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MEMORY IMPAIRMENTS IN ADULTS WITH DYSLEXIA

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SUMMARY

Background: The aim of our study was to analyze the functioning of various aspects of memory in adults with developmental dyslexia, as compared to adults without developmental dyslexia.

Material/ Methods: Our research involved a total of 180 adults, mostly students and university graduates from the Tri-City metropolitan region in north central Poland. The criterion group consisted of 93 adults with developmental dyslexia, while the control group consisted of 87 adults without developmental dyslexia.

Results: The results obtained confirm the assumption of a lower level of functioning of individuals with dyslexia in relation to phonemic analysis and phonemic awareness, phonological awareness and verbal working memory, visual working memory and perception in a task requiring the analysis and synthesis of details of a complex pattern, recalling data from the mental lexicon. The two groups did not differ in terms of working visuospatial memory (spatial span). These results are consistent with a majority of scientific reports on memory functioning in adults with developmental dyslexia.

Conclusions: Our findings confirm the phonological deficit hypothesis, as the most profound disturbances were observed in phonological processing and verbal working memory. Moreover, our studies do not provide support for the compensation model of dyslexia, as diverse memory deficits persist into adulthood. However, adults with dyslexia were aware of their cognitive limitations in terms of memory.

Key words: working memory, visuospatial memory, phonological skills, phonological awareness

INTRODUCTION

Reading and writing (text reception and text construction) are complex skills. The language user is required to employ numerous cognitive functions simultaneously, including working memory and long-term memory for the three sensory modalities involved (visual, auditory, and kinesthetic), attention, perception via pathways (visual, auditory, and kinesthetic pathway), thinking, linguistic and metalinguistic knowledge (Pachalska et al., 2012). Moreover, a developed linguistic ability at the phonological, morphological, syntactic, and semantic levels is a prerequisite for acquiring proficiency in reading and writing, as well as graphomotor dexterity, accompanied by the effective sensorimotor integration of all these functions (Bogdanowicz, 2003).The ability to read and write, both accurately and fluently, is impaired in individuals with developmental dyslexia, a specific language-based learning disorder that is neurobiological in origin. The cause of the observed disturbances are insufficient phonological processing abilities, leading to difficulties in decoding individual words, to a degree unexpected in relation to age and other cognitive and academic skills (Reid Lyon, Shaywitz & Shaywitz, 2003). Moreover, there have been certain candidate genes identified as contributing to dyslexia (Wysocka, Lipowska, Kilikowska, 2010). It is difficult to present a comprehensive list of symptoms of dyslexia, because it is a heterogeneous disorder, i.e. people with dyslexia differ from each other in terms of the cognitive profile of disturbances (Reid et al., 2006). Thus the symptomatology of dyslexia is rich. Not only are there difficulties in accurate and/or fluent reading and proficient spelling, but these may be, and frequently are, accompanied by reduced reading comprehension and poor written expression. Moreover, other cognitive deficits of academic skills are characteristic of dyslexia. People with dyslexia often manifest a deficit in learning implicit language regularities, including phonological, orthographic, and morphological rules. Furthermore, there is a high rate of comorbidity between motor difficulties, especially dyspraxia, and dyslexia. It must be mentioned here that the symptoms of dyslexia change throughout the lifespan. Bogdanowicz (2009) notes that reading difficulties are the first to subside with age, while spelling mistakes tend to be a more persistent symptom. She also indicates that the cognitive profile of an adult dyslexic, and an individual literacy level (the type and severity of symptoms) depend on the amount of practice under the guidance of a remedial teacher, and on the individual characteristics of the person affected by dyslexia (on their intelligence, as well as the type, scope and degree of developmental deficits which are the cause of the academic difficulties). Such factors as the lack of contact with language, the cessation of conscious control and work on the problem, or stressful situations may, at any stage of life, result in the reappearance or worsening of the dyslexic symptoms.

In this paper we would like to focus on the issue of memory functioning in adults with developmental dyslexia. The role of different types of memory in mastering reading and writing skills cannot be overestimated. “The task of learning to read in an alphabetic system entails learning to associate letters with their

sounds, and reaching an understanding of how sounds can be put together to make words (blending). Conversely, learning to spell requires the child to be able to pull the sounds of spoken words apart (segmentation) and to associate the relevant letters (or speech patterns) with them" (Hatcher & Snowling, 2004, p. 71). The quality of written expression depends on working memory. It must be remembered, though, that prior automatization of writing letters and producing ideas is required for an optimal use of its resources (Peverly, 2006). Since the 90s, the phonological deficit hypothesis is considered in the literature to be the dominant and most scientifically documented concept explaining the causes of specific difficulties in reading and writing (Beaton, 2004; Lundberg & Hoien, 2001, Nicolson & Fawcett, 2008). Indicating difficulties with the processing of speech sounds as the main source of the observed problems, this theory suggests that the basis of developmental dyslexia is a phonological deficit, and a deficit in verbal working memory, which result in specific difficulties in reading. Hatcher, Snowling and Griffiths (2002) argue that developmental dyslexia may be confirmed in adults, with 95% accuracy, by means of only four tests, which assess correct spelling, reading non-words, working memory (repeating digits), and writing speed. These skills and abilities are directly related to phonological processing. Twenty years of experience in scientific research, referred to by Swanson and Sáez (2003), suggest that deficits in working memory - phonological, semantic, and visuospatial – constitute the fundamental problem of children and adults with specific learning difficulties. This applies especially to those aspects of the phonological system which are responsible for accurate and rapid access to language codes. This statement has been confirmed by reports of studies demonstrating memory deficits in adults with dyslexia, especially working verbal memory (phonological) (Bogdanowicz, 2009; Di Betta & Romani, 2006, Fawcett & Nicolson, 1997, Hatcher et al., 2002, Lundberg & Hoien, 2001, Martin et al., 2010; Smith-Spark et al., 2003; Smythe, 2007) and the recall of verbal labels from the mental lexicon (Martin et al., 2010; Shessel & Reiff, 1999; Smythe, 2007). Moreover, it has been shown that syntactic deficits in adults with dyslexia are influenced by both working memory and word-reading ability (Wiseheart et al., 2009).

However, the results of studies examining visuospatial working memory in individuals with dyslexia are not so clear. Research conducted by Winner et al. (2000) demonstrated that in a majority of the different visuospatial trials used, the performance of people with dyslexia was generally lower, usually at a slower pace and with less precision, than the level of performance in the control group. Conversely, in an experimental trial based on a three-dimensional computer-generated virtual environment used by Attree, Turner and Cowell (2009), adolescents with developmental dyslexia scored significantly higher in the task assessing incidental spatial memory. Smythe and Gyarmathy (2007) believe that individuals with developmental dyslexia often out-perform those without the disorder in a memory task based on memorizing pairs of simple illustrations, due to their preference for the global method of information processing. Most researchers, however, are inclined to argue that people with dyslexia are not sig-

nificantly different from their peers without this disorder when visuospatial tasks and materials are used (Swanson, Ashbaker & Lee, 1996), or as far as storing non-verbal data and semantic aspects of verbal information in long-term memory (Jorm, 1983) and working visuospatial memory are concerned (Di Betta & Romani, 2006; Jeffries & Everatt, 2004), with the exception of more difficult tasks (Smith-Spark et al., 2003).

In the present study, therefore, we assumed that memory deficits in adults with dyslexia manifest primarily in tasks involving linguistic, rather than visuospatial material. We analyzed the level of functioning of adults with difficulties in reading and writing in relation to phonological working memory and phonological awareness as the most diagnostic indices of dyslexia at the cognitive level. In addition, the functioning of people with dyslexia was compared to their nondyslexic peers in terms of visuospatial working memory, both sequential and in association with the spatial analysis of a complex pattern. The respondents were also requested to self-report the functioning of their short-term and long-term memory.

MATERIAL AND METHODS

Our study involved 318 adults aged 18-30 years. However, due to a significant amount of missing data - each participant was approached in two sessions, while not all of them were available for a second assessment - the final sample consisted of 180 participants. As a result, in the test group there were 101 females (56.1%) and 79 males (43.9%). The distribution of students by the type of school/college they attended was as follows: social sciences (32.8%), exact sciences (20%), humanities (17.8%), artistic studies (10%), environmental studies (8.9%), languages (6.7%), and sports (3.9%).

The occurrence of dyslexia, a variable of particular importance for our purposes, was assessed on the basis of an independent report issued by state psychological and educational counseling centers. This diagnosis was prepared according to the criteria of the Polish Ministry of National Education. These criteria include:

- an average level of intelligence (IQ over 85) or higher;
- below average achievement tests scores for reading and writing,
- processing deficit symptoms in one or more areas of cognitive and / or language functioning.

In our sample, 93 subjects (51.7%) had a diagnosis of dyslexia. All the participants were native speakers of Polish and gave informed consent to take part in the study. The gender and fields of study distributions represent the actual distribution of these variables in the Polish population for the academic year 2007/2008. The frequency distribution of dyslexia, however, is a variable that has been controlled by counterbalancing, i. e. it does not reflect the actual proportions, but allows for accurate comparisons of the cognitive functioning of people with and without dyslexia.

The study reported in this paper was part of a larger research project analyzing the profiles of cognitive and motivational functioning of adults with dyslexia.

The assessments were conducted in the Tri-City metropolitan region of Poland (Gdańsk-Sopot-Gdynia) in the period from October 2007 to July 2008. The research team was comprised of graduate and postgraduate students from the Institute of Psychology at the University of Gdansk, Poland, and the University of Social Sciences and Humanities in Sopot, Poland. The study was conducted in two sessions, which differed in the mode of administration of tests. In the first group session, study participants completed those tests that do not require additional monitoring (e.g., precise time measurement or the presentation of visual and auditory stimuli that require analysis). Therefore, the methods used in this phase of the study belong to the paper-and-pencil type. In the second individual session, each participant performed a series of tasks and test trials, the outcome of which is susceptible to distortion under the influence of uncontrolled external stimuli, or which require individual instruction and monitoring. In this session, the participant was assessed by an experimenter, in the "one-to-one" assessment model. In total, the assessment of one participant lasted for more than two hours, because the study included an interview, and a number of tests diagnosing cognitive, emotional and motivational functioning, while those described in the current paper refer only to memory.

The following research methods were used:

- *Word-Medial Sound Deletion* - an experimental trial designed by the authors specifically for this study. The examiner, with his mouth covered, reads a list of nonwords. The participant deletes a previously indicated sound from each of the nonwords given, thus creating a new, one- or two-syllable word, which exists in Polish. For instance, if you delete the sound /n/ from the non-word *knasa*, the word *kasa* („cash") is formed. This trial assesses phonemic segmentation and phonemic awareness; phonological working memory is also involved.
- *Unknown Language Test* (Bogdanowicz et al., 2008) – Part Two, which assesses phonological memory. This test was adapted by the authors specifically for this study, by preparing more difficult source material for the subject to memorize. The examiner reads 4 lists of non-words. The lists are longer in each subsequent trial, and consist of from 3 (6 syllables in all words) to 6 (14 syllables in all words) nonwords (which consist of 1, 2 or 3 syllables each). The participant's task is to memorize the non-words given, and repeat them in any order.
- *Phonological Awareness Test* - adaptation (Kaja & Nair, 2003). This test examines multidimensional phonological awareness, as it requires the simultaneous performance of two phonological operations. The trial consists of two types of tasks – task A and task B. Task A involves the encoding of the given words. The examiner produces the words, which the subject must encode by inserting the syllable *ka* (the pronunciation of which is similar to "ca" as in "catastrophe") prior to each syllable. Thus, the encoded word *woda* ("water") becomes „ka wo ka da". The level of difficulty gradually increases: the examiner begins with a two-syllable word (*losy* – "history"), and ends with a five-syllable one (*stowarzyszenie* – "association"). In the final trial the participant must

manage an entire sentence (*Filadelfia jest miastem*. – "Philadelphia is a city."). Task B involves the decoding of the given words. The participant tries to guess what word the examiner is saying. The level of difficulty gradually increases: the examiner begins with a two-syllable word (*kadzwo kanek – dzwonek* - "bell"), and ends with a five-syllable one (*kaza kaszyf karo kawa kanie – zaszyfrowanie* - "encryption"). In the final trial the participant must manage an entire sentence: *Kapa kani kasprze kada kaje kasa kała katę. - Pani sprzedaje sałatę* "The lady is selling lettuce.").

- *Auditory Memory* (writing), a test of verbal working memory, which is part of the battery *Profiler* (Smythe, 2007).The test consists of two parts. During the first part, the participant is asked to write a series of numbers produced by a psychologist. Each sequence is longer than the previous one by one digit. The longest sequence consists of 8 digits. Only after hearing the entire sequence of digits is the participant allowed to start writing. The second part requires recalling the given numbers in the reverse order, also in writing. The longest sequence consists of 5 digits.
- *Spatial Span*: Wechsler Memory Scale III – adaptation (Pachalska & Lipowska, 2006) – a test of visuospatial memory. The participant reproduces a sequence of hand movements forwards and backwards, starting with two consecutive movements. In both cases, blocks are used. These are employed to demonstrate the sequence of movements, and to store and reproduce the sequence directly. On the side of the blocks, visible only to the examiner, numbers are placed to facilitate the demonstration of the forwards and backwards movement sequences.
- *Difficult Figure* – reproduction from memory (Bogdanowicz et al., 2008). The test is designed to assess visual memory and visual perception, visual-motor coordination, attention, and visual-motor control and coordination. The examiner places in front of the participant a blank A4 sheet of paper, laid horizontally, and above it the model pattern to be reproduced, in the same position. The participant's task is to copy a difficult figure without using a ruler or an eraser. The pattern used is a complex geometrical figure, consisting of 16 simple elements combined in a way which carries no meaning. Therefore, it is difficult to organize them into a whole figure in order to reproduce the whole pattern. There is no time limit, but the examiner records the time taken to redraw the figure. Later, he or she removes the pattern. Three minutes after the participant completed the copying task, the psychologist continues the assessment. A second blank A4 sheet is placed horizontally in front of the subject, and the subject is asked to reproduce the figure from memory. The quality of the reproduction is assessed separately for each component, then the results are added. The reliability of the Difficult Figure test is satisfactory (Cronbach's $\alpha = 0.704$), especially the average correlation between the tasks (0.372). In this study only the results from the second task (figure reproduction from memory) were analyzed.
- *Revised Adult Dyslexia Check List* - KODD (Vinegrad, 1994), Polish translation and adaptation by Bogdanowicz & Krasowicz (2000).The questionnaire

is used as a screening test for the diagnosis of adults with dyslexia. It includes a list of questions, each of which refers to one of the symptoms of dyslexia. If the subject selects nine or more positive answers in the questionnaire, it confirms the presence of dyslexia. The confidence increases if most of the answers are ”YES” to the following questions, which are highly diagnostic: 17, 13, 7, 16, 18, 10, 19, 14, 20, 4, 1, 11. The assessment based on the questionnaire is only of an indicative character, and should be treated as an index for an eventual full assessment. In the questionnaire, 8 out of the 20 questions concern the issue of memory: Question 10, ”Do you find it difficult to take messages on the telephone and pass them on correctly?”; Question 11, “When you have to say a long word, do you sometimes find it difficult to get all the sounds in the correct order?”; Question 12, ”Do you find it difficult to do sums in your head without using your fingers or paper?”; Question 13, “When using the telephone, do you tend to get the numbers mixed up when you dial?”; Question 14, “Do you find it difficult to say the months of the year forwards in a fluent manner?”; Question 15, “Do you find it difficult to say the months of the year backwards?”; Question 16: “Do you mix up dates and times and miss appointments?”; Question 20: “Did you find it hard to learn your multiplication tables at school?”.

- *Questionnaire*, which is a part of the battery Profiler (Smythe, 2007). The questionnaire is used as a screening test for the diagnosis of adults with dyslexia. It includes a list of questions, each of which refers to one of the symptoms of dyslexia. Answers are given on a scale from 1 (rarely / very easy) to 4 (usually / very difficult). In the questionnaire, 6 out of 15 questions concern the issue of memory: Question 3, “Do you confuse the names of objects, for example ‘table’ for ‘chair’?”; Question 7, “Do you get confused when given several instructions at once?”; Question 8, “Do you make mistakes when taking down telephone messages?”; Question 9, “Do you find it difficult to find the right word to say?”; Question 13, “Did you learn your multiplication tables easily?”; Question 14, “How easy do you find it to recite the alphabet?”

RESULTS

The basic assumption of the theory of phonological deficit in the pathogenesis of developmental dyslexia is the occurrence of a specific impairment in the representation and processing of speech sounds (phonemes) in persons with dyslexia. This impairment manifests itself in disturbances of phonological awareness (i.e., difficulty in segmenting, blending, and manipulating phonological elements) and of phonological memory. To assess working phonological memory the following tests were administered: the Word-Medial Sound Deletion test, the Phonological Memory subtest from the Unknown Language Test, and the Phonological Awareness Test. The results are shown in Table 1.

The t-test for independent samples shows that subjects with dyslexia scored significantly lower than subjects without dyslexia in all the trials that measure

Table 1. The level of functioning of phonological memory and phonological awareness in the compared groups

Diagnostic Tests	no dyslexia		dyslexia		significance			
	M	SD	M	SD	t	df	p	d
Word-Medial Sound Deletion								
Sound deletion	9.51	0.80	8.98	1.35	3.22	151.05	0.001***	0.52
Unknown Language								
Phonological memory	8.91	2.47	7.75	2.41	3.17	178	0.002**	0.48
Phonological Awareness Test								
Encoding	5.63	1.64	5.04	1.98	2.17	178	0.032*	0.32
Decoding	4.61	1.98	3.91	1.93	2.38	178	0.018*	0.36
Phonological awareness (total score)	10.24	3.32	8.96	3.32	2.59	178	0.010*	0.39

*p<0.05; **p<0.01; ***p<0.001

phonemic segmentation and phonemic awareness (t = 3.22, p = 0.001), phonological working memory for nonwords (t = 3.17, p = 0.002), and phonological awareness (t = 2.17, p = 0.032 for encoding, t = 2.38, p = 0.018 for decoding, t = 2.59, p = 0.010 for total score). The difference between the groups was largest in the case of phonemic segmentation and phonemic awareness, as measured with Cohen's d estimator (d = 0.52, medium effect size). These results confirm the findings indicating phonological disturbances as a crucial deficit in developmental dyslexia.

Numerous scientific reports have pointed to memory deficits in people with dyslexia. For example, Smith-Spark et al. (2003) reported significant disturbances of verbal working memory in persons with dyslexia, both in digits and in words recall. According to some researchers, however, adults with dyslexia do not differ significantly from those without dyslexia in terms of storing information of a spatial character (Smith-Spark et al., 2003). The results of the level of memory functioning in the two research groups, measured with the Auditory Memory trial from the Profiler, the Visuospatial Memory subtest from the Wechsler Memory Scale III, and Difficult Figure Test: Reproduction, are presented in Table 2.

The analysis of the results presented in Table 2, measured with the t-test for independent samples, indicates that adult participants with developmental dyslexia perform a task of immediate recall of digits significantly worse in comparison with adult participants without developmental dyslexia, in all three trials (forward: t = 2.73, p = 0.007, backward: t = 1.74, p = 0.083: statistical trend, total: t = 2.64, p = 0.009). The effect size, however, was small, with d = 0.41, d = 0.26, and d = 0.40, respectively. This result is consistent with reports in the literature, indicating a deficit of verbal working memory and sequential data processing as the characteristic symptoms of developmental dyslexia in adulthood.

Compared with these reports, the results showing the performance of tasks involving visuospatial memory task seem to be of particular interest. Although the test is based also on the use of working memory and the reproduction of se-

quential material, the results indicated no significant differences between dyslexics and non-dyslexics(t=0.36, p=0.720; t=0.49; p=0.628; t=0.47, p=0.639, for forward reproduction, backward reproduction and the sum of scores in both trials, respectively). This result suggests that the working memory deficits observed in developmental dyslexia concern only the manipulation of verbal sequential, as opposed to non-verbal sequential material.

Similarly, a summary of the results (Table 2) scored by the participants with developmental dyslexia and without developmental dyslexia in the task measuring visual memory and visual perception (organization, style, and accuracy) when reproducing a previously memorized pattern after a 3-minute delay demonstrates that the criterion group performed on this test at a significantly lower level than the control group (t = 3.57, p = 0.001), with the effect size being medium, d = 0.54.This visuospatial task requires the analysis and synthesis of the details of a complex pattern, and measures also the structuralization of perception, which may account for the lower score in the criterion group.

Moreover, we examined different aspects of long-term and working memory, as measured with the Revised Adult Dyslexia Check List and the Questionnaire from the Profiler.

A t-test for independent samples (see Table 3) shows that significant differences were found between the two research groups in the majority of the questions used, with the exception of V12, difficulty in adding (t = 0.503, p = 0.615). In all memory aspects, the level of performance in the criterion group was below that of the control group.

A large effect size was observed in:

- KDD8: memorizing and passing on telephone messages in written form (t = 6.266, p = 0.000, d = 1.00);
- KDD14: reciting the alphabet (t = 5.934, p = 0.000, d = 0.82).

Table 2. The level of functioning of verbal and visuospatial memory in the compared groups

	no dyslexia		dyslexia		significance			
	M	SD	M	SD	t	df	p	d
Auditory Memory – writing								
Working auditory memory (forward)	5.14	1.00	4.74	0.94	2.73	178	0.007**	0.41
Working auditory memory (backward)	6.90	1.29	6.57	1.23	1.74	178	0.083[a]	0.26
Working auditory memory (total)	12.05	1.87	11.32	1.81	2.64	178	0.009**	0.40
Spatial Span								
Working visuospatial memory (forward)	9.20	1.85	9.10	1.83	0.36	178	0.720	0.05
Working visuospatial memory (backward)	8.34	1.99	8.20	1.90	0.49	178	0.628	0.07
Working visuospatial memory (total)	17.54	3.43	17.31	3.09	0.47	178	0.639	0.07
Difficult Figure								
Visual memory and perception	22.06	3.90	19.88	4.27	3.57	178	0.001***	0.54

*p<0.05; **p<0.01; ***p<0.001; [a] tendency level

A medium effect size was observed in:

- V20: learning multiplication tables (t = 5.193, p = 0.000, d = 0.73);
- V11: – distorting long words (t = 6.130, p = 0.000, d = 0.69);
- V16: – confusing dates and hours (t = 4.576, p = 0.000, d = 0.68);
- V10: memorizing and passing on telephone messages – orally (t = 4.113, p = 0.000, d = 0.61);
- KDD9: recalling a word from mental lexicon (t = 4.949, p = 0.000, d = 0.56);

V5: memorizing the sense of the text read (t = 4.161, p = 0.000, d = 0.56).

A small effect size was observed in:

- KDD7: understanding several instructions given at the same time (t = 3.891, p = 0.000, d = 0.44);
- V13: confusing the order of digits (t = 2.491, p = 0.014, d = 0.36);
- V14: reciting lists (t = 2.027, p = 0.044, d = 0.31).

The differences between the adults with and without dyslexia in V15 (backward list reciting) and KDD3 (confusing the names of objects) failed to reach sig-

Table 3. The level of memory functioning (self-report) in the compared groups

		no dyslexia		dyslexia		significance test			
		M	SD	M	SD	t	df	p	d
Adult Dyslexia Checklist									
V10	Memorizing and passing on telephone messages – orally	0.08	0.28	0.27	0.44	4.113	183.5	0.000***	0.61
V11	Distortion of long words	0.31	0.46	0.64	0.48	6.130	312	0.000***	0.69
V12	Difficulty in adding	0.31	0.47	0.34	0.48	0.503	312	0.615	0.06
V13	Confusing the order of digits	0.07	0.25	0.16	0.37	2.491	192.8	0.014*	0.36
V14	Reciting lists (e.g. months)	0.02	0.14	0.07	0.26	2.027	169.9	0.044*	0.31
V15	Reciting lists (e.g. months) – backwards	0.23	0.42	0.33	0.47	1.815	240	0.071[a]	0.23
V16	Confusing dates and hours	0.09	0.29	0.30	0.46	4.567	182.7	0.000***	0.68
V20	Learning multiplication tables	0.16	0.37	0.43	0.50	5.193	205.1	0.000***	0.73
Questionnaire (Profiler)									
KDD3	Confusing names of objects	1.10	0.35	1.20	0.49	1.769	203.3	0.078[a]	0.25
KDD7	Understanding several instructions given at the same time	1.65	0.65	1.97	0.77	3.891	312	0.000***	0.44
KDD8	Memorizing and passing on telephone messages – in written form	1.16	0.36	1.63	0.79	6.266	155.7	0.000***	1.00
KDD9	Recalling a word from mental lexicon	1.77	0.62	2.15	0.72	4.949	312	0.000***	0.56
KDD14	Alphabet reciting	1.32	0.50	1.74	0.66	5.934	210.2	0.000***	0.82

*p<0.05; **p<0.01; ***p<0.001; [a] tendency level
Higher score signifies lower performance.
Question KDD13 was omitted, as it is worded exactly as Question V20.

nificance, as these results placed at the level of statistical trend: t = 1.815, p = 0.071, and t = 1.769, p = 0.078, respectively.

These scores suggest that individuals with developmental dyslexia are well aware of their own cognitive problems as far as memory functioning is concerned. The indicated difficulties concerned verbal working memory (KDD8, V10, KDD7, V13) and information recall from the mental lexicon (KDD14, V20, V11, V16, KDD9, V14). It must be remembered, however, that while all the analyzed questions assess skills and abilities requiring some aspects of memory, other, and diverse, cognitive functions are also involved in their fluent and/or accurate execution.

DISCUSSION

A review of the literature on the functioning of working memory in adults does not provide an unambiguous answer regarding the exact nature of the deficit observed in developmental dyslexia. This is due to the fact that researchers apply different cognitive models and use incompatible terminology. Therefore, there is some controversy as to what skills, abilities, or processes are actually being examined by specific assessment methods. The only assumption that seems to be indisputable is the fact that adult dyslexics have problems with working verbal (phonological) memory (Bogdanowicz, 2009; Di Betta & Romani, 2006; Fawcett & Nicolson, 2003, 1997; Hatcher et al., 2002; Laasonen et al., 2012, Lundberg & Hoien, 2001; Rack, 1997; Singleton, Horne & Simmons, 2009; Smith-Spark et al., 2003; Shessel & Reiff, 1999; Smythe, 2007; Swanson & Sáez, 2003; Szczerbiński, 2007). In our study we obtained results consistent with those reports: a significantly lower level of functioning of adult participants with developmental dyslexia, as compared with their nondyslexic peers, in relation to phonemic segmentation and phonemic awareness (as measured with the Word-Medial Sound Deletion trial), phonological awareness and phonological working memory (Phonological Awareness Test: encoding & decoding), and verbal working memory for non-words (Unknown Language) and digits (Auditory Memory – writing).

Currently, the problem of visuospatial working memory in adults with dyslexia remains an open issue. Some scientists argue that this group does not differ significantly from their peers without the disorder (Di Betta & Romani, 2006; Everatt, Weeks & Brooks, 2008; Jeffries & Everatt, 2004; Singleton, 2004, Swanson et al. , 1996). Some researchers even suggest that there may be specific strengths of individuals with developmental dyslexia in relation to spatial memory (Attree et al., 2009; Smythe & Gyarmathy, 2007). However, there are studies that question these reports (Swanson & Sáez, 2003). In our study, the criterion group did not differ from the controls in terms of immediate visuospatial working memory on sequential material (as measured with Spatial Span: Wechsler Memory Scale III), which is in accordance with the majority of the literature. However, adult participants with developmental dyslexia scored significantly lower on the measure of visual memory and perception (the analysis and synthesis of details of the Difficult Figure reproduced after a three-minute delay), as compared to adult par-

ticipants without dyslexia. Both trials (Spatial Span and Difficult Figure) rely on visuospatial memory. However, the former, more than the latter, involves global visuospatial processing, rather than requiring the analysis of visual details with emphasis on their location in space and in relation to one another. It has been argued in the literature on specific difficulties in reading and writing that problems with lateralization and spatial orientation are common in developmental dyslexia (Bakker, 1990; Bednarek & Grabowska, 2002; Høien & Lundberg, 2000; Pachalska et al. 2009). Moreover, according to Smith-Spark et al. (2003) limitations in visual working memory in developmental dyslexia depend largely on the level of cognitive demands. One could argue that the task of unexpected reproduction of a complex figure is a more challenging task than the immediate recall of a simple sequence of movements. Thus this higher difficulty level may account for the deficit observed in adult dyslexic participants.

To sum up, as far as working memory of adults with developmental dyslexia is concerned, we observed deficits in phonemic and phonological awareness, verbal working memory on sequential material, and visual memory and perception. Furthermore, dyslexic participants performed on a level with their nondyslexic peers in visuospatial working memory task.

Moreover, the dyslexic participants self-reported deficits in verbal working memory, and in information recall from the mental lexicon. The latter finding is also consistent with reports of poor access to long-term memory store as characteristic of developmental dyslexia (Shessel & Reiff, 1999; Singleton et al., 2009; Smythe, 2007; Pachalska et al., 2007).

The presented results are commensurate with a majority of the scientific reports on adults with dyslexia. Above all, however, these findings confirm the phonological deficit hypothesis formulated by Snowling (2000). According to Ramus (2004), a key deficit in dyslexia is a phonological one, while other deficits (magnocellular and cerebellar) only co-occur, but do not cause difficulties in reading and writing specific to dyslexia.

Moreover, our study failed to provide substantial support for the compensation model of dyslexia in adults with reference to various aspects of memory, since we observed verbal and visual working memory, and long-term memory deficits persisting into adulthood. This would suggest that crucial cognitive processes cannot be trained to an average level, or be compensated for. Furthermore, it must be mentioned that the most strongly represented group among the participants were university students, whose high intellectual potential is conspicuous when compared to the rest of the population. Consequently, this group had more opportunities and abilities to compensate for any potential congenital deficits; nevertheless, they failed to do so. It is interesting, however, that adults with dyslexia are well aware of their limitations, and report problems with verbal working memory, subsequently confirmed in the assessment methods used, as well as problems with long-term memory.

While analyzing the results of our study one should bear in mind that it may be difficult to separate certain cognitive functions from each other (see also

Pachalska et al., 2009). For example, the most popular tools for measuring working memory simultaneously assess phonological abilities, e.g. digit span. In our study, both working memory and phonological abilities are involved in the tasks of Auditory Memory – writing, Word-Medial Sound Deletion, Unknown Language, Phonological Awareness Test, and all the questions on the two questionnaires. An obvious, though not widely utilized method to test pure working memory without the influence of phonological processes,is the use of visuospatial tasks without the phonological component, e.g. Difficult Figure or Spatial Span, both used in the discussed study. However, these tasks rely also on attention, as do verbal working memory tasks to a certain degree. None of the hypotheses concerned attention, but it cannot be ruled out that it is the attention deficit that constitutes one of the key symptoms of dyslexia (cf. Buchholz & Davies, 2005; Reid & Wearmouth, 2008; Swanson & Sáez, 2003).

Additional correlations between the trials were calculated. It was found that the strongest relations occur between the measures of Phonological Awareness and Sound Deletion ($r=0.35$; $r=0.38$; $r=0.42$; $p=0.05$ for encoding, decoding, and total score, respectively), and between Phonological Awareness and Auditory Memory ($r=0.33$; $p=0.05$ for total scores). These tasks rely heavily on phonological processing abilities, disturbances of which constitute the core deficit in developmental dyslexia.

CONCLUSIONS

Developmental dyslexia, as mentioned before, is not limited to a specific developmental period (especially the school years), but remains a problem throughout one's lifetime, and its symptoms are also present after the completion of the formal stage of education. This persistence of symptoms was also demonstrated in our study. Our results agree with the contemporary linguistic approach to dyslexia, as the most profound disturbances were observed in phonological processing and verbal working memory. However, we noticed accompanying problems with visuospatial processing of complex figurative material. This suggests that different aspects of memory, not only those connected to phonological information processing, are impaired in developmental dyslexia. We hope that the gathering of data about the difficulties of adults with dyslexia will allow for the further development of complex tools for the diagnosis and therapy of this group, including tests and tasks assessing the functioning of various aspects of memory.

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