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PRECONDITIONS OF MATHEMATICS KNOWLEDGE AND SKILLS[a]

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SUMMARY

The main aim of this research is to determine developmental abilities that are preconditions of acquiring mathematics knowledge and skills.

The sample consisted of 115 typically developing children of both genders, aged between 8 and 11 (M=9.78). Acadia test of developmental abilities was applied to assess the abilities that are considered necessary for acquiring academic knowledge and skills. Achievements in different areas of Mathematics were assessed on the basis of teachers' questionnaire based on General achievement standards.

The results of this research reveal a statistically significant influence of various developmental abilities, assessed by means of Acadia test, on achievements in different areas of Mathematics, presented through total scores: visuomotor skills (p≤0.000-0.003), perceptive functions (p=0.033-0.018), language skills (p=0.004-0.020), verbal and nonverbal reasoning (p=0.002; p=0.023) and auditory short-term memory (p=0.015).

Children with lower scores on Visuomotor Coordination and Sequencing subtest (below 25th percentile) had significantly lower achievement in all mathematics areas (p≤0.000-0.039). Children with lower scores on Visual Discrimination subtest had significantly lower achievement in the area of multiplication and division (p=0.003-0.010), geometry (p=0.002-0.036) and measurements and measures (p=0.009-0.016). Lower copying skills (below 25th percentile) were related to lower addition and subtraction achievements (p=0.012-0.046), while lower scores on Auditory Memory subtest were related to lower knowledge of integers (p=0.017-0.029). Children with lower scores on Concept Formation subtest had lower achievements in the areas of addition and subtraction (p=0.009-0.011), multiplication and division (p=0.002), geometry (p=0.017-0.045) and measurements and measures (p=0.013-0.009).

The results obtained in this study indicate that among numerous developmental abilities, visuomotor coordination, visual discrimination, copying skills, verbal reasoning and auditory short-term memory can be singled out as areas of great importance for the development of various aspects of mathematics. Thus, in the context of prevention and early intervention, it would be desirable to focus more on the development of visuomotor and integrative skills at the preschool level.

Key words: developmental abilities, mathematics, Acadia test

INTRODUCTION

Mathematics is one of the basic academic fields which includes different aspects such as arithmetic, geometry, algebra, etc. Their acquisition depends on numerous factors of different origin, some of which are intelligence, motivation, self-confidence in mathematics, anxiety related to mathematics, and different cognitive skills (specific and general) (Geary, 2011; Gligorović, 2010).

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Low achievement in mathematics is a serious problem since mathematics skills are a very significant element of adaptive skills, especially in industrially and technologically developed areas. Numerical data are present in all aspects of everyday life – e.g. in assessing the time needed to get from one part of town to another, making financial decisions, paying bills, estimating how many people are in a room or how much food should be prepared for a certain number of guests.

According to the results of some studies on mathematics skills in elementary school children, about 21% of eleven-year olds fail to master the appropriate mathematics syllabus, while 5% fail to master the skills appropriate to the age of 7. These difficulties tend to persist to adulthood. It is estimated that basic numerical skills necessary for everyday situations are not developed in as many as one fifth of adults (Cragg & Gilmore, 2014), which greatly influences the choice and possibility of permanent employment. These people are usually limited to manual and low-wage jobs (Dowker, 2005). Apart from difficulties in various aspects of mathematics, poor reading skills also reduce employment possibilities and influence wage levels. However, poor mathematics skills proved to have a greater negative influence on professional life, even in persons with good reading skills (Parsons & Bynner, 1997).

A meta-analysis of longitudinal studies on a sample including over 34000 schoolchildren, determined that mathematics skills at the preschool level (especially numbers and ordinality) were the best predictors of future general academic achievement. It turned out that early mathematics knowledge was a better predictor of future success than early literacy, attention, socio-emotional functioning and intelligence (Duncan et al., 2007).

Individual differences in the level of acquired mathematics knowledge and skills are common. However, these differences are in certain cases so pronounced that they can be characterized as a problem or a difficulty (Geary, 2004). It is believed that between 3% and 6% of children express difficulties in mathematics to the extent that classifies them as children with dyscalculia (Dowker, 2005; Fuchs et al., 2005; Shalev et al., 2000). Apart from that, about 10% of children continuously achieve poor results in mathematics (the so-called low achievers). Both groups of children have difficulties in understanding and representing quantity, remembering basic arithmetic facts and acquiring mathematical procedures which cannot be explained by lower intellectual achievement (Geary, 2011).

The 10^{th} percentile on standardized achievement tests is usually applied in research as a boundary which establishes the difference between low achievers and children with dyscalculia. Children whose mathematics achievements are below the 10^{th} percentile for two consecutive school years are usually classified as children with dyscalculia, while those whose achievements are between 11^{th} and 25^{th} percentile are classified as low achievers (Chong & Siegel, 2008; Geary, 2011; Sigmundsson, Anholt & Talcott, 2011). Apart from this criterion, some researchers also use somewhat stricter boundaries in defining a specific difficulty in mathematics, which is usually 15^{th} or 20^{th} percentile (Reigosa-Crespo et al., 2012; Rubinsten & Sury, 2011; Shalev et al., 2000).

Difficulties in mathematics may be expressed in different ways. They are most frequently manifested as difficulties in recognizing symbols, mirror writing of numbers, difficulties in recognizing basic mathematical operations, acquiring and remembering mathematical facts, solving contextual tasks, etc. (Neumärker, 2000).

When dyscalculia or severe difficulties in mathematics are concerned, a frame of reference usually consists of average intellectual abilities and the absence of sensory impairments and emotional problems, with the emphasis on unexpected low achievement with regard to child's abilities and learning opportunities. However, unexpected low achievements in mathematics are also related to several developmental disabilities, such as phenylketonuria (Antshel, 2010), spina bifida (English et al., 2009), Turner syndrome (Mazzocco, 2009), Williams syndrome (O'Hearn & Luna, 2009), and Fragile X syndrome (Murphy, 2009). The results of these studies indicate the presence of specific cognitive profiles which are considered the basis of their difficulties in different aspects of mathematics, regardless of the level of intellectual functioning. Typical development represents a good landmark in determining the characteristics of different developmental disabilities. Similarly, the results of studies performed on clinical population may provide a new insight into the predictors of mathematics knowledge and skills in typically developing population, and the presence of learning disabilities.

In our previous research, it was determined that achievements in different areas of mathematics had a significant and relatively high correlation (r=0.41-0.50) with children's developmental status, assessed by means of Acadia test (Gligorović & Buha, 2015). Children whose general score on Acadia test was in the lowest range (below 25th percentile) also had significantly lower achievements in all the assessed areas of mathematics (knowledge of integers, basic arithmetic operations, geometry, measurements and measures) ($p \leq 0.000$-0.05).

With regard to the fact that mathematics skills, as a complex system, are based on the functioning of different cognitive abilities, the aim of this research was to expand the information obtained in our previous research (Gligorović & Buha, 2015), and to determine the developmental abilities which are preconditions of acquiring mathematics knowledge and skills.

METHOD

The sample consisted of 115 typically developing children of both genders (60/52.2% girls and 55/47.8% boys), aged between 8 and 11 (M=9.78; SD=0.59), attending 3rd and 4th grade of elementary school. Boys and girls were equal with regard to age ($F_{(1)}=1.781$, $p=0.185$). In accordance with the selection criterion, children with below-average intelligence were not included in the sample.

Instruments and procedure

Acadia test of developmental abilities (Atkinson, Johnston & Lindsay, 1972) was used to assess the abilities necessary for acquiring academic knowledge and skills. The test was developed with the aim to determine the cause of learning failure in schoolchildren, and it was translated and adapted in Croatia in 1985 (Novosel & Marvin Cavor, 1985). It was further adapted for Serbian language and standardized with regard to the achievements of younger schoolchildren in Serbia (Gligorović et al., 2005). The test consists of 13 subtests aimed at assessing the set of verbal and nonverbal abilities which are considered preconditions for acquiring academic knowledge and skills. It includes subtests which assess **perceptive functions** (Auditory Discrimination – Subtest 1, Visual Discrimination – Subtest 3, and Audio-Visual Association – Subtest 6), **memory** (Visual Memory – Subtest 5, and Auditory Memory – Subtest 8), **visuospatial** and **visuoconstructive abilities** (Visuomotor Coordination and Sequencing – Subtest 2, Drawing Shapes – Subtest 4, and Drawing – Subtest 13), **language skills** (Acquired Language Treasure – Subtest 10, and Automatic Language Treasure – Subtest 11), and **reasoning** (Concept Formation – Subtest 9, Sequence and Coding – Subtest 7, and Visual Association – Subtest 12).

Achievements in the areas of Mathematics were assessed on the basis of teachers' questionnaire based on General achievement standards for the end of the first education cycle. Teachers' assessment of achievements in mathematics included integers, addition and subtraction, multiplication and division, geometry, and measurements and measures. Teachers were asked to evaluate every child's level of knowledge/skill (expected for the child's grade or at the level of a previous grade). If they considered that a child's achievements met the requirements, teachers were asked to determine the precise level (elementary, intermediate, or advanced) and assess to what extent the child mastered the knowledge and skills appropriate for the given level (1 minimally, 2 partly, 3 completely). Each of the Mathematics areas could be awarded the maximum of 10 points. General score of teachers' assessment of students' achievements was obtained by summing up the results of the assessed areas (inter-correlation of the areas ranges from 0.84 to 0.92).

RESEARCH RESULTS

According to the results of our previous research on the same sample, the mean values of most teachers' questionnaire scores, based on General achievement standards, as well as the total scores in Mathematics (AM=36.23, SD=9.542) were grouped towards intermediate and higher levels of mastered knowledge and skills. There was no statistically significant influence of age and gender ($p>0.05$) on the results of the questionnaire (Gligorović & Buha, 2015).

The results of the participants on Acadia test subtests are shown in Table 1.

Table 1 *Basic statistical characteristics of students' achievements on Acadia test subtests*

	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13
Min	22	25	36	22	24	12	20	23	32	24	33	35	7
Max	61	63	60	62	63	67	67	71	73	68	65	71	66
M	55.10	45.30	52.79	41.57	51.6	50.93	54.61	46.76	54.96	56.91	55.97	58.17	40.37
SD	5.43	9.10	5.14	9.26	7.17	8.07	8.70	10.43	8.17	7.73	6.07	8.66	11.80

With regard to the percentile ranks of the results on Acadia test subtests, the sample was divided into three groups for each subtest, where the first group consisted of the participants with the lowest scores (up to 25^{th} percentile), the second group consisted of the participants with average scores (25^{th}-75^{th} percentile), and the third group consisted of the most successful participants (above 75^{th} percentile) (detailed in Table 2).

Table 2 *Sample distribution with regard to percentile ranks of achievements on Acadia test subtests*

	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13
PR	n(%)	n(%)	n(%)	n(%)	n(%)	n(%)	n(%)	n(%)	n(%)	n(%)	n(%)	n(%)	n(%)
≤ 25	50 (43.5)	29 (25.2)	36 (31.3)	31 (27.0)	38 (33.0)	45 (39.1)	32 (27.8)	29 (25.2)	36 (31.3)	35 (30.4)	37 (32.2)	32 (27.8)	29 (25.2)
25-75	37 (32.2)	65 (56.5)	66 (57.4)	59 (51.3)	58 (50.4)	53 (46.1)	55 (47.8)	60 (52.2)	62 (53.9)	74 (64.3)	54 (47.0)	64 (55.7)	62 (53.9)
≥ 75	28 (24.3)	21 (18.3)	13 (11.3)	25 (21.7)	19 (16.5)	17 (14.8)	28 (24.3)	26 (22.6)	17 (14.8)	6 (5.2)	24 (20.9)	19 (16.5)	24 (20.9)

PR – percentile rank

A significant correlation was determined between achievements on Acadia test subtests and the assessed areas of mathematics by applying Pearson correlation coefficient (Table 3). The overall achievement in mathematics (MS) had significant positive correlations with the results of all subtests (r=0.19-0.41) except Auditory Discrimination (A1) and Drawing (A13) (p>0.05), which, unlike other subtests, did not have a significant relation with the success in individual areas of mathematics. Visuomotor Coordination and Sequencing (A2), which had the highest correlation with the achievement in the area of measurements and measures (r=0.43), and Concept Formation (A9) which had the highest correlation with the achievement in arithmetic operations (r=0.42-0.46) are the subtests which were singled out as those with significant correlations with individual areas of mathematics.

Table 3 *Correlation of the results of Acadia test subtests and teachers' assessment of achievements in mathematics*

Acadia test		MATHEMATICS					
		I	AS	MD	G	MM	MS
A1	r	0.068	0.111	0.136	0.150	0.125	0,124
	p	0.478	0.245	0.155	0.117	0.192	0,194
A2	r	0.389	0.391	0.367	0.392	0.434	0,413
	p	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0,000**
A3	r	0.254	0.273	0.384	0.314	0.334	0,329
	p	**0.007**	**0.004**	**0.000**	**0.001**	**0.000**	**0,000**
A4	r	0.267	0.292	0.353	0.331	0.281	0,320
	p	**0.005**	**0.002**	**0.000**	**0.000**	**0.003**	**0,001**
A5	r	0.144	0.206	0.204	0.239	0.192	0,207
	p	0.132	**0.030**	**0.031**	**0.011**	**0.043**	**0,029**
A6	r	0.239	0.207	0.192	0.208	0.167	0,211
	p	**0.012**	**0.029**	**0.043**	**0.028**	0.079	**0,026**
A7	r	0.163	0.262	0.302	0.255	0.236	0,256
	p	0.088	**0.006**	**0.001**	**0.007**	**0.013**	**0,007**
A8	r	0.240	0.182	0.227	0.205	0.167	0,213
	p	**0.011**	0.056	**0.017**	**0.031**	0.079	**0,025**
A9	r	0.330	0.416	0.460	0.370	0.386	0,411
	p	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**
A10	r	0.323	0.285	0.351	0.337	0.291	0.332
	p	**0.001**	**0.002**	**0.000**	**0.000**	**0.002**	**0.000**
A11	r	0.358	0.375	0.382	0.340	0.341	0.375
	p	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**
A12	r	0.159	0.174	0.219	0.203	0.166	0.193
	p	0.096	0.067	**0.021**	**0.033**	0.081	**0.042**
A13	r	0.107	0.096	0.138	0.153	0.076	0.119
	p	0.264	0.317	0.148	0.109	0.429	0.212

I= Integers; AS= Addition and Subtraction; MD= Multiplication and Division; G= Geometry; MM= Measurements and Measures; MS= Mathematics-total score.

By applying Analysis of variance, it was determined that the results of most Acadia test subtests, expressed in percentile ranks, had a statistically significant influence on the success in mathematics in general and individual areas of mathematics (Tables 4-13). Achievements on the subtests Auditory Discrimination (A1: F(2)=0.467, p=0.628), Visual Memory (A5: F(2)=2.781, p=0.066), Visual Association (A12: F(2)=2.871, p=0.061), and Drawing (A13: F(2)=0.814, p=0.446) did not make significant differences to the success in mathematics in general. With the exception of the results of Visual Memory subtest (Table 7), the results of the mentioned subtests did not make significant differences to the achievement in individual areas of mathematics knowledge and skills (Auditory Discrimination: I – F(2)=1.088, p=0.358; AS – F(2)=0.872, p=0.458; MD – F(2)=0.683, p=0.564; G – F(2)=1.335, p=0.267; MM – F(2)=0.821, p=0.485; Visual Association: I – F(2)=2.539, p=0.084; AS – F(2)=2.764, p=0.068; MD – F(2)=2.962, p=0.056; G – F(2)=2.623, p=0.077; MM – F(2)=2.247, p=0.111; Drawing: I – F(2)=0.754, p=0.473; AS– F(2)=0.356, p=0.701; MD – F(2)=1.076, p=0.344; G – F(2)=1.283, p=0.281; MM – F(2)=0.654, p=0.522). The following segment presents statistically significant results.

Table 4 shows students' achievement in different areas of mathematics with regard to their results on Visuomotor Coordination and Sequencing subtest (A2).

Table 4 *Visuomotor Coordination and Sequencing (A2) and teacher's assessment of students' achievement in mathematics*

Mathematics	A2 score	AM	SD	F(2)	p
Integers	≤ 38	6.56[ab]	2.063	11.066	**0.000**
	39 - 53	7.95[a]	1.768		
	≥ 54	8.90[b]	1.071		
Addition and Subtraction	≤ 38	6.74[cb]	1.873	8.435	**0.000**
	39 - 53	7.84[c]	1.766		
	≥ 54	8.80[b]	1.322		
Multiplication and Division	≤ 38	6.30[cb]	2.163	8.468	**0.000**
	39 - 53	7.45[c]	2.023		
	≥ 54	8.65[b]	1.268		
Geometry	≤ 38	5.59[cb]	2.080	9.074	**0.000**
	39 - 53	6.72[cd]	1.915		
	≥ 54	7.95[bd]	1.432		
Measurements and Measures	≤ 38	5.26[ab]	2.212	10.834	**0.000**
	39 - 53	6.83[a]	2.051		
	≥ 54	7.90[b]	1.334		
Mathematics (total score)	≤ 38	30.44[ab]	9.732	10.552	**0.000**
	39 - 53	36.80[a]	9.103		
	≥ 54	42.20[b]	6.049		

Values marked with the letter "a" are statistically significantly different at the level ≤ 0.01,"b" at the level ≤ 0.000, and "c" and "d" at the level <0.05.

Teachers' assessment of achievement in mathematics in general, as well as in individual areas, was significantly related to the development level of visuomotor coordination, especially in children who had the lowest achievement on this subtest (below 25th percentile). The development level of visuomotor coordination is highly significant for geometry, since there were significant differences in the assessment of geometry knowledge/skills between students who achieved average and above-average results on this subtest (detailed in Table 4).

Table 5 shows students' achievement in different areas of mathematics with regard to their results on Visual Discrimination subtest (A3).

Table 5 *Visual Discrimination (A3) and teachers' assessment of students' achievement in mathematics*

Mathematics	A3 score	AM	SD	F(2)	p
Integers	≤ 51	7.22[a]	1.726	3.529	**0.033**
	52 – 57	7.92	2.018		
	≥ 58	8.82[a]	1.079		
Addition and Subtraction	≤ 51	7.14	1.693	3.577	**0.031**
	52 – 57	7.95	1.881		
	≥ 58	8.55	1.572		
Multiplication and Division	≤ 51	6.36[bc]	1.915	7.875	**0.001**
	52 – 57	7.78[b]	2.074		
	≥ 58	8.45[c]	1.214		
Geometry	≤ 51	5.83[ab]	1.540	7.275	**0.001**
	52 – 57	6.88[a]	2.142		
	≥ 58	8.18[b]	1.471		
Measurements and Measures	≤ 51	5.69[ab]	1.802	6.661	**0.002**
	52 – 57	6.95[a]	2.271		
	≥ 58	7.91[b]	1.300		
Mathematics (total score)	≤ 51	32.25[ab]	8.101	3.529	**0.033**
	52 – 57	37.48[a]	10.002		
	≥ 58	41.91[b]	6.252		

Values marked with the letter "a" are statistically significantly different at the level ≤ 0.05, and "b" and "c" at the level ≤ 0.01.

The development level of visual discrimination was significantly related to general achievement, as well as to different areas of mathematics. However, there were no significant differences between the selected groups of participants in the addition and subtraction area (detailed in Table 5).The significance of visual discrimination is particularly evident in acquiring knowledge and skills in multiplication and division, geometry, and measurements and measures.

Table 6 shows students' achievement in different areas of mathematics with regard to their results on Drawing Shapes subtest (A4).

Table 6 *Drawing Shapes (A4) and teachers' assessment of students' achievement in mathematics*

	A4 score	AM	SD	F(2)	p
Integers	≤ 34	6.97[a]	2.275	4.296	**0.016**
	35 - 48	7.95	1.641		
	≥ 49	8.36[a]	1.729		
Addition and Subtraction	≤ 34	6.90[ab]	2.289	5.085	**0.008**
	35 - 48	7.91[a]	1.455		
	≥ 49	8.36[b]	1.753		
Multiplication and Division	≤ 34	6.45[b]	2.339	6.274	**0.003**
	35 - 48	7.44	1.946		
	≥ 49	8.36[b]	1.578		
Geometry	≤ 34	5.86[b]	2.133	5.129	**0.007**
	35 - 48	6.68	1.901		
	≥ 49	7.56[b]	1.805		
Measurements and Measures	≤ 34	5.90[a]	2.257	3.805	**0.025**
	35 - 48	6.65	2.022		
	≥ 49	7.48[a]	2.104		
Mathematics (total score)	≤ 34	32.07[b]	10.869	6.161	**0.003**
	35 - 48	36.63	8.495		
	≥ 49	40.12[b]	8.604		

Values marked with the letter "a" are statistically significantly different at the level ≤ 0.05, and "b" at the level ≤ 0.01.

Mathematics in general, as well as all individual areas, were significantly related to the development level of visuomotor and visuospatial abilities assessed by the ability to copy geometric shapes. The achievement on this subtest was particularly evident in acquiring knowledge and skills in addition and subtraction (detailed in Table 6).

Table 7 shows students' achievement in different areas of mathematics with regard to their results on Visual Memory subtest (A5).

Table 7 *Visual Memory (A5) and teachers' assessment of students' achievement in mathematics*

	A5 score	AM	SD	F(2)	p
Integers	≤ 47	7.34	1.990	1.949	0.147
	48 – 57	7.91	1.842		
	≥ 58	8.35	1.766		
Addition and Subtraction	≤ 47	7.21[a]	1.933	3.448	**0.035**
	48 – 57	7.88	1.789		
	≥ 58	8.53[a]	1.463		
Multiplication and Division	≤ 47	6.89	2.011	1.987	0.142
	48 – 57	7.54	2.123		
	≥ 58	8.00	1.936		
Geometry	≤ 47	6.03	2.060	3.536	**0.033**
	48 – 57	6.88	1.973		
	≥ 58	7.41	1.734		
Measurements and Measures	≤ 47	6.13	2.120	2.126	0.124
	48 – 57	6.77	2.207		
	≥ 58	7.35	1.902		

Values marked with the letter "a" are statistically significantly different at the level ≤ 0.05.

Differences in the achievement on Visual Memory subtest were not significantly related to the total score of teacher s' assessment of students' achievement in mathematics ($F_{(2)}$=2.781, p=0.066). By analyzing individual areas, a statistically significant relation was determined between the development level of visual memory and the achievement in addition and subtraction and geometry. A detailed analysis indicated a significant difference between the groups of participants only in addition and subtraction. This difference was present between students whose development level of visual short-term memory was below 25th percentile and students whose achievements on this subtest were above 75th percentile (detailed in Table 7).

Table 8 shows students' achievement in different areas of mathematics with regard to their results on Audio-Visual Association subtest (A6).

Table 8 *Audio-Visual Association (A6) and teachers' assessment of students' achievement in mathematics*

	A6 score	AM	SD	F(2)	p
Integers	≤ 49	7.16[a]	1.879	4.793	**0.010**
	50 – 56	8.06	1.943		
	≥ 57	8.63[a]	1.258		
Addition and Subtraction	≤ 49	7.16[a]	1.804	4.421	**0.014**
	50 – 56	8.02	1.892		
	≥ 57	8.50[a]	1.265		
Multiplication and Division	≤ 49	6.77	1.987	3.756	**0.026**
	50 – 56	7.67	2.179		
	≥ 57	8.19	1.559		
Geometry	≤ 49	6.14	1.773	2.962	0.056
	50 – 56	6.90	2.211		
	≥ 57	7.38	1.708		
Measurements and Measures	≤ 49	6.05	1.999	3.272	**0.042**
	50 – 56	6.90	2.283		
	≥ 57	7.44	1.825		
Mathematics (total score)	≤ 49	33.27[a]	8.888	4.159	**0.018**
	50 – 56	37.55	10.102		
	≥ 57	40.13[a]	7.302		

Values marked with the letter "a" are statistically significantly different at the level ≤ 0.05.

A statistical analysis determined that the achievement on Audio-Visual Association subtest was significantly related to the achievement in mathematics in general, as well as in individual areas (with the exception of Geometry). However, a detailed analysis did not determine statistically significant differences between the groups of participants in knowledge and skills in the areas of multiplication and division and measurements and measures (detailed in Table 8).

Table 9 shows students' achievement in different areas of mathematics with regard to their results on Sequence and Coding subtest (A7).

Table 9 *Sequence and Coding (A7) and teachers' assessment of students' achievement in mathematics*

	A7 score	AM	SD	F(2)	p
Integers	≤ 51	7.33	2.123	2.192	0.117
	52 – 60	7.74	1.905		
	≥ 61	8.37	1.497		
Addition and Subtraction	≤ 51	7.03[a]	1.956	4.291	**0.016**
	52 – 60	7.81	1.716		
	≥ 61	8.41[a]	1.716		
Multiplication and Division	≤ 51	6.50[b]	2.418	5.349	**0.006**
	52 – 60	7.46	1.881		
	≥ 61	8.22[b]	1.695		
Geometry	≤ 51	6.00[a]	2.213	3.436	**0.036**
	52 – 60	6.69	1.872		
	≥ 61	7.37[a]	1.884		
Measurements and Measures	≤ 51	5.87	2.403	3.141	**0.047**
	52 – 60	6.78	1.978		
	≥ 61	7.22	2.044		
Mathematics (total score)	≤ 51	32.73[a]	10.589	3.906	**0.023**
	52 – 60	36.48	8.973		
	≥ 61	39.59[a]	8.368		

Values marked with the letter "a" are statistically significantly different at the level ≤ 0.05, and "b" at the level ≤ 0.01.

Success on Sequence and Coding subtest was significantly related to the achievement in different areas of mathematics, except knowledge of integers. The difference in teachers' assessment of achievement was particularly evident in students whose development level of nonverbal inductive reasoning was below 25^{th} percentile (detailed in Table 9).

Table 10 shows students' achievement in different areas of mathematics with regard to their results on Auditory Memory subtest (A8).

Table 10 *Auditory Memory (A8) and teachers' assessment of students' achievement in mathematics*

	A8 score	AM	SD	F(2)	p
Integers	≤ 39	6.81[ab]	2.271	5.049	**0.008**
	40 – 54	8.05[a]	1.610		
	≥ 55	8.21[b]	1.817		
Addition and Subtraction	≤ 39	6.93[b]	2.286	3.768	**0.026**
	40 – 54	8.03[b]	1.583		
	≥ 55	7.96	1.654		
Multiplication and Division	≤ 39	6.33[ab]	2.631	4.926	**0.009**
	40 – 54	7.73[a]	1.736		
	≥ 55	7.71[b]	1.829		
Geometry	≤ 39	5.70[b]	2.350	4.322	**0.016**
	40 – 54	6.97[b]	1.646		
	≥ 55	7.00	2.187		
Measurements and Measures	≤ 39	5.85	2.568	2.445	0.091
	40 – 54	6.88	1.851		
	≥ 55	6.92	2.244		
Mathematics (total score)	≤ 39	31.63[b]	11.738	4.395	**0.015**
	40 – 54	37.67[b]	7.860		
	≥ 55	37.79	9.404		

Values marked with the letter "a" are statistically significantly different at the level ≤ 0.01, and "b" at the level ≤ 0.05.

Students whose achievement on Auditory Memory subtest was below 25th percentile had lower achievement in mathematics in general, as well as in individual areas, except in measurements and measures (detailed in Table 10).

Table 11 shows students' achievement in different areas of mathematics with regard to their results on Concept Formation subtest (A9).

Table 11 *Concept Formation (A9) and teachers' assessment of students' achievement in mathematics*

	A9 score	AM	SD	F(2)	p
Integers	≤ 50	7.06[a]	2.300	4.151	**0.018**
	51 – 62	8.05[a]	1.599		
	≥ 63	8.38	1.586		
Addition and Subtraction	≤ 50	6.89[bc]	2.246	6.627	**0.002**
	51 – 62	8.05[b]	1.431		
	≥ 63	8.50[c]	1.592		
Multiplication and Division	≤ 50	6.29[bc]	2.504	8.838	**0.000**
	51 – 62	7.77[b]	1.630		
	≥ 63	8.38[c]	1.586		
Geometry	≤ 50	5.86[ab]	2.212	5.172	**0.007**
	51 – 62	6.90[a]	1.792		
	≥ 63	7.56[b]	1.861		
Measurements and Measures	≤ 50	5.63[bc]	2.327	6.560	**0.002**
	51 – 62	7.00[b]	1.931		
	≥ 63	7.50[c]	1.862		
Mathematics (total score)	≤ 50	31.71[bc]	11.132	6.813	**0.002**
	51 – 62	37.77[b]	7.901		
	≥ 63	40.31[c]	8.154		

Values marked with the letter "a" are statistically significantly different at the level <0.05, and "b" and "c" at the level ≤ 0.01.

Achievement in mathematics in general, as well as in individual areas, largely depended on the development level of verbal reasoning, especially in students whose score on this subtest was below 25th percentile (detailed in Table 11).

Table 12 shows students' achievement in different areas of mathematic with regard to their results on Acquired Language Treasure subtest (A10).

Table 12 *Acquired Language Treasure (A10) and teachers' assessment of students' achievement in mathematics*

	A10 score	AM	SD	F(2)	p
Integers	≤ 54	7.12[a]	2.100	3.191	**0.045**
	55 – 64	8.10[a]	1.742		
	≥ 65	7.83	1.835		
Addition and Subtraction	≤ 54	7.12	1.919	3.029	**0.052**
	55 – 64	8.04	1.727		
	≥ 65	7.83	2.041		
Multiplication and Division	≤ 54	6.50[a]	2.260	4.826	**0.010**
	55 – 64	7.76[a]	1.549		
	≥ 65	8.00	1.908		
Geometry	≤ 54	5.91[a]	1.913	3.602	**0.031**
	55 – 64	7.00[a]	1.986		
	≥ 65	7.00	2.098		
Measurements and Measures	≤ 54	5.79[a]	2.027	3.996	**0.021**
	55 – 64	7.03[a]	2.171		
	≥ 65	6.83	1.472		
Mathematics (total score)	≤ 54	32.44[a]	9.758	4.076	**0.020**
	55 – 64	37.93[a]	9.109		
	≥ 65	37.50	8.503		

Values marked with the letter "a" are statistically significantly different at the level < 0.05.

Even though the relation between the level of lexical development and the achievement in addition and subtraction area was on the verge of statistical significance ($p \leq 0.05$), there were no statistically significant differences between groups of participants with different levels of achievement on Acquired Language Treasure subtest. In all other individual areas, as well as in mathematics in general, lower achievement was determined in participants whose level of lexical abilities was below 25th percentile. However, statistical significance was determined only with regard to participants whose lexical abilities were average (from 25th to 75th percentile) (Table 12).

Table 13 shows student' achievement in different areas of mathematics with regard to their results on Automatic Language Treasure subtest (A11).

Table 13 *Automatic Language Treasure (A11) and teachers' assessment of students' achievement in mathematics*

	A11 score	AM	SD	F(2)	p
Integers	≤ 53	7.17[a]	1.748	5.261	**0.007**
	54 – 60	7.79	1.984		
	≥ 61	8.77[a]	1.541		
Addition and subtraction	≤ 53	7.19[a]	1.704	5.496	**0.005**
	54 – 60	7.70	1.986		
	≥ 61	8.77[a]	1.193		
Multiplication and division	≤ 53	6.64[a]	1.791	5.722	**0.004**
	54 – 60	7.45	2.283		
	≥ 61	8.45[a]	1.471		
Geometry	≤ 53	5.89[a]	1.833	5.797	**0.004**
	54 – 60	6.79	2.079		
	≥ 61	7.64[a]	1.706		
Measurements and measures	≤ 53	5.92[a]	2.048	4.942	**0.009**
	54 – 60	6.70	2.241		
	≥ 61	7.68[a]	1.701		
Mathematics (total score)	≤ 53	32.81[a]	8.562	5.949	**0.004**
	54 – 60	36.43	10.150		
	≥ 61	41.32[a]	7.233		

Values marked with the letter "a" are statistically significantly different at the level < 0.01.

The development level of morphosyntactic aspect of language development was significantly related to all areas of mathematics ($p<0.01$). Differences in achievement were particularly evident between students whose results were below 25th percentile and those whose success on this subtest was above 75th percentile (Table 13).

DISCUSSION

This research shows that a set of different functions and abilities contributes to the acquisition of mathematics knowledge and skills which to a certain extent reflect the typology of mathematical difficulties: visuospatial-motor type, semantic type (long-term memory), and procedural type (working memory) (Geary, 2004; Mazzocco, 2009).

Visuomotor coordination and *visuospatial integration*, assessed by the ability to trace a line and copy geometric shapes, were significantly related to all areas of mathematics.

It is well known that tracing ability represents one of the most important abilities in acquiring writing skills (Graham, 1999). However, it has recently been associated with the acquisition of knowledge and skills in different areas of mathematics, which was confirmed in this study. One of the studies determined that visuomotor coordination was significantly related to the ability to remember mathematical facts (simple arithmetic tasks), while visuospatial integration was also significantly related to procedural calculation (Pieters et al., 2012). Furthermore, the same study determined that children with dyscalculia had significantly more difficulties in the areas of visuomotor coordination and visuospatial integration, which is the result other researchers also obtained (Jongmans et al., 2003). The relation between visuomotor coordination and the ability to remember mathematical facts is hard to explain directly.

Thus, as assumed by the authors, it is possible that the quality of attention underlies this relation.

There is a belief that mathematics engages spatial reasoning, i.e. that spatial skills support the process of representation, analysis, and drawing conclusions on the basis of relations among objects (Clements & Sarama, 2011). Studies on brain visualization also support the relation between visuomotor abilities and calculation. These studies indicate that solving arithmetic tasks activates the parietal cortex, which is believed to represent a structural basis of visuospatial information processing (Rosenberg-Lee et al., 2011).

Recent studies indicate that visuaspatial abilities are also significantly related to the development of early mathematics skills. It has been determined that they significantly contribute to the acquisition of number sequences (Gunderson et al., 2012), and represent a strong predictor of the ability to identify a number and its size, as well as the ability to compare amounts (Son & Meisels, 2006; Verdine, Irwin et al., 2014).

Apart from that, it has been determined that manipulating visuospatial toys (such as Lego bricks) by copying given models at preschool and early elementary-school age significantly contributes to the development of mathematics skills in children (Grissmer et al., 2013, according to Verdine, Golinkoff et al., 2014). A similar result was obtained in much younger participants, which indicates that the relation between visuospatial abilities and mathematics skills is established as early as the age of three (Verdine, Golinkoff et al., 2014).

This research determined that the ability of *visual discrimination* significantly contributed to the acquisition of different mathematics knowledge and skills, especially in the areas of multiplication and division, geometry, and measurements and measures. Difficulties in differentiating similar stimuli may be manifested as problems in identifying mathematical symbols, understanding information presented as images, diagrams, or graphs (Gligorović and Vujanić, 2003), or understanding mass values of a number, and even basic understanding of quantity (Mazzocco, Singh Bhatia & Lesniak-Karpiak, 2006). By studying different aspects of visual abilities and motor skills in children with dyscalculia and typically developing children, it was determined that visual perception was necessary for calculating procedures, such as “borrowing and lending” and “transfer” (Pieters et al., 2012). Apart from that, visual abilities in general, especially visual discrimination, are considered a mediator of the relation between the abilities to approximately determine quantity/numerousness and calculation (Zhou et al., 2015).

Furthermore, this research determined that children with low achievement on *auditory memory* tasks had significantly lower achievement in all areas of mathematics (except in the area of measurements and measures), while children with difficulties in *visual memory* had lower achievement in the area of addition and subtraction.

The results of similar studies showed that auditory memory (phonological loop) was more significant than visual memory for doing mathematical tasks at this age (Holmes & Adams, 2006). The significance of visual short-term memory is more pronounced at a younger age, especially before the age of seven. Since children at that age still do not use spontaneous verbal repetition, they rely much more on visuospatial representations in retaining information (McKenzie, Bull & Gray, 2003). It turned out that visual short-term memory was a good predictor of achievement in different aspects of mathematics (knowledge of numbers and arithmetic operations, mental arithmetic, geometry, and interpretation of mathematical information) at the beginning of schooling, and that with age it remained significant only in solving complex mathematical tasks (Holmes & Adams, 2006). Authors believe that younger children mostly rely on visual memory mechanisms (visuospatial contour) in solving mathematical tasks, which indicates a predominant usage of visual encoding strategies at the beginning of formal schooling. In time, with the development of verbal strategies, phonological loop gains higher significance in solving mathematical tasks. However, when symbolic-linguistic arithmetic or direct strategy of remembering information cannot be applied, tasks are solved by going back to early visuaspatial strategies (Holmes & Adams, 2006). Also, it is believed that different modalities of short-term memory are responsible for different areas of mathematics, and that working memory is the only common denominator of general achievement in mathematics (Geary et al., 2007). In our research, a higher significance of auditory memory for acquiring different mathematics knowledge and skills was potentially the result of the fact that the set of memory tasks included tasks which involved the engagement of central executive system (verbal working memory), and also that the design of the applied subtests required the application of two different mechanisms of retaining information – simultaneous and sequential.

Apart from memory, perceptive and motor skills, it was determined that verbal and, to a somewhat lesser extent, nonverbal *reasoning* significantly contribute to acquiring mathematics knowledge and skills.

Reasoning abilities, related to the concept of fluid intelligence (Buha & Gligorović, 2015; Novosel & Nikolić, 1989), are usually closely related to academic success, especially to achievement in mathematics (Primi, Ferrão & Almeida, 2010; Taub et al., 2008). Fluid intelligence is generally defined as the ability to use mental operations in solving new problem situations, whose solving exceeds the routine approach or mere memorization. These operations include the following abilities: drawing conclusions, concept formation, classification, developing and testing hypotheses, identifying relations, understanding implications, and generalization (Primi, Ferrão & Almeida, 2010).

Nonverbal reasoning tasks, usually in the form of inductive reasoning (as is the case with a part of the task on Sequence and Coding subtest), are mainly significantly associated with the ability to solve contextual tasks, and to a lesser extent with calculation. This can be explained by the fact that in solving contextual tasks it is necessary to form mental representation of the problem (Jõgi & Kikas, 2016). Inductive reasoning tasks, as well as mathematical tasks, are based on the ability to notice patterns and relations among numbers or geometric shapes, which is often considered pre-algebraic reasoning. Numerous studies determined that this ability was related to early mathematics skills (Mulligan & Mitchelmore, 2009).

Verbal reasoning tasks (in this research in the form of drawing conclusions, applying classification and taxonomic categorization) usually have stronger relations with academic achievement n different fields including mathematics (Floyd, Evans & McGrew, 2003; Taub et al., 2008). Even though the reasoning mechanism underlying these tasks belongs to the concept of fluid intelligence, the usage of verbal mode requires the application of the acquired knowledge. Thus, it is believed that tasks of this type are the expression of crystallized intelligence, since their solving depends on the ability to acquire information and access stored knowledge, which is influenced by cultural environment, education, and language development (Wasserman & Tulsky, 2005).

With regard to that, it is not surprising that this research determined that different aspects of *language skills* were related to the ability to master mathematics content. By applying the same instruments for the assessment of developmental abilities, a previous study determined that lexical-semantic abilities had a moderate correlation with the achievements in mathematics, and that the correlation with morphosyntactic language aspect was significantly higher (Glumbić, Brojčin & Kaljača, 2004).

One of the hypotheses about the role of language in mathematical abilities is that language is the basis of reasoning, and thus of mathematical reasoning as well. According to this hypothesis, words used for counting are necessary for the development of the concept of numbers larger than three or four. With regard to that, children growing up in cultures where there are few or no words for denoting numbers will not develop the right or full understanding of the concept of numbers. This hypothesis is based on the example of Amazon tribes (Piraha and Munduruku cultures) who do not use words to denote numbers, and whose ability to think about exact amounts is reduced to very small numbers (Gelman & Butterworth, 2005; Gelman & Gallistel, 2004; Pica et al., 2004).

Neuroanatomic studies point to a potentially different interpretation of the relation between language and mathematics. Main areas of the brain involved in numerical processing are located in the parietal lobe, far from the areas responsible for language processing. Furthermore, brain lesions which cause difficulties in calculation are not necessarily accompanied by language difficulties, and vice versa. The example of people with autism also indicates structural dissociation. Apart from the pronounced deficit in the development of speech-language skills, people with autism do not have difficulties in performing exact arithmetic operations (Butterworth, 1999, according to Pica et al., 2004), which points to the fact that complex arithmetic operations may be performed without using words. Also, it has been determined that the activity in Broca's area is reduced while doing numerical tasks, which implies that numerical and language processing are in opposition (Gelman & Butterworth, 2005). This leads to the fact that having a rich vocabulary of numbers certainly facilitates the acquisition of counting and calculation, but that it is not necessary for the development and possession of numerical concepts.

A certain relation definitely exists, which is indicated by correlative studies on typically developing population and difficulties in mathematics with which children with dyslexia and developmental language disorder are faced (Gligorović, 2010). In typically developing population, for example, it has been determined that the range of vocabulary (receptive and expressive) significantly and highly correlates with the understanding of cardinal numbers in preschool children (Negen & Sarnecka, 2012), and that language skills account for a significant part of arithmetic skills variance at preschool and early elementary school age (Praet et al., 2013). Also, it is believed that difficulties in understanding speech may hinder solving mathematical problems and affect the conceptual understanding of calculation, as well as success in doing contextual tasks (Jordan, Hanich & Kaplan, 2003). This relation between language and mathematics is most clearly observed in children with developmental language difficulties (Fazio, 1999), in whom problems in mathematics are manifested as difficulty in acquiring number sets and developing numeracy (Donlan et al., 2007).

Research results indicate that speech-language skills are related to understanding rational numbers (Seethaler et al., 2011). According to authors, language skills may facilitate conceptual understanding of rational numbers as a result of formal (educational) and informal experience while participating in various everyday activities (e.g. understanding the expression "half of something").

Language skills are one of the most important preconditions of acquiring early mathematics skills (Toll & Van Luit, 2014). Big individual differences in language and mathematics skills may be observed at preschool age (Fuchs et al., 2010), and they have a tendency to persist at older age (Tymms, Merrell & Henderson, 1997).

CONCLUSION

By summing up the results, it can be concluded that visuospatial and visuoconstructive abilities, visual perception, short-term memory, language skills, and reasoning significantly contribute to the acquisition of knowledge and skills in different areas of mathematics.

Children whose achievements on Visuomotor Coordination and Sequencing subtest were below 25th percentile had significantly lower achievement in all areas of mathematics ($p \leq 0.000$-0.039) compared to children whose achievements were above 25th percentile. Of all the assessed areas of mathematics, geometry was singled out as an area which was significantly related to the development level of visuomotor coordination since achievement differences in the area of geometry were significant when both students with average (from 25th to 75th percentile) and above-average (above 75th percentile) results in visuomotor coordination were compared ($p=0.042$).

Children who had poor results on Drawing Shapes subtest (the lower quartile) had lower achievements in the area of addition and subtraction. Their achievements were significantly different from the achievements of children with average ($p=0.046$) and above-average development level of the ability to copy geometrical shapes and lines ($p=0.012$). Their achievement was lower in all other areas of mathematics, but statistically significant only when compared to children whose development level of visuomotor and visuospatial abilities was within the upper quartile ($p=0.003$-0.025).

Children who had low achievements on Visual Discrimination subtest (below 25th percentile) had significantly worse results in the areas of multiplication/division ($p=0.003$-0.010), geometry ($p=0.002$-0.036), and measurements and measures ($p=0.009$-0.016) compared to children who had average and above-average result on this subtest. When compared to children in the upper quartile, these children had a lower level of knowledge and skills in all areas of mathematics ($p=0.002$-0.049), except in the area of addition and subtraction ($p>0.05$).

Achievement on Audio-Visual Association subtest was significantly related to success in all areas of mathematics, except geometry. Significant differences among groups of children with different level of achievement on this subtest (upper and lower quartile) were determined in the knowledge of integers (p=0.027) and addition and subtraction (p=0.040).

Children who had poor results on Auditory Memory subtest had significantly lower achievement in the knowledge of integers (p=0.017-0.029) and multiplication and division compared to all other groups of participants (p=0.013-0.055). The group with the lowest achievement in auditory memory had significantly worse results in the areas of geometry and addition and subtraction, but only when compared to children whose achievements on this subtest were average (p=0.024-0.032). The area of measurements and measures was not significantly related to the development level of auditory memory (p>0.05).

Achievement on Visual Memory subtest was significantly related to the success in the areas of addition and subtraction and geometry. However, significant differences among groups of children with different level of achievement on this subtest were noticeable only in the area of addition and subtraction. Children whose achievements were in the lower quartile got significantly worse marks from their teachers than children whose achievements on this subtest were in the upper quartile (p=0.040).

Nonverbal reasoning, assessed by Sequence and Coding subtest, was significantly related to all the assessed areas of mathematics, except knowledge of integers. Significant differences in achievements were determined between children whose level of inductive reasoning was in the lower and upper quartile, in the areas of arithmetic operations (addition/subtraction (p=0.013) and multiplication/division (p=0.005)) and geometry (p=0.030).

Verbal reasoning, assessed by Concept Formation subtest, was significantly related to all areas of mathematics. Children whose achievements on this subtest were below 25^{th} percentile, had a significantly lower level of mathematics knowledge and skills compared to children who had average (p=0.002-0.039) and above-average achievements (p=0.002-0.013).

Lexical-semantic and morphosyntactic language skills significantly contribute to the acquisition of mathematics knowledge and skills in all the assessed areas. Students with achievements below 25^{th} percentile on Automatic Language Treasure subtest (morphosyntax) had significantly worse results in all areas of mathematics (p=0.001-0.002). Low achievement on Acquired Language Treasure subtest (lexis) was significantly related to poor results in the areas of knowledge of integers (p=0.039), multiplication and division (p=0.010), geometry (p=0.028), and measurements and measures (p=0.017), but not in the area of addition and subtraction (p>0.05).

Bearing in mind a wide range of developmental abilities which contribute to the acquisition of knowledge and skills in different areas of mathematics, it would be desirable to conduct a systematic assessment of cognitive-motor abilities at preschool age in order to detect children at risk and provide a foundation for the development of mathematics skills by adequate and timely stimulation of different abilities – visual, motor and language.

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