WORKING MEMORY AND READING ABILITY IN CHILDREN—A PSYCHOLINGUISTIC PERSPECTIVE

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Abstract
The aim of this paper is to give an insight into the reading process and working memory as factor that affects this process at early stages of its development. The basic assumption of the psycholinguistic view is that reading is a linguistic, metalinguistic and metacognitive activity that requires conscious control of cognitive processes involved.
The study covered 1138 children from reception class as well as the 1st grade. The subjects were examined using the Reading Tests Battery that offers a comprehensive evaluation of various aspects of reading: letter recognition and naming, isolated words decoding and pseudowords decoding. Executive functions were measured with the use of the Working Memory Test. Each task of the test corresponds to one of the working memory functions highlighted by Klaus Oberauer: simultaneous storage and processing, supervision and coordination.
The main results confirm a significant relationship between general indicators of working memory and the results of reading tests. The highest correlations were obtained for the *Letter Naming* and *Letter Recognition* tests as well as all three working memory test measures. Monitoring function did not correlate with the reading measures, and the function of coordination featured a very low level of covariance.

Keywords: reading development, executive functions, working memory, letter knowledge, reading accuracy

1. INTRODUCTION

The theoretical base of the present study is the model of acquiring reading skills in Polish developed by Grażyna Krasowicz-Kupis (2008) and the model of reading and

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spelling acquisition in the Polish language developed by Elżbieta Awramiuk and Grażyna Krasowicz-Kupis (2014) on the basis of conducted studies involving children aged 5-8 (Awramiuk, 2006, 2011; Krasowicz-Kupis, 1999, 2004, 2008). It is assumed that reading is a complex psycholinguistic activity which consists of decoding the text and interpreting its content. The basic assumptions underlying the concept of the presented paper concern the fact that reading is:

1) a linguistic activity–a form of communication based on language,
2) a metalinguistic activity based on print awareness (the function of writing and the relationship between print and word), awareness of the phoneme-grapheme correspondence, and of the linguistic features which are necessary in the speech formation and its monitoring,
3) a metacognitive activity that requires conscious control of cognitive processes involved in reading, and more specifically, in reading comprehension,
4) a pragmatic and metapragmatic activity–requiring the conscious use of written texts and control of their application from the perspective of personal and social goals (Krasowicz-Kupis, 2008).

Reading, both decoding and comprehension, requires that the reader possesses language skills–phonological, morphological, syntactic, semantic, as well as pragmatic ones. Moreover, it requires advanced cognitive abilities, including attention, memory, perception, executive functions, etc., as well as conceptual thinking. In addition, reading demands the involvement of cognitive control processes which are expressed in the metacognitive and metalinguistic nature of these activities (Krasowicz-Kupis, 1999).

1.1 The model of reading and spelling acquisition in Polish

In the literature concerning reading and spelling development in children different models were developed, mainly for English speaking populations. The most popular one is probably Uta Frith's proposal (Frith, 1985), in which the child's reading development is divided into 3 phases: logographic, alphabetic and orthographic. In Polish studies there is no confirmation of a logographic phase (Sochacka, 2004). Analysis of reading acquisition should take into account the specificity of Polish language and orthography. Polish is an Indo-European language belonging to the Slavic group. The alphabetical system consists of 44 graphemes, i.e. letter and letter combinations referring to particular phonemes. Only 14 letters of the Polish alphabet are always read in the same way regardless of the graphic and phonological context. In the case of the other letters, their correct decoding requires an analysis of the closest graphic context. Polish spelling is moderately transparent (shallow) as compared to some other languages such as e.g. English or French. The transparency of the Polish writing system is much higher in the direction from sign (Grapheme) to sound (Phoneme), what determines how easy it is to read words, i.e. to decode them into the strings of sounds. It means that it is much easier to read than to write in Polish. Readers, after acquiring some general rules about digraphs, alternative marking of soft (palatal) consonants (either by a diacritic or by letter "I" eg. Ć-CI) and devoicing can decode a Polish written text and read it correctly without even knowing what it means.

According to theoretical assumptions concerning the reading process, as well as the specificity of Polish orthography and empirical studies on reading and writing in Polish, the model of the acquisition of reading and writing in Polish was formulated. In this model reading and spelling abilities go through three main stages: the preliminary stage (before formal instruction of learning to read and write), the key stage which includes the mastery of reading and writing, and the proficiency stage which includes the automation of the use of reading and writing (Awramiuk & Krasowicz-Kupis, 2014).

The initial stage refers to the period preceding the formal process of learning to read and write, when children already have contact with print. The main components of the readiness to learn to read and write are then formed. Basic language skills are developed, and print awareness is formed–children acquire knowledge about its functions, conventions and principles. The basis of linguistic awareness is shaped and motivation to read is stirred, which is a very important psychological element of the readiness to use print. In this phase, the child knows that what it heard can be written down, but does not see the relationship between the spoken and the written signs.

The preliminary stage covers the period until the beginning of formal reading instruction, which is determined not only by the child's chronological age, but rather by the age of entering school (Krasowicz-Kupis, 2004). Due to changes in legal regulations in Poland children start school at the age of 6 or 7 years.

The key stage (acquisition of script, learning to write/read) begins with formal education and it requires guidance or support from more competent readers, e.g. teachers. Their goal is to explain the principles of the letter code and the phoneme-grapheme relationship. The essence of this phase is to "work out the code" used in print and become competent in using it. The final achievement is the technical proficiency in reading and writing.

In the case of reading, the key stage goes through three phases:

- analytical phonological reading,
- transition phase between phonological reading and global word reading,
- domination of the global reading strategy–word and phrasal (Krasowicz-Kupis, 1999).

In the analytical phonological stage there is a clear dominance of the strategy based on phonological processing using the letter-phoneme correspondence. At this stage, reading is affected by phonological skills, especially phonological awareness. Although the child sees the connection between grapheme and phoneme, it does not yet understand that reading and writing are not a direct conversion of sounds into letters. Dominance of timing errors (repetition of sounds and numerous pauses) and a small number of distortion errors is typical.

The transitional stage between phonological-analytical reading and global word reading appears in the second year of learning. The analytical strategy still dominates, but it is based on parts larger than separated phonemes. The analytical-phonological strategy based on the phoneme is replaced by the phonological strategy based on syllables and larger word segments, sometimes transforming into a global word strategy, which at this stage is not fully effective yet.

The phase of global strategies (verbal and phrasal) is characterized by predominance of global reading. When reading a text, the child, to a greater extent, focuses on phrases corresponding to syntactic and semantic structures.

The proficiency stage (the automation of writing/reading) starts when children read and write in an advanced manner, without aware analysis of the letter material. Reading becomes quick and the technical aspect becomes important only in reading difficult words. Therefore, this stage is characterized by use of the writing code without conscious analysis of its content. Then, reading and spelling are subordinated to its main goal, and their use is clearly pragmatic.

The study presented in this paper relates to children on the key stage, when they discover the grapheme-phoneme correspondence and start to read under formal instruction. In this context the importance of executive functions beside phonological skills will be considered.

1.2 Reading abilities, executive functions and working memory

Defined broadly, term “executive functions” (EFs – executive functions) means a range of functions that enable an individual to self-regulate and engage in goal-directed behaviour (Best & Miller, 2010; Carlson, Zelazo & Faja, 2013; Diamond, 2013; Lyon & Krasnegor, 1996; Müller & Kerns, 2015). Precisely defining the concept of “executive functions” is not a simple task. The discussion on its definition and structure is still ongoing (e.g. Kielar-Turska & Kosno, 2013). Also the term “executive functions” in Poland is not unambiguous–researchers use two terms in parallel (cf. Jodzio, 2008; Kielar-Turska & Kosno, 2013; Putko, 2008). Despite different understanding of the term EF, there is a consensus that there are three or four core executive functions: inhibition (inhibitory control) and interference (selective attention) control, monitoring and shifting (cognitive flexibility), as well as working memory (e.g. Denckla, 1996; Diamond, 2013; Lehto, Juujarvi, Kooistra & Pulkkinen, 2003; Miyake, Friedman, Emerson, Witzki, Howerter & Wager, 2000; Miyake & Friedman, 2012; Pennington, 1997), which have also been shown in studies with children aged 8-13 years (Letho et al., 2003).

Inhibition is the ability “to overcome strong tendencies to react in a certain way and generate a reaction different from habitual one”, flexibility/shifting can be understood as “the ability to react quickly to changing stimulus conditions”, and working memory is “a basic cognitive system that stores information to be used in the present and manipulates them for use in current tasks” (Kielar-Turska & Kosno, 2013, p. 13; Diamond, 2013).

Establishing a link between literacy and executive function is still an open task. There is a relatively small body of research which would address executive functions in the context of literacy, both in developmental and clinical studies (Booth, Boyle & Kelly, 2010; Jabłoński, 2013; Varvara, Varuzza, Sorrentino, Vicari & Menghini, 2014; Walda, van Weerdenburg, Wijnants & Bosman, 2014).

Studies on the relationships of executive functions and literacy are varied and show that working memory, inhibition and flexibility are important for mathematical skills and skills related to reading and writing acquisition in preschool children (Röthlisberger, Neuenschwander, Cimeli, Michel & Roebers, 2012), although the interrelations are not clear due to the developmentally changing structure of EF in that period of life.

Considering EFs' importance for education from a developmental perspective, the results of many different studies indicated that:

- EFs are important for mathematic skills;
- EFs are more important for school readiness than IQ and pre-literacy skills are for reading or maths (Blair & Razza, 2007; Morrison, Ponitz & McClelland, 2010);
- EFs predict both maths and reading competence throughout the school years (Borella, Carretti & Pelegrina, 2010; Duncan, Dowsett, Claessens, Magnuson, Huston, Klebanov, Pagani & Japel, 2007; Gathercole, Pickering, Ambridge & Wearing, 2004).

Looking at the relationship between reading and EFs, mainly reading comprehension was connected with EFs.

The relationship between EFs and reading could be also considered from the perspective of EFs' specificity, but relatively few studies have examined subcomponents of EFs separately. The findings suggest that inhibition is very important in the early stages of development; it precedes and somewhat paves the way for the development of new functions, such as task switching, which is important for the reading process (Altemeier, Abbott & Berninger, 2008; Booth, Boyle & Kelly, 2014; Chung & McBride-Chang, 2011). Inhibitory control (refraining from impulsive behaviour and behaving according to adopted rules (Head – Toes – Knees – Shoulder task, HTKS)) was associated with phonological awareness, knowledge of letters, and vocabulary as well as reading comprehension skills for preschool and school children (Ponitz, McClelland, Jewkes, Connor, Farris & Morrison, 2008; von Suchodoletz, Gestsdottir, Wanless, McClelland, Birgisdottir, Gunzenhauser & Ragnarsdottir, 2013). There is also evidence which suggests that shifting appears to be a weaker predictor of reading ability than other EF components (Bierman, Nix, Greenberg, Blair & Domitrovich, 2008).

Working memory is a predictor of both mathematical and reading achievements in children at primary school level (Christopher, Miyake, Keenan, Pennington, DeFries, Wadsworth, Willcutt & Olson, 2012; Chung & McBride-Chang, 2011; Kibby, Lee & Dyer, 2014). As for writing it has been shown that EFs such as inhibition and planning are responsible for the initiation of behaviour associated with the desire to write something (implementation of a certain intention) and to monitor its progress at the cognitive level (thinking about the content of the message). On the emotional and attentional level inhibition of other competing reactions and ignoring interfering stimuli appear very important (Booth & Boyle, 2009) Simple spelling skills showed no connection with inhibition (Altemeier, Abbott & Berninger, 2008). Furthermore, in samples of typically developing children, scores on complex memory tasks predict reading achievement independently of measures of phonological short term memory (Swanson 2003; Swanson & Howell, 2001).

Considering the importance of EFs for school success from a clinical perspective, the results of some studies on dyslexia should be analysed. They do not always show consistent results—some of them confirm significant EF deficits in these individuals, others indicate a similar level of performance in the EF tasks by children and adults with dyslexia as compared to controls (Booth et al., 2010). EFs such as auditory attention, visual-spatial attention, short-term verbal and visual memory, visual working memory as well as verbal shifting were analysed in the studies mentioned (Varvara et al., 2014). It means that cognitive deficits in reading disorders may be limited to more specific mechanisms within individual executive function (Swanson, 2006).

Referring to the fact that working memory measures are classified as executive functions tasks (e.g. Carlson, 2005; Roebers, Röthlisberger, Cimeli, Michel & Neuenschwander 2011; Röthlisberger, Neuenschwander, Cimeli, Michel & Roebers, 2012), in the present study, EF measurement is based on a three-function model of working memory devised by Oberauer (Oberauer, Süß, Schulze, Wilhelm & Wittman, 2000; Oberauer, Süß, Wilhelm & Wittman, 2003). It is a theoretical framework which unifies working memory and executive functions under the facet model of working memory (Sędek, Krejtz, Rydzewska, Kaczan, & Rycielski, 2016). This model singles out three fundamental functions of working memory: (a) simultaneous storage and processing, (b) the function of supervision and (c) the function of coordination.

The findings cited thus far suggest that literacy development can be associated with executive functions. The primary focus of this paper is the extent to which reading abilities at the early stage of their development are associated with executive functions, mainly working memory, in typically developing sample of children.

2. METHOD

2.1 Participants

The present study is a part of a research project which aims to standardize the tests for the assessment of reading and writing. Data presented in this article are based on a sample of 1138 children from 5;6 years to 8;11 years old[1], attending reception class (RC) and 1st grade. The mean age in reception class was 6;4, in 1st Grade 7;9. The distribution of age and educational level in the sample is presented in Table 1. The study was nationwide, educational institutions—kindergartens and schools—were randomly selected for the study, and in each of them—after obtaining consent from the parents—children from one class unit of a given type (reception class or 1st grade) were subjected to the test.

Table 1. Distribution of age and educational level in the sample

Age group	up to age 6	6;0-6;5	6;6-6;11	7;0-7;5	7;6-7;11	8;0-8;5	Total
Reception class	177	157	170	122	18	-	644
1st grade	-	-	22	73	201	198	494
Total	177	157	192	195	219	198	1138

2.2 Procedure

The study discussed in this paper was a part of a main research project which aims to standardize the tools to diagnose the risk of dyslexia. Each of the participants was tested individually in a quiet area (specially prepared room) of the school or kindergarten for 4 sessions lasting up to 60 minutes per day, during the period of maximally one week. To reduce fatigue, a break dedicated to physical play was made in the middle of each session. Testing was carried out by child clinical psychologists who had completed a three-day training session with the authors of the test. The tests were administered in a fixed sequence designed to vary task demands across the testing session.

In the study, three tests batteries developed in Institute for Educational Research—Spelling Tests Battery, Reading Tests Battery and Phonological Tests Battery—were used. In addition, in the main project many other psychological tools were used for the assessment of fluid intelligence level (Cattell's Culture Free Intelligence Test), Rapid Automatized Naming Test, working memory and phonological memory tests. By considering different skills and cognitive functions, it was possible to investigate the relation between spelling, reading and other skills.

The teaching model or approach used by teachers formally introducing reading and writing to their students in classes was not controlled. The reason is that due

[1] By Act of Parliament signed on the 30th of August 2013, in September 2014 all 7-year-olds and 6-year-olds born in the first half of 2008 started school. The 6-year-olds born in the second half of 2008 could start school if their parents so desired. In September 2015, all children born in 2009, i.e., all 6- and 7-year-olds born between July and December 2008, started compulsory schooling. After the change of government in October 2015, compulsory school starting age at 6 was reversed (29th of December 2015). In the school year 2016/2017, all 7-year-olds will start school with those 6-year-olds whose parents wish them to start school and who have completed their reception year.

to the inflectional characteristics of the Polish language, the optimal method of teaching literacy used in Poland is the lexical variant of the analytical and synthetic method. It consists of performing a visual and auditory analysis of a word containing a letter or phoneme, and then synthesizing it back.

2.3 Materials

2.3.1 Assessment of reading skills

Reading abilities were assessed by using the *Reading Tests Battery* (Krasowicz-Kupis, Bogdanowicz, Wiejak, 2015a). Different versions of the battery were prepared for reception class and 1st grade. Tests designed for RC included: *Letter Naming* and *Letter Recognition*, assessing the knowledge of letters, *Words* test—measuring decoding of simple unrelated words, and *The Island-pseudowords*—assessing decoding pseudowords which are presented in a visual context (illustrations). The battery for 1st graders included also 4 tests: *Letter Naming, Words, The Island-pseudowords* (decoding pseudowords in visual context) and *Pseudowords* (decoding unrelated pseudowords without visual context—assessing reading of isolated nonwords). The use of pseudowords in reading tasks is very important for the diagnosis of pure decoding (based on phonological processing), as it minimizes the impact of associations connected with meaning. Reading nonwords is generally considered as the measure of pure phonological processing, and the analysis of the errors may also indicate the reading strategy (Krasowicz-Kupis, 1999, 2008; Snowling, 2000). All tests included in the battery are characterized by good or very good psychometric properties, reliability (Mosier's reliability coefficient for RC version r = .95, for 1st grade version r = .87; Cronbach's Alpha reliability coefficients for separate tests range from .81 to .97) and validity, both construct and criterion-related (Krasowicz-Kupis et al., 2015a). The structure of *Reading Tests Battery* is presented in Table 2.

Table 2. Reading Tests Battery—description

Subtest name	Target group	Description
Letter Naming	1st grade, RC	The test is used to evaluate the active knowledge of letters. The child is asked to name the letter indicated by the examiner on the board. The test consists of 32 letters, arranged in random order.
Letter Recognition	RC	The test is used to evaluate the passive knowledge of letters. The child has to show on the board containing 8 letters those that are named by examiner. The test consists of 14 letters.
Words	1st grade, RC	The test is designed to assess reading aloud unrelated words. It allows assessing accuracy and speed of decoding of unrelated words. The child is asked to read aloud the words for 60 seconds. The test consists of 28 words.

Pseudowords	1st grade	The test requires the reading of a list of pseudowords presented on the board. It assesses the accuracy and speed of nonword decoding. The child is asked to read aloud the words for 60 seconds. The test consists of 28 pseudowords.
The Island-pseudowords	1st grade, RC	The test requires the reading of pseudowords presented on the board with support in the form of illustrations. Nonwords are presented as names describing a fairy tale world shown in the picture. The test for RC consists of 9 pseudowords, and for 1st grade of 12 pseudowords.

2.3.2 Assessment of working memory

Assessment of working memory was made on the basis of the *Working Memory Test* (Sędek et al., 2016). The test is based on the working memory model devised by Oberauer et al. (2000, 2003). This model singles out three fundamental functions: (a) simultaneous storage and processing, (b) the function of supervision and (c) the function of coordination. Earlier research conducted by Krejtz (2012) convincingly showed that computer-based tasks to measure the various functions of working memory, constructed on the basis of Oberauer's theoretical concept, were a significant predictor of school achievement for elementary school sixth-graders and above. The test comprises three tasks for measurement of working memory. The function of simultaneous storage and processing was operationalised in a task termed *Counting span*. The function of supervision was operationalised in a task called *Set switching* and the function of coordination was operationalised as a task termed *Spatial short term memory* (detailed description of tasks see Sędek et al., 2016). Test tasks were based on visual stimuli and were conducted using a tablet. The test is a standardized diagnostic tool with a confirmed high reliability and validity. The reliability was assessed using Cronbach's Alpha: counting span (.70), set switching (.85) spatial short term memory (.75) (Sędek, Krejtz, Rycielski, Kaczan & Rydzewska, 2015). The structure of the Working Memory Test is presented in Table 3.

Table 3. Working Memory Test—description

Task name	Description	The working memory function in Oberauer's model
Counting span	Conducting operations on the presented visual material (despite appearances of conflicting content) and storing their results. The task is about calculating certain objects showed on consecutive charts (selection criteria provided calculation ranging from 1 to 5), memorizing them, and then recovering their number in the order of exposition.	Simultaneous storage and processing
Set switching	Ability to switch between two types of decisions.	Supervision

	In this task, in the square divided into 4 cells, we screen, individually, and in accordance with clockwise movement drawings of a girl's or a boy's face (happy face, sad face). The task is about switching between making a decision as to whether the presented face is that of a BOY (when it shows in upper cells) or whether it is HAPPY (when it shows in lower cells), using the same buttons symbolizing the YES vs. NO response.	
Spatial short term memory	Ability to coordinate the elements of higher order structure. The task is about remembering cells on a matrix on which the same objects appear (between 2 and 5), and then indicating the cells.	Coordination

3. RESULTS

Descriptive statistics (means and standard deviation) for the reading ability and working memory measures on both educational levels are reported in Table 4 and 5, together with group comparisons. As expected, the measures used for the diagnosis reading ability as well as working memory differed between the RC and 1st grade groups. Children differed significantly in all aspects of working memory and all measures of reading ability, e.g. letter naming and words decoding.

Table 4. Descriptive statistics for Reading Tests Battery (RTB) scores

RTB	Reception class			1st grade			U
	N[a]	M	SD	N	M	SD	
Letter naming	644	13.82	10.59	494	29.30	3.19	26252.50***
Letter recognition	644	9.74	4.63	-	-	-	-
Words	458	12.81	15.35	493	37.21	14.83	35200.50***
The Island-pseudowords	457	6.68	6.37	494	17.03	5.65	-
Pseudowords	-	-	-	492	27.57	14.02	-

[a] *Only the children who named at least 5 letter in Letter naming could take the test Words, Pseudowords, The Island-pseudowords*
****p <.001*

Table 5. Descriptive statistics for Working Memory Test scores

WMT	Reception class			1st grade			U
	N*	M	SD	N	M	SD	
Counting span	644	47.30	22.07	497	63.35	18.88	101480.50***
Set switching	636	79.93	17.76	495	88.42	13.56	124696.50***
Spatial short term memory	640	91.95	3.76	492	94.47	2.76	104390.50***

****p <.001*

Next, we examined the associations between the working memory and reading ability measures. A series of Pearson's correlations were performed to investigate relations between variables. Correlation coefficients were computed between the main scores, and the resulting matrix of correlation coefficients is shown in Table 6.

Significant correlations were found among almost all of the reading tests and three measures of working memory, namely simultaneous storage and processing, supervision and coordination. These relations however are moderate or weak. Moderate relationships have been found only for the measures of the letter knowledge (recognition and naming) and counting span in the RC group. Letter naming and recognition are only slightly less related to two other working memory functions, which are monitoring and control of current cognitive operations and memory.

In 1st grade, letter naming, word and pseudoword decoding with visual context are also significantly related to all working memory functions included in the test. Pearson correlation coefficients revealed no significant correlations between set switching and decoding pseudowords presented without visual context, and a very weak relationship when the visual context is added (*The Island-pseudowords*). It is worth noting that the correlations of pseudowords decoding with EFs are significant but negative. This means that a higher level of ability to conduct operations on the presented visual material (despite appearances of conflicting content) and storing their results, as well as spatial short term memory, results in worse performance in the pseudowords reading test.

The next question in the analysis was which factors, besides working memory, explained reading ability. In order to answer this question, 3 multiple regression analyses with separate measures of reading abilities (letter naming, letter recognition, decoding word, nonword decoding) as dependent variables were performed, separately for each educational level. The predictors were: three working memory measures, age and nonverbal IQ (fluid intelligence). Due to the fact that at the time of conducting this research, children in Poland could enter school at the age of 6 or 7 years, the further analysis includes an additional variable which is the age of the child.

Model 1 included three working memory measures: counting span, set switching and spatial short term memory. Model 2 added age, and model 3 added fluid intelligence level.

The results of the three models are given in Table 7 and Table 8.

Table 6. Pearson's correlation coefficients of reading measures and working memory

	Reception class N= 683			1st grade N=532		
	Counting span	Set switching	Spatial short term memory	Counting span	Set switching	Spatial short term memory
Letter Naming	.35**	.29**	.30**	.26**	.25**	.18**
Letter recognition	.34**	.29**	.32**	-	-	-
Words	.20**	.16**	.17**	.24**	.12**	.19**
The Island-pseudowords	.20**	.17**	.18**	.26**	.10*	.14**
Pseudowords	-	-	-	-.13**	-.01	-.14**

** p < .05; ** p < .01; ***p <.001*

a - The RC sample size varied according to the measurement in the range of 444 to 644.

b - The 1st grade sample size varied according to the measurement in the range of 458 to 494

Table 7. Summary of the linear regression analyses—Reception class

	Letter naming			Letter recognition			Words			The Island-pseudowords		
	Adjusted R^2	ΔR^2	β	Adjusted R^2	ΔR^2	β	Adjusted R^2	ΔR^2	β	Adjusted R^2	ΔR^2	β
Model 1	.19	.19		.19	.19		.06	.06		.06	.06	
Counting span			.24***			.23***			.14**			.14**
Set switching			.18***			.18***			.11*			.12*
Spatial short term memory			.16***			.18***			.10*			.11*
Model 2	.28	.09		.26	.07		.10	.04		.09	.03	
Counting span			.20***			.19***			.13**			.12**
Set switching			.16***			.16***			.11**			.12**
Spatial short term memory			.12***			.14***			.08			.10*
Age			.32***			.28***			.22***			.17***
Model 3	.31	.03		.31	.05		.11	.01		.10	.01	
Counting span			.17***			.14***			.11*			.11*
Set switching			.12***			.10**			.09*			.11*
Spatial short term memory			.07			.07*			.05			.07
Age			.28***			.23***			.20***			.15***
IQ			.19***			.28***			.11*			.10*

** p < .05; ** p < .01; ***p<.001*

Table 8. Summary of the linear regression analyses—1st grade

	Letter naming			Words			Pseudowords			The Island-pseudowords		
	Adjusted R^2	ΔR^2	β	Adjusted R^2	ΔR^2	β	Adjusted R^2	ΔR^2	β	Adjusted R^2	ΔR^2	β
Model 1	.11	.11		.07	.07		.02	.02		.06	.06	
Counting span			.20***			.19***			-.09*			.23**
Set switching			.21***			.07			.02			.07
Spatial short term memory			.06			.10*			-.11*			.04
Model 2	.11	.00		.08	.01		.03	.01		.07	.01	
Counting span			.20***			.19***			-.09*			.23***
Set switching			.21***			.07			.03			.06
Spatial short term memory			.06			.09*			-.09*			.03
Age			.02			.12**			-.10*			.08
Model 3	.12	.02		.09	.01		.03	.00		.08	.01	
Counting span			.18***			.18***			-.08			.21***
Set switching			.18***			.05			.04			.05
Spatial short term memory			.03			.07			-.07			.01
Age			.01			.12**			-.09*			.07
IQ			.15***			.10*			-.09			.11*

** p < .05; ** p < .01; ***p<.001*

In reception class, the strongest association of working memory was with letter naming ($F(3,644)=53,60$; $p<.001$) and letter recognition ($F(3,644)=53.12$; $p<.001$), accounting for 19% of the variation in both skills. Association with word decoding ($F(3,473)=10.51$; $p<.001$) and pseudowords decoding ($F(3,472)=11.33$; $p<.001$) was weaker, accounting for 6% of the variation.

In 1st grade, the strongest association with working memory measures was observed in the case of letter naming ($F(3,494)=21.84$; $p<.001$), which explained 11% of the variance. In the entire group, working memory was a significant, but weak predictor of the decoding abilities. The results show that between 2% (for pseudowords) and 7% (for words) of the variance in children's decoding abilities can be predicted by the working memory measures. As anticipated, the strongest association in both groups for all reading abilities measures was with counting span.

Model 2 included age, adding between 3% (for pseudowords decoding) and 9% (letter naming) of explained variance in the reading ability in reception class, and only 1% of variation in 1st grade.

In the last model, in the reception class 31% of the variance in letter naming and letter recognition was explained by all variables (working memory, age, IQ; letter naming: $F(5,642)=61.53$;$p<.001$; letter recognition: $F(5,642)=62.77$; $p<.001$). All variables included predicted 11% of the variation in word reading ($F(5,470)=12.61$; $p<.001$) and 10% of the variation in nonword decoding ($F(5,470)=10.91$, $p<.001$). In the 1st grade group, IQ added 1% of explained variance in all reading abilities.

The results show that the strongest predictor in all cases was the 'counting span' task that measures conducting operations on the presented visual material and storing their results. Working memory is an important predictor of the basic skills underlying literacy acquisition, that is, knowledge of letters. Its role decreases in the case of reading isolated words, as this process is based on phonological awareness.

4. DISCUSSION

This study was inspired by evidence from recent research and pointed out that executive functions, especially working memory, are important for reading acquisition. Among the studies that have focused on assessing the relationship between EF and reading abilities there is no consensus regarding the contribution of each of the executive functions in reading outcomes. However, data show that working memory appears to play an important role at the earliest stage of learning to read by children entering the school.

The main purpose of the current study was to examine the relationship of EFs' measures based on the three-function model of working memory devised by Oberauer et al. (2000, 2003) with reading ability on preliminary and key stages of its development, according to the model of Awramiuk and Krasowicz-Kupis (2014).

The reading ability in the RC group shows high variability. Some of the children at this educational level were able to recognize and to name letters, some of them were able to decode words and pseudowords in visual context quite fluently. The tools used in the study allowed for qualitative analysis of the reading strategy and reading errors. They showed that children in the RC group used different strategies during reading—more global and effective or analytical and less effective. These data reflect that the assessed RC children represented two different stages according to the theoretical model of acquisition of reading in Polish: initial phase and first substage of key phase, including dominance of analytical and phonological strategies (Awramiuk & Krasowicz-Kupis, 2014). In any case, efficient reading requires the participation of phonemic awareness combined with the letter knowledge and print awareness.

In our study the measures of basic functions underlying reading (letter knowledge) as well as speed and accuracy in decoding (pseudowords and unrelated words) were included, which made it possible to look for the link between working memory and the various reading skills. The research findings indicate that the relationships between working memory and reading measures are strongest in case of basic functions underlying reading, like letter knowledge (to the same degree for letter recognizing and naming). This relationship applies to both educational levels—reception class (before formal reading instruction) as well as 1st grade. It is important to highlight that these compounds stay significant, even when the effects of child's age and fluid intelligence are taken into account.

Most of the existing literature did not indicate which specific working memory function is related to reading ability on early stages of its development. Our data indicate that reading ability showed reliable associations only with simultaneous storage and processing measured by the task *counting span*. The term processing means transforming new or retrieved information from long-term memory; this in turn may lead to creating new content. Storage keeps briefly presented new information over a period of time (Sędek et al., 2016). These data are consistent with results obtained by Campfield, Kaczan & Rycielski (2017, in the current special issue). For reading ability, the set of variables describing working memory was not the strongest predictor, although its contribution to the predictive power of the model was above 6%. Here, spatial short term memory ceased to exert any significant influence.

Our results provide evidence that, in the 1st grade group, there was no significant correlation between pseudoword decoding accuracy and the function of supervision, measured by the task *set switching.* The supervision function in Oberauer’s model is responsible for monitoring and control of running cognitive operations. With this feature it is possible to selectively activate relevant content and procedures, as well as to inhibit the insignificant ones (Sędek et al., 2016).

The lack of correlation between the mentioned variables may be due to the fact that the task requires the child to read nonwords, so the child does not have the possibility to assess which information is relevant and which is not. The use of pseudowords enabled assessing pure decoding skills, based mainly on phonological processing, as it minimizes the impact of associations connected with meaning. These findings are consistent with studies that have included measures of shifting and showed that it's a weaker predictor for early literacy than inhibiting components (Bierman et al., 2008).

The third working memory function that has been measured is coordination, operationalized as *spatial short term memory* task. It is understood as the ability to create higher order structures from available elements (Sędek et al., 2016). Spatial short term memory correlates significantly but rather weak with all reading abilities in reception class and 1st grade pupils. This kind of EF involves mainly visual abilities which are not important for early reading skills, the latter being strongly connected with phonological processing (Krasowicz-Kupis, 2008 Krasowicz-Kupis, Wiejak & Bogdanowicz, 2015b).

We should consider also the task specificity. It is hard to isolate the working memory function as well as core executive functions in one task (Diamond, 2013). Typically, two or three functions are engaged. From the one side this can be a methodological problem in studying EFs connections with other cognitive efforts, but from the other side it is more natural for childrens' cognitive abilities. Some studies suggest that not three core EF's functions but only one (Willoughby, Wirth, Blair & The Family Life Project Investigators, 2012) or two factors—inhibitory control and shifting (Lee, Bull & Ho 2013) —can be found in preschool children.

5. CONCLUSIONS

The results of the study on the relationship between working memory as an important aspect of EFs and reading ability presented in this paper show various forms of relations depending on the educational level (RC and 1st grade), the type of reading skill (letter knowledge, words and pseudowords reading) and the function of working memory (simultaneous storage and processing, supervision and coordination). Generally, most of reading measures used as well as working memory functions feature significant relationships, but maximally on a moderate level.

Results concerning RC children present:

- letter knowledge in RC is connected with the simultaneous storage and processing working memory's function in Oberauer's model on a moderate level and only slightly less related to monitoring and control of current cognitive operation as well as to the function of coordination;
- working memory accounts for 19% of the variation in letter naming and letter recognition;
- word and pseudoword reading generally don't relate to the function of supervision.

In the 1st grade results present:

- a weak relationship between simultaneous storage and processing and letter knowledge;
- a weak relationship between the function of coordination and all reading skills: letter knowledge, words and pseudowords decoding;
- working memory as a significant, but weak predictor of the decoding abilities; results show that between 2% (for pseudowords) and 7% (for words) of the variance in children's decoding abilities can be predicted by the working memory measures.

Overall, our findings suggest that the use of working memory, mainly simultaneous storage and processing, can be a good predictor of basic reading ability at the initial stage, before formal instruction of learning to read and write. The regression analyses showed that RC children's letter knowledge was significantly predicted by working memory and age, and 1st grade children's letter naming only by working memory. Working memory alone predicted 19% of the variance in letter knowledge in RC, and 11% of variance in1st grade. Our results are consistent with data from other languages showing relations of EF with letter knowledge (e.g. Davidse, de Jong, Bus, Huijbregts, & Swaab, 2011; Matthews, Ponitz & Morrison, 2009). These data indicate that working memory can be used in combination with phonological skills in the prediction of reading ability of children starting formal literacy instruction.

The presented analysis did not include phonological processing skills like phonological awareness, which is critical for learning to read any alphabetic writing system. This special role of phonological processing in literacy acquisition raises questions about the relation between phonological awareness and executive functions. Conscious control of cognitive processes engaged in making phoneme judgements and manipulations requires the involvement of sustained attention, working memory and response inhibition. Further investigation of the relationship between the two processes described above and literacy outcomes is needed.

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