, 2013). Because of an overload of WM, mind-wandering during cognitive tasks may be common among young children with low WM functions, which unfortunately may result in missed learning opportunities (Kane, Brown, McVay, Silvia, Myin-Germeys & Kwapil, 2007). We believe that it will be beneficial for school counselors and special education practitioners to access easy to administer standardized tests in order to screen students with possible memory and attention problems. If used together with other psychoeducational evaluation instruments, memory scales may help school counselors and special education specialists in the evaluation and referral stage. Relatedly we aimed to determine the impact of WM, visual memory and sequential memory performance on mathematics achievement.

A major limitation of this study is the limited age range of the sample. Our sample consists only of 9-year-old children, and as previously stated, studies should be conducted for other age groups, and with the other subtests, in order for the battery to be used with elementary school children. Another major limitation is lack of construct validity, unfortunately, at the time the study was conducted there was no memory test for elementary school children which could be used as evidence for construct validity.

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