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COGNITIVE SKILLS AND MATHEMATICAL PERFORMANCE, MEMORY (SHORT-TERM, LONG-TERM, WORKING), MENTAL PERFORMANCE AND THEIR RELATIONSHIP WITH THE MATHEMATICAL PERFORMANCE OF PRE-SCHOOL STUDENTS

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Abstract:
The purpose of this research is to examine the effect of cognitive capabilities and flowing intelligence on mathematical proficiency of pre-school students, shortly before attending elementary school. Eighty kindergarten students participated in the survey. Student performance was assessed in terms of short term memory (auditory and verbal short-term memory, visual short-term, semantic and non-semantic memory), working auditory and visual memory, visual long-term memory, fluid intelligence and math performance. Based on the results, there was a strong positive correlation (,777) between verbal working memory and mathematical performance. Moderate positive correlation between mathematical performance and short-term memory, visual spatial working memory, visual long-term memory and fluid intelligence was also found.
To identify which factors have predictive value for mathematical competence, regression analysis was used. It has been found that verbal working memory is an important factor in explaining mathematical competence. Combined with long-term visual spatial working memory, they can more accurately predict the level of mathematical performance. The results show that verbal working memory is the best predictor of mathematical performance. Visual long-term memory follows, and finally

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visual spatial working memory seems to have the lowest impact on a student's mathematical performance.

Keywords: mathematical performance, short-term memory, working memory, long-term memory, fluid intelligence

1. Introduction

Mathematics is a basic lesson in every curriculum, and any difficulties in this field affect both school performance and everyday life, since mathematical skills are very important in modern Western societies in a multitude of cases (i.e. decision-making) (Reyna & Brainerd, 2007).

Mathematical knowledge is a special case, since new knowledge requires mastery of any relevant previous knowledge, which is not the case with other subjects. In the case of students with learning difficulties in mathematics, teaching and learning of new concepts and skills is considered inefficient without the prerequisite concepts or skills being acquired (Miller & Mercer 1997). Surveys show that a lot of students face difficulties related to mathematical learning. Approximately 7% of school children have a cognitive or neuropsychological deficit that interferes with the acquisition of adequate mathematical skills (Geary, 1993, Gross-Tsur, Manor & Shalev, 1996). While relevant predictive indicators of literacy development have been studied during pre-school years, the predictive factors of mathematical skills have not been explored as much. Several cognitive mechanisms on which mathematical skills are based have been proposed and their contribution to the development of mathematical skills has been studied. According to the available studies, it appears that the ability to distinguish quantities (size comparisons), counting capacity, number recognition, working memory, short-term memory, long-term memory, object identification, and speed of information processing are the basis for understanding of several important principles of the arithmetic system (Cf Resnick, 1989, Okamoto & Case, 1996, Gersten, Jordan, & Flojo, 2005, Lemer, Dehaene, Spelke, & Cohen, 2003 Geary, Hamson & Johnston 1997). Few studies have been systematically investigating the factors determining mathematical learning, especially among pre-school children, particularly during the transition from kindergarten to elementary school. (Geary, Hamson, & Hoard, 2000; Geary, Hoard, & Hamson, 1999). However, the ability to predict mathematical performance in elementary school on the basis of early math performance in kindergarten poses the risk that the correlation analysis will be inaccurate, since it cannot adequately manage all the relevant factors underlying the learning of children's mathematics during their development phase. Thus, there is a risk that studies will overestimate the results of mathematical performance during kindergarten in relation to their later mathematical performance. This can happen due to two reasons. First, it is not possible to know all the factors that can affect mathematical performance during the development phase, but only some of them, such as work memory or cognitive potential. For example, in their research, Deary, Strand, Smith and Fernandes (2007) found that children's intelligence measured at age of 11 represented 59% of the variance in their mathematical achievement at the age of 16. Obviously, the remaining percentage is the result of other factors. Mathematical performance is influenced by both prior knowledge and other factors responsible for a significant share in early and late mathematical performance. For example, in a study that includes data from 1,124 children, the relationship between the initial mathematical performance and the performance in third grade was 0.72, while at the age of 15 was 0.66. Since these correlations mainly reflect the stability of the factors that form the basis of mathematical performance during the development phase, the role of early intervention that affects mathematical performance at this age becomes increasingly important. The procedures for understanding mathematical concepts have been studied but there are areas that need to be further investigated (Nye, Clibbens, & Bird, 1995).

This study focuses on verifying the level of mathematical performance in kindergarten immediately before students begin their primary school education (in Greece, children are enrolled in elementary school at the age of 6). The purpose of the research is to identify those factors associated with mathematical performance in kindergarten as well as those who may be able to predict the subsequent mathematical performance.

1.1. Basic Cognitive Functions and Mathematical Performance

Researchers investigating the numerical difficulties of children attribute these difficulties to a number of cognitive mechanisms. Student performance in mathematics is influenced by a number of factors and competencies that depend on cognitive mechanisms and help achieve high performance in mathematics. Such abilities as early identification of numbers, understanding of the size of numbers and counting are predictive indicators of mathematical performance (Geary, Hamson, & Hoard, 2000; Geary, Hoard, & Hamson, 1999),

The theoretical models attempt to interpret the students' difficulties in mathematics based on weaknesses in the recall of basic numerical data, the use of inappropriate calculation procedures (Barrouillet, Fayol & Lathulière, 1997; Geary, Brown, & Samaranayake, 1991; Jordan & Montani, 1997), the difficulties in the representation of numerical information (Geary, 1993). These difficulties appear to be due to deficits in the functioning of cognitive mechanisms and functions such as working memory, short-term memory, and long-term memory.

1.2. The Role of Short-Term Memory in Mathematical Performance

Students' difficulties in mathematics may be due to short-term memory failure. Studies show that students' performance in mathematics was significantly lower in students with difficulties in short-term memory function (Geary et al., 1991, 2000; Geary, Hoard, & Hamson, 1999; Hitch & McAuley, 1991; Passolunghi & Siegel, 2001). Short-term memory is differentiated from working memory since it is a passive storage system that requires the recall of information without the intervention of any mental work (Cantor, Engle, & Hamilton, 1991; Cornoldi & Vecchi, 2000; Engle, 2002; Vecchi & Cornoldi, 1999). These are the digit span forward method for auditory verbal short-term memory (VSTM), recollection of images for short-term semantic memory or frames for short-term non-semantic visual memory. Some researchers report that children with mathematical difficulties show weaknesses in auditory verbal short-term memory (Siegel & Ryan, 1989), while others argue that these children have a general deficiency over the entire range of short-term memory, namely auditory verbal and visual (Hitch & McAuley, 1991, Swanson, 1993; Turner & amp; Engle, 1989).

Working memory requires more proactive processes such as the reverse iteration of numerals or words, during which information is temporarily retained, manipulated, and transformed by the use of mental factors. Research has shown that short-term memory processes and working memory processes trigger different factors (Daneman & Carpenter, 1980; Engle, Cantor, & Carullo, 1992; Swanson, 1994). Therefore, children with learning difficulties in mathematics are likely to have problems in short-term memory regardless of problems in working memory. Although research shows that there is a relationship between short-term memory and mathematical difficulties, the causes of this relationship are unknown.

1.3. The Role of Working Memory in Mathematical Performance

Children with special learning difficulties in mathematics often take a lot of time to calculate and make mistakes due to limitations and weaknesses in working memory (Hitch & McAuley, 1991; Siegel & Linder, 1984; Siegel & Ryan, 1989; Swanson, 1993).

The Baddeley & Hitch model, (Baddeley & Hitch 1974; Baddeley, 1996, 2000), comprises of two subsystems:

1) The Articulatory loop that specializes in the processing of phonological - linguistic information. It is related to the numbering ability (Healy & Naime, 1985; Logie & Baddeley, 1987), to multiplication (Lee & Kang, 2002) and to calculating ability (Henry & MacLean, 2003). It has a special role in preserving oral information of mathematical problems and supports the retrieval of mathematical data from long-term memory (Holmes & Adams, 2006). However, some studies have argued that the articulatory loop does not play an important role in mathematical performance (Bull & Johnston, 1997; McLean & Hitch, 1999; Reuhkala, 2001).

2) The Visual-Spatial sketch pad is considered to be responsible for the processing and short-term storage of visual and spatial information. It is thought to work with visual images (Baddeley 1997; Baddeley & Logie, 1999). McLean and Hitch (1999) observed that children with arithmetic difficulties had a disturbed visual library, while Maybery and Do (2003) achieved similar results by observing performance on a project called Corsi Blocks, related to mathematical performance in different domains such as number measurements and space-related activities. In order to understand the value of a digit within a number and its relation to other digits, it is important to understand its visual position. The visual-spatial sketch pad is considered to function precisely with audiovisual information involved in mathematical problems, for example the position of the variables in a problem (Ashcraft, 1996). It has also been shown that the mental line of numbers, which includes consecutive left-to-right numbers, has a spatial basis (Zorzi, Prittis. & Umilta, 2002; Zorzi, Priftis, Meneghello, Marenzi, and Umilta, 2006). In addition, it has been suggested that the relationship between the visual-spatial sketch pad and the mathematical performance may derive from an anomaly in this mental arrangement of this line of numbers (Bachot, Gevers, Fias, & Roeyers, 2005).

Generally, the role of visual-spatial working memory in mathematical skills has garnered less attention from researchers, despite the fact that mathematics is an object of audiovisual content. Children with non-verbal difficulties, i.e. with difficulties in mathematics and painting, have experienced a deficiency in the operation of the visual-spatial sketch pad (Comoldi, Rigoni, Tressoldi, & Vio, 1999). These results support the view suggested by Heathcote (1994), which assumes that the visual-spatial sketch pad can function as a "mental blackboard", i.e. as a mental work environment for mathematical interventions.

Several studies have shown the relationship of working memory and mathematical performance (Hitch, 1978; Holmes & Adams, 2006; Logie & Baddeley, 1987; Siegel & Ryan, 1989; Swanson, 1993). In general, working memory is related to a variety of arithmetic and mathematical skills that are used for counting and solving simple addition and subtraction problems (Adams & Hitch, 1997; Geary, 1990; Geary & Widaman, 1992; Hitch, 1978; Logie, Gilhooly, (Geary, 1993; Hitch & McAuley, 1991; Passolunghi & Pazzaglia, 2005; Passolunghi & Siegel, 2001, 2004; Siegel & Ryan, 1989; Swanson, 1993). On the basis of existing data, it seems likely that different components of working memory can emphasize mathematical processes at different ages (Henry & MacLean, 2003; Holmes & Adams, 2006; McKenzie, Bull, & Gray, 2003). In addition, different areas of working memory seem to relate to different areas of mathematical performance. Much of the research on mathematics and working memory has focused on mental calculations while the other mathematics sectors have received less attention.

1.4. Visual long-Term Memory and Mathematical Performance

In addition to primary memory and working memory, secondary (long-term) memory also plays an important role in mathematical performance. It is the process of transforming primary memory into a different code for its long-lasting preservation or storage, which is the process of secondary long-term memory. The development of long-term mnemonic operation seems to follow a specific order. First, in the infancy stage, recognition is based on familiarity, while later the ability to retrieve specific information appears. Long-term memory, based on the type and nature of the information is divided into verbal long-term memory and visual long-term memory. Their assessment is similar.

There is a perception that long-term visual memory is unclear and easily altered when subjected to interference. Thus, although individuals can remember thousands of images, it is supposed that these memories are devoid of details. Contrary to this hypothesis, research (Brady, Konkle, Alvarez & Oliva, 2008) shows that long-term memory is capable of storing a huge number of images in great detail. Participants saw images of 2,500 items for five and a half hours. Then they were shown pairs of pictures and they were asked to indicate which of the two they had them in three different states. The performance in each of these conditions was extremely high (92%, 88% and 87% respectively), indicating that the participants successfully retained detailed information from thousands of images. These effects have implications for cognitive models (object recognition models) and are challenging for nerve memory storage and recovery models, which must be able to explain and interpret such a large and detailed storage capacity. The theories of the representation of numerical events in long-term memory (Siegler & Shrager, 1984) point out that the performance of simple numeric queries depends on long-term memory recollection. The power with which these elements are stored and therefore the probability of their successful recovery is based on the experience of the correlation of the problems and the responses formed, each time a particular numerical problem is dealt with, regardless of the correctness of the response. A student with long-term memory deficits may have difficulty with mathematical tables, geometric shapes, or algebraic formulas. In a review of research on cognitive deficits in children with mathematical difficulties (Geary, 1993), two main categories were identified. The first one is related to counting deficits, computational skills and working memory (Geary, 1990; Geary, Bow-Thomas, & Yao, 1992) and is manifested by the use of developmental immature numerical procedures which usually return to normal levels after 2 or 3 years of schooling. The second category involves more of a permanent difficulty in the representation and retrieval of numerical events from long-term semantic memory.

Long-term information retrieval skills have been linked to learning in mathematics over school years. This is why major cognitive assessment tests (Woodcock-Johnson, Wechsler, 2014) consider the broader cognitive factor called long-term recovery or storage and recovery, i.e. the ability to incorporate new information into the previous ones, to store them and to be able to recover them effectively.

Some researchers argued that difficulties in retrieving information, including words and numerical events, from long-term memory represent a specific cognitive deficit that results in serious delays in the early development of mathematical skills (Geary, 1993; Geary et al., 1999). The results of these studies show that the ability to retrieve information from long-term memory is important for the development of early math computing skills. Significant relationships between information retrieval and various fields of mathematics were generally evident from the age of 6 to about 8 years of age. It appears that after the age of 9, this relationship is weaker.

1.5. Fluid Intelligence and Mathematical Performance

The acquisition and application of mathematical skills are of great social importance due to the educational needs, day-to-day activities and work (Mullis et al., 2001; Rivera-Batiz, 1992; Rourke & Conway, 1997).

Studies have focused their attention on house-related and community-related variables and how they affect mathematical performance (Fleischner, 1994). For example, the importance of home-based educational tools (e.g. books, study aids, parents' educational level) influences the prediction of success or failure in mathematics (Mullis et al., 2001). The training of teachers in mathematics, the focus and content of teaching materials and the time spent during mathematics teaching also appear to be strong predictors of the development of mathematical skills (Carnine, 1991; Lyon, Vaasen, & Toomey, 1989; Mullis et al., 2001; Russell & amp; Ginsburg, 1984).

However, very little is known about cognitive processes that contribute to mathematical performance or relate to learning difficulties in mathematics (Geary, 1993, 1994; Rourke & Conway, 1997). Most researches examining the effect of cognitive processes on the development of mathematical skills usually include only a limited set of specific conceptual and procedural skills related to relatively limited fields in mathematics (Bryant & Rivera, 1997; Fleischner, 1994; Hoard, Geary, (Gersten & Chard, 1999). Numerical deficits or developmental immature numerical processes (Geary, 1993) have been identified as serious causes of learning difficulties in mathematics. In addition, the general cognitive processes that affect mathematical performance have been studied and show to have limited scope. The research has focused mainly on three cognitive processes: (a) working memory; (b) storage and retrieval of information in long-term memory; and (c) visual processing capabilities (Ashcraft 1995; Dark & Benbow 1990; 1991; & Hutch, 2000; Geary & Burlington-Dubree, 1989; Geary & Hoard, 2001; Hulme & Roodenrys, 1995; McLean & Hitch, 1999; Noel, Desert, Aubrun, & Seron, 1996; Rourke, 1993; Swanson, 1993).

The correlation between general intelligence and academic performance is moderate and varies according to the literature at from about 0.55 to 0.60 (Naglieri & Bornstein, 2003; Neisser et al., 1996) and often intelligence tests are used to predict the academic performance of students (Gustafsson & Undheim, 1996; Spinath, Spinath, Harlaar, & Plomin, 2006). In general, however, the role of intelligence in predicting academic performance is controversial. Some researchers (Jensen, 1998; Watkins, Lei, & Canivez, 2007) claim that this relationship is due to the causal role of the general intelligence agent known as "g". Conversely, other researchers (Fagan, 2000; Luo, Thompson & Detterman, 2003; Naglieri & Das, 2005) attribute this relationship to basic cognitive skills. It is estimated that non-verbal intelligence tests (i.e. Raven), those that are free of the language factor, have been found to better predict academic performance compared to tests including oral language activities. Researchers (McCallum, 2003; Naglieri & Ford, 2003, 2005) even suggest these tests are more appropriate for another reason. They better achieve the assessment of children with different levels of language, knowledge and academic skills and a low socio-cultural background. In fact, Raven's Colored Progressive Matrices (CPM) is perhaps the best tool for educational and clinical observations (Raven & Raven, 2003). The user instructions are simple and the short time it requires makes it a very handy tool. The CPM has good assessment and predictive validity (Pind, Gunnarsdottir, & Johannesson, 2003; Rohde & Thompson, 2007; Rushton, kuy, & Fridjhon, 2003), but the test and retest process shows weaknesses for periods of more than one year (Kazlauskaite & Lynn, 2002; Raven & Raven, 2003).

Mathematics performance is one of the topics studied in the context of academic performance and intelligence (Deary, Strand, Smith & Fernandes, 2007; Luo, Thompson, & Detterman, 2003). Using Cattle-Horn-Carroll's (CHC) theory, McGrew et al. (1997) explored the contribution of the seven broader cognitive abilities of this theory to mathematical performance. They identified the broader cognitive abilities of CHC, crystallized intelligence, fluid intelligence and processing speeds as factors affecting mathematical performance beyond the proven effects of the general factor "g". Similar results were found in a later study (Keith, 1999), where it was also found that mathematical performance is strongly influenced by the general factor "g" but also by a number of other factors such as crystallized intelligence, fluid intelligence, and processing speed. Both surveys confirm the results of a previous survey (Gustafsson & Balke, 1993), where the contribution of the general factor "g" and cognitive abilities was recognized in academic performance in general and in mathematics in particular.

The purpose of this research is to examine the relationship between cognitive abilities and mathematical performance. Specifically, what are the relations between short-term memory, working memory, long-term memory, fluid intelligence and their relation to the mathematical adequacy of the kindergarten students?

1.6. The Aim of Current Study

The above theoretical and research data led to the formulation of the following research questions:

1. Are cognitive abilities and fluid intelligence related to each other and to what extent?
2. Which of the variables (visual short-term semantic memory, visual short-term non-semantic memory, auditory verbal short-term memory, working memory, long - term memory, fluid intelligence) are related to the mathematical performance of kindergarten students?
3. Can cognitive abilities and fluid intelligence be predictive factors of mathematical performance and to what extent?

2. Material and Method

2.1. Participants

80 primary school students (50 boys and 30 girls) with average age of 5 years and 10 months (SD = 3.60 months, range = 13 months, min = 63 months, max = 76 months) took part in the survey. All students completed their activities except for two students who did not complete two activities.

2.2. Procedure

All participants were evaluated individually during their school hours in their school. For the whole process, the consent of their parents was requested. The evaluation was made individually in a quiet classroom at the end of the school year, in May and June. The classes that participated in this study were commended for their participation and therefore undertook to perform the activities properly.

2.3. Measurements

The tools used to measure the cognitive abilities and fluid intelligence of sample students are described below. The children completed their assessment in three phases. The first phase was to evaluate the cognitive abilities of short-term memory and fluid intelligence. In the second phase working and long-term memory were evaluated. In the third and final phase, the degree of mathematical performance was evaluated. Children were allowed short breaks during the evaluation to ensure that they remained focused.

2.3.1. Short-Term Memory

It was decided that both types of short-term memory should be evaluated. Auditory verbal short-term memory and visual short-term memory with its two subtypes (visual short-term semantic memory and visual short-term non-semantic memory). For auditory verbal short-term memory (ADS), the subscale "memory number" of Athena test was used to diagnose learning difficulties (Paraskevopoulos et al., 1999). The subscale measures the child's ability to repeat, by memory, series of digits, which increase gradually. It consists of 16 rows of 3 to 7 digits. The digits in each row are randomly selected between digits 1 through 9. These numerical rows are presented to the child, one at a time, orally, in a uniform manner (the speech rate is one digit per second). The child repeats the order immediately after it is spoken.

For visual short-term memory, the "picture memory" (AMP) and "shape memory" (AMS) subscales of learning difficulties were used (Paraskevopoulos et al., 1999). The two subscales are identical, except that in the first coherent material is used, while the other uses abstract shapes (material without meaning). "Picture Memory" consists of 16 sets of common object pictures and "Shape Memory" of 6 other series of shapes, which become gradually longer. These rows are displayed on the same tabs. The objects in the pictures were chosen so that they were similar to make it easier for the child to recognize them, but at the same time different, in order not to facilitate the formation of morphological clusters. The shapes have been chosen to be distinct in order to facilitate their differentiation, but at the same time unusual for the child, so that semantic coding is not facilitated.

2.3.2. Working Memory

The Baddeley and Hitch working memory model includes two subsystems, the articuratrory loop and visual- spatial sketchpad (Baddeley & Hitch, 1974, Baddeley, 1996, 2000). The articuratory loop (WM) was evaluated with the subscale memory of the Greek "wisc iii" (Greek adaptation; Georgas, Paraskevopoulos, Bezevegis, et al., 1997). It consists of 15 series of numerals that are read to the child and are gradually becoming larger. The child must repeat each sequence, in a straight and reverse order. For the visual spatial sketchpad, the Memory detection and investigation tool was used in the Kindergarten and Primary School and, in particular, the visual memory subscale (VM) which evaluates the recall of a small array of objects located in specific locations over a frame. The examiner places the objects on the frame, removes them, and then asks the child to place them in the correct position. The process is repeated until the child places all objects in the correct positions. After a short 5 minute break, the child is asked to place the items in the correct positions (VMDR delayed recall). Also the "immediate recall" (RVI) activity of the visual information retrieval scale of the same tool was used. This scale involves recalling a series of objects that the examiner places in a complex frame (different points of a large image). After the researcher removes them, the child is asked to place them at the right points of the image. In the immediate recollection process, the placement is done immediately after the removal of the objects by the researcher and the visual working memory is evaluated.

2.3.3. Long-Term Visual Memory

The evaluation of visual long-term memory is done by recalling encoded visual-spatial representations, such as the location of objects in space, and is an important skill for the person's functionality. In order to evaluate this function, the tool for detecting and investigating memory disturbances in the Kindergarten and Primary School was used, namely the visual information retrieval scale. This scale involves recalling a series of objects that the researcher places in a complex frame (different points of a large image). After the researcher removes them, the child is asked to place them at the right points of the image. In delayed recall (RVIDR), placement occurs after 30 minutes. Delayed Recall evaluates long-term memory.

2.3.4. Fluid Intelligence

Fluid intelligence has been found to be particularly relevant to general intelligence (Kvist & Gustafsson, 2008; McArdle & Woodcock, 1998). It has often taken a leading role in studies on academic performance. Fluid intelligence (R) was evaluated using the Raven Colored Progressive Matrices CPM (Raven Colored Progressive Matrices CPM), which requires analytical reasoning for the abstract audiovisual material. Its instructions are simple and its application takes certain small amount of time. Students were asked to choose the right answer for each item in the answer sheet. Silence and individual work were necessary. The maximum score was 36. Raven is known to be one of the most important fluid intelligence assessment tests.

2.3.5. Mathematical Performance

Early mathematical performance refers to all the knowledge and skills that are a prerequisite for effectively introducing a pre-school and early-school child into school mathematics in formal education (Van de Rijt, Van Luit & Pennings, 1994). These mainly concern the creation of the concept of number, as the basic field of school mathematics in the early years of formal education.

The “Utrecht Early Numeracy Test” was chosen to evaluate early mathematical performance. This is a single test consisting of eight modules of project-questions. At a very early stage, children develop the ability to count discontinuous quantities, which they often use for the purposes of comparing two sets instead of a one-to-one corresponding (Fuson, 1988, Gelman & Gallistel, 1978). The deployment skills development phases are acoustic counting, non-synchronized counting, structured counting, *resultative* and shortened counting.

The construction of the “Utrecht Early Numeracy Test” was based on a synthesis approach covering both the Piaget competencies and the development stages of the measurement skill. The eight sections of the Criterion are: Comparison, classification, one-to-one correspondence, seriation, the use of number words, structured counting, resultative counting, general understanding of numbers.

3. Results

3.1. Data Analysis

3.1.2. Descriptive Statistics

The averages, the standard deviations, the performance range and the smallest and the highest performance grades by rating are presented in the table below (Table 1).

Table 1: Descriptive statistics

	N	M	SD	RANGE	MIN	MAX
Short – term memory						
(ADS)	78	10,61	6,46	27	1	28
(AMP)	80	9,25	4,07	19	3	22
(AMS)	80	7,87	3,99	16	0	16
Working memory						
(WM)	78	7,25	2,49	9	2	11
(VM)	80	22	2,96	9	16	25
(VMDR)	80	4.47	0.95	4	1	5
(RVI)	80	47,35	3,34	13	37	50
Long term memory						
(RVIDR)	80	9,5	0,95	4	6	10
Fluid intelligence						
Raven - CPM **(R)**	80	17,22	3,58	15	11	26
Math Performance						
ENT (MA)	80	26,87	7,20	29	9	38

ADS= Auditory Verbal Short-Term Memory, AMP= Visual Short-Term Semantic Memory, AMS= Visual Short-Term non Semantic Memory, WM= Working Memory, VM= Visual Memory, VMDR= Visual Memory Delayed Recall, RVI= Retrieval Visual Information, RVIDR= Retrieval Visual Information Delayed Recall, R= Fluid Intelligence - Raven – CPM (Raven Colored Progressive Matrices), ENT (MA) = Early Numeracy Test- Mathematical Performance

3.1.3. Correlations

Pearson correlation coefficients were calculated to examine the correlations between the domains evaluated (Table 2).

Table 2: Correlations between variables

		1	2	3	4	5	6	7	8	9	10
1	(ADS)										
2	(AMP)	,397**									
3	(AMS)	,317**	**,595****								
4	(WM)	,636**	,492**	**,538****							
5	(VM)	,339**	,382**	,290**	,387**						
6	(VMDR)	,210	,093	,056	,228*	,560**					
7	(RVI)	,135	,134	-048	,131	,214	,470**				
8	(RVIDR)	,112	,260*	,282*	,278*	,461**	**,514****	-016			
9	Raven - CPM **(R)**	,225*	**,528****	,326**	,429**	,387**	,228*	,202	,278**		
10	ENT (MA)	**,497****	472**	,461**	**,777****	**,572****	,337**	,148	**,569****	,455**	
* p < .05. ** p < .01. *** p < .001.											

ADS= Auditory Verbal Short-Term Memory, AMP= Visual Short-Term Semantic Memory, AMS= Visual Short-Term non Semantic Memory, WM= Working Memory, VM= Visual Memory, VMDR= Visual Memory Delayed Recall, RVI= Retrieval Visual Information, RVIDR= Retrieval Visual Information Delayed Recall, R= Fluid Intelligence - Raven – CPM (Raven Colored Progressive Matrices), ENT (MA)= Early Numeracy Test- Mathematical Performance

Activities evaluating short-term memory are linked with moderate to satisfactory correlation (AMS * AMP =, 595). Working memory is associated with auditory verbal short-term memory and visual short-term non-semantic memory with moderate to satisfactory correlation (WM * ADS =, 636 and WM * AMS =, 538). Fluid intelligence is positively correlated with moderate potency with visual short-term semantic memory (R * AMP =, 528), while the correlation of other variables were weak to moderate (R * ADS =, 225 R * AMS =, 326 R * WM =, 429 R * VM =, 387 R * VMDR = 228 and R * RVIDR =, 278). Finally, mathematical performance is moderately positively related to auditory verbal short-term memory (MA * ADS =, 497), visual short-term semantic memory (MA * AMP =, 472), and visual short-term non-semantic memory (MA*AMS= ,461). It also correlates moderately to satisfactory with the visual spatial working memory (MA * VM =, 572) and visual long-term memory (MA * RVIDR =, 569). The relationship between mathematical performance and fluid intelligence tends to be moderate (MA * R =, 455). A very strong correlation, the strongest correlation between all variables exists between mathematical performance and verbal working memory (MA * WM =, 777).

3.1.4. Regression analysis

To look at which factors have predictive value for the level of mathematical performance, a series of multiple regression analyses were performed. The researchers chose to introduce all predictive variables at once to see which of the factors were significantly predictive of mathematical performance and how much fluctuation they explain. Then the variables that are not good predictors of mathematical performance were excluded. It was found that verbal working memory is an important factor in explaining mathematical performance (Model 1- Table 3). Then the hypothesis that the addition of visual long-term memory better explains the level of mathematical performance was tested (Model 2 - Table 3). Finally, adding the visual working memory further explains the level of mathematical performance (Model 3 -Table 3). From the results, it seems that the verbal working memory is the best predictor of the level of mathematical performance. Visual long-term memory followed, while less than three variables contribute to working memory (table 3).

Table 3: Regression analysis for mathematics performance

Dependent Variable	**Independent Variables**	**Beta**	**t**
Math Performance	**Model 1**		
	Auditory Verbal Working Memory F=115,89***, R^2= ,604	,777	10,7***
	Model 2		
	Auditory Verbal Working Memory	,657	10,00***
	Visual Long – term Memory F=93,89***, R^2= ,715	,354	5,39***
	Model 3		
	Auditory Verbal Working Memory	,584	8,63***
	Visual Long – term Memory	,296	4,49***
	Visual Working Memory F=71,36***, R^2= ,743	,200	2,86**
* p < .05. ** p < .01. *** p < .001.			

Observing the results of Table 3 it is evident that based on model 1, the independent variable verbal working memory (WM) alone interprets the percentage of variance (R2 =, 604), which is 60%. By adding the second variable, which is the visual long-term memory (model 2), it is shown that the ability to predict the level of mathematical performance increases (R2 =, 715) and becomes 71%. That is, the addition of the second variable of the visual long-term memory adds an additional 11% to the prediction rate of math level. Based on the latest model (model 3), it is shown that adding the third variable of the visual working memory adds an additional 3% (R2 =, 743) to 74% of the prediction model. From the results, it can be concluded from the three variables that affect mathematical performance, that the most important is the verbal working memory (for model 1 Beta = 777 for model 2 Beta = 657 and for model 3 = Beta = 584) the next one is the visual long-term memory (model 2 Beta =, 354 and model 3 Beta =, 296), while the last is visual working memory (model 3 Beta =, 200).

4. Conclusion and Discussion

This study aimed at examining the variables related to the mathematical performance of kindergarten students and the predictive relationship between cognitive abilities and fluid intelligence with the level of mathematical performance of kindergarten children. Therefore, each component of cognitive abilities was evaluated.

4.1. Correlation of variables

The correlation analyses showed that the correlation of short-term memory (visual and auditory verbal) with mathematical performance tends to be moderate (ADS * MA =, 472 AMP * MA =, 472 AMS * MA =, 461) (VM * MA =, 572), while for the verbal working memory was very strong (WM * MA =, 777). Long-term memory is moderately correlated to mathematical performance (RVIDR * MA =, 514), while mathematical performance and fluid intelligence correlation tend to be moderate (MA * R =, 455).

Some researchers (Swanson, 1994; Passolunghi & Siegel, 2001) argue that the difficulties in short-term memory are independent of the difficulties in working memory. In the present study it appeared to be partially true in the kindergarten students since the short-term memory activities are positively associated only with the verbal working memory with moderate to satisfactory correlation (WM * ADS =, 636 WM * AMP =, 492 and WM * AMS =, 538), while the relationship between the visual spatial working memory and the short-term memory appears to be weak (VM * ADS =, 339 VM * AMP =, 382 and VM * AMS =, 290).

Some researchers report that children with mathematical difficulties have weaknesses in auditory verbal short-term memory (Siegel & Ryan, 1989), while others argue that children with learning difficulties in mathematics have a general shortage over the whole range of short-term memory, namely auditory and visual Hitch & McAuley, 1991; Swanson, 1993; Turner & amp; Engle, 1989). They estimate that mathematical performance is linked to the overall performance of short-term memory in general (Geary et al., 1991, 2000; Geary, Hoard & Hamson, 1999; Hitch & McAuley, 1991; Passolunghi & Siegel, 2001) and show that deficiencies in auditory verbal short-term memory are related to learning difficulties in mathematics. These results refer to older age groups. However, the findings of our study in kindergarten students show similar results, since there seems to be moderate positive correlation (ADS * MA =, 497) between auditory verbal short-term memory and mathematical performance. In fact, for kindergarten students, the entirety of short-term memory (auditory verbal and visual), as well as visual short-term memory, is associated with mathematical performance with moderate positive correlation (AMP * MA = 472 and AMS * MA = 461).

On the basis of existing data, it is possible that different components of working memory are related to mathematical processes at different ages (Henry & MacLean, 2003; Holmes & Adams, 2006; McKenzie, Bull, & Gray, 2003). In addition, different areas of working memory seem to be required in different areas of mathematical performance. In general, the role of working memory in mathematical performance is well documented (Hitch, 1978; Holmes & Adams, 2006, Logie & Baddeley, 1987; Siegel & Ryan 1989; Swanson 1993 Bull & Scerif 2001; Gathercole & Pickering 2000a; Hecht et al., 2001; Holmes & Adams, 2006, Noel et al., 2004, Passolunghi et al., 2007, Swanson & Kim, 2007). In fact, in research (Friso-van den Bos et al., 2013) it was found that most of the elements of working memory are more related to general mathematical tests, such as national tests and curricula rather than purely numerical knowledge . It seems that total working memory (verbal and visual) is related to mathematical performance (Geary, Hoard, Byrd-Graven, Nugent, & Numtee, 2007). In particular, verbal working memory relates to performance in mathematics (Geary, Brown, & Samaranayake, 1991, Hitch & McAuley, 1991), and in a study by Swanson and Kim (2007), it appears to correlate with the performance in mathematics by children aged 6 to 10 years. In another study (Bull & Johnston, 1997), there also appeared to be a strong correlation between math performance in 7-year old students' tests and verbal working memory test performance. However, there are studies that lead to the conclusion that there is insufficient evidence to support this correlation (Gathercole & Pickering, 2000b; Holmes & Adams, 2006). The results of the current research show a strong correlation between mathematical performance and verbal working memory in kindergarten students. Indeed, this correlation is the strongest correlation found to exist between mathematical performance by all the cognitive factors examined in this research (WM * MA =, 777).

The relationship between visual working memory and mathematical performance is present in normal children of different ages (eg Blair & Razza, 2007; Bull, Espy, & Wiebe, 2008; De Smedt et al., 2009; Swanson & Kim, 2007; Van der Ven, Kroesbergen, Boom, & Leseman, 2012). Also, in children with learning difficulties in mathematics, lower performance has been observed in activities evaluating the visual spatial working memory relative to their peers who do not encounter difficulties in mathematics (McLean & Hitch, 1999; Van der Sluis, Van der Leij, & De Jong, 2005). The results of this research showed that the relationship between visual spatial working memory and mathematical performance to students of typical kindergarten students is moderate to satisfactory (VM * MA =, 572). The findings of the research show that the findings of the bibliography for older age groups also apply to the tested age group.

The important relationship between information retrieval from long-term memory and various fields of mathematics is evident from an early age and is strongly associated with mathematical performance (McGrew & Wendling, 2010). The deficits in the ability to recall numerical events are consistently associated with difficulties and poor performance in mathematics (Geary, 2011). However, although the role of long-standing memory has been emphasized as a key feature of mathematical learning, empirical studies have received relatively less attention as a major contributor to the development of mathematical knowledge. In the present study, the long-term memory and mathematical performance correlation in typical kindergarten students is moderate to satisfactory (RVIDR * MA =, 569).

In terms of fluid intelligence, it was found to be related to visual short-term semantic memory (picture memory) moderately. Typically, individual short-term memory enumeration tests show a moderate correlation with the general factor "g" (.30 to .50). For example, auditory verbal short-term memory is associated with the general factor "g" with a correlation of about 0.40 (Gignac & Weiss, 2015). In the present study, the results of these investigations are not confirmed, since in the field of auditory verbal short-term memory the correlation with the fluid intelligence was found to be positive but relatively weak (R * ADS =, 225). Activities evaluating visual short-term memory also show a modest correlation with the general factor "g" (Osterrieth, 1944; Rey, 1941). However, in another study (Reynolds, Keith, Flanagan, and Alfonso 2013) using the Woodcock-Johnson III subclass "Picture Recognition" (Woodcock et al., 2001), visual short-term memory showed a moderate correlation with the general factor "g" (, 528). The same degree of correlation is shown by the results of this study, where visual short-term memory was found to be positively related to fluid intelligence as measured by CPM (R * AMP =, 528) in typical kindergarten students.

Fluid intelligence, which usually refers to reasoning ability, is linked to later academic performance and problem solving (Jensen, 1998), with the early numeracy capability (Kroesbergen et al., 2009) as well as with subsequent mathematical performance (Deary et al., 2009). al., 2007, Moenikia & Zahed-Babelan, 2010). It appears to include some of the most important parameters associated with problem solving as well as strategies involved in the improvement of mathematical performance. Research shows that there is a rather modest correlation between fluid intelligence and mathematical performance (McGrew & Flanagan 1998; Flanagan, McGrew, & Ortiz 2000; Flanagan, Ortiz, Alfonso, & Mascolo, 2002). However, so far the research has not elucidated the relationship between fluid intelligence and early mathematical performance. In the present study, there was a rather modest correlation between fluid intelligence and mathematics as measured by the CPM test (R * MA =, 455) in kindergarten students.

As reported, mathematical performance has a modest correlation with verbal working memory (VM * MA =, 497 MA * AMP =, 472 and MA * AMS =, 461) 572), visual long-term memory (RVIDR * MA =, 569) and fluid intelligence (R * AMP =, 528). The greatest correlation found in the research was between mathematical performance and verbal working memory (WM * MA =, 777) a correlation strong, to very strong.

4.2. Prediction of mathematical performance

In terms of predicting mathematical proficiency, in the present study it was shown (Table 3) that the verbal working memory is the best predictor variable (R2 =, 604), followed by the visual long-term memory and finally the visual spatial working memory has the lowest contribution to predicting the mathematical performance of the three variables. The role of verbal working memory in the prediction of mathematical performance has been highlighted in a series of studies. It seems even more likely that mathematical difficulties are more predictable through the process of evaluating verbal working memory, especially when it involves an evaluation of the inverse repetition of numerals. In several studies (Andersson & Lyxell, 2007, Geary, Hoard, Byrd-Craven, & DeSoto, 2004; Hitch & McAuley, 1991; Passolunghi & Siegel, 2001, 2004; Siegel & Ryan, 1989; reverse repetition identifies children with mathematical difficulties from their typically developing classmates. Such an assessment of the verbal working memory was also used in this research. Many of the previous studies have been conducted in children aged 7 years and over. However, for children who are just entering primary school, many of the school activities they are called to respond to are completely new and therefore can pose particularly great problems on cognitive processes such as memorial functions. The contribution of the verbal working memory to the prediction of mathematical performance seems to be valid for the age group of kindergarten students, based on the results of this research. These findings are consistent with the findings of research showing that the verbal working memory of the children in kindergarten is the main predictor of early and second grade numbering (Robinson, Menchetti, & Torgesen, 2002; Simmons & Singleton, 2008) . However, this research appears to be a predictive factor of mathematical performance overall and not only of the early numerical skills.

Regarding the field of visual spatial working memory the range of results is large and often inconsistent. Both static and dynamic measurements of visual spatial working memory have been found to identify and differentiate children with mathematical difficulties from their typically developing peers (D'Amico & Guarnera, 2005; Reukhala, 2001). However, the findings of other surveys (McLean & Hitch, 1999; Van der Sluis et al., 2005) show that only dynamic visual rather than static visual working memory can differentiate the two groups of students (students with mathematical difficulties and typically developing students). In other studies it was found that visual - spatial memory does not differentiate the two groups (Andersson & Lyxell, 2007; Bull, Johnston & Roy, 1999; Temple & Sherwood, 2002; Wu et al.), while a variation of the dynamic visual spatial working memory can achieve the differentiation of the two groups (Passolunghi & Cornoldi, 2008). (Geary, Hoard, Byrd-Craven et al., 2007, 2008). Combined models of dynamic and static visual -spatial working memory report either zero results or simply record trends. However, according to research data (Alloway, 2009) regarding the contribution of working memory to mathematical skills in children aged seven and eight, visual - spatial memory can predict math performance for this age group. These findings provide a useful starting point in research into the contribution of working memory to mathematical skills. In terms of predicting mathematical proficiency in the present study it was shown that visual spatial working memory is also an important predictive variable where, in combination with verbal working memory and visual long-term memory (model 3), it can be a predictive factor of mathematical performance for kindergarten students.

Looking at the role of long-term memory in mathematical performance, it is estimated that storage and retrieval capacity is a broad cognitive factor that is increasingly recognized as playing a key role in learning. Although the role of long-term memory recovery has been emphasized as a critical feature of mathematical learning in empirical studies, it has received relatively less attention as a wider cognitive factor associated with the development of mathematical skills. However, long-term memory recovery skills have been associated with learning in mathematics during school years (Pauly, Linkersdörfer, Lindberg, Woerner, Hasselhorn & Lonnemann, 2011, Van der Sluis, De Jong & Van der Leij 2004, Willburger, Fussenegger, Moll, Wood & amp; Landerl, 2008). Children with learning problems in mathematics have difficulties in understanding quantitative data, storing and retrieving basic mathematical events from long-term memory and learning mathematical problem-solving processes (Geary, 2011).

It is likely that the predictive power of recalling information from long-term memory during the first years of primary schooling is due to the fact that the recollection of mathematical data from long-term memory, and in particular from long-standing memory, is necessary for the solution of simple mathematical problems (Ashcraft, 1995). In the present study, visual long-term memory is the second major predictor of mathematical performance after verbal working memory (model 2)

Fluid intelligence has been linked to later academic performance in problem solving (Jensen, 1998), as well as with later mathematical performance in general (Deary et al., 2007; Moenikia & Zahed-Babelan, 2010). However, the research so far has not elucidated the relationship between fluid intelligence and early mathematical performance and whether it is a predictive factor in mathematical performance, a fact that also appeared in the results of this research since it did not proved to be a strong predictor. It seems that verbal working memory is the main predictive factor of later mathematical performance (Alloway, 2009; Panaoura & Philippou, 2007; Passolunghi et al., 2008). This research seems to confirm this assumption since the findings show that verbal working memory is the main predictor of the level of mathematical performance. Until now, research has dealt with cognitive abilities and predictability of mathematical performance. However, some of the cognitive skills have been examined in some specific areas of mathematical performance and in children mainly attending elementary school. The originality of this research lies in the fact that a wide range of cognitive skills was examined, in the same sample, and the possibility of predicting the entirety of mathematical performance rather than just some areas of mathematical performance.

5. Recommendations

The sample consisted of 80 students from the 43rd educational region of Greece (Prefecture of Arta). This is constitutes an important limitation of this research. For this reason, we estimate that a sample of a larger geographic range and size is required. Despite this limitation, this study is highly important. It explores a wide range of cognitive skills in kindergarten students, and their correlation with later mathematical performance. It has been shown that working memory (acoustic and visual) combined with long-term memory can contribute to the estimation of later mathematical skills. Children with cognitive disabilities are likely to face difficulties in a wide range of learning activities due to their inability of remembering and executing instructions, remaining focused on learning as well as to planning and monitoring progress and steps required, as the problem progresses. Based on this, Gathercole et al., (2006) argued that these children may be unable to follow through a multitude of structured learning activities in the classroom, thus losing opportunities to learn, practice skills, and achieve gradual progress. Children with cognitive difficulties are particularly disadvantaged, as these skills appear to be critical, especially in the early development of mathematical skills. Specifically, evaluating these cognitive functions of working memory and long-term memory in time seems to be a powerful tool for predicting later mathematical proficiency. Such an assessment could be carried out at the end kindergarten or at the beginning of a student's attendance of elementary school. Educational awareness of the role of cognitive skills in mathematical performance, the need for methodological adaptation, as well as that of intervention methods can help students overcome the difficulties and achieve satisfactory results.

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