Life Span and Disability XXII, 2 (2019), 223-253

Investigating memory functions in dyslexia and other specific learning disorders

Metehan Irak[1], *Gözem Turan*[2], *Berna Güler*[1] *& Zehra Orgun*[1]

Abstract

Although linguistic deficits are frequently reported in children with dyslexia, the role of memory mechanisms underlying these impairments have yet to be clearly defined. It is still unclear whether the main reason for dyslexia is due to a phonological impairment, or more specific memory dysfunctions, such as deficits in memory encoding or memory retrieval. The purpose of this study was to try to determine, or rule out, the role of memory functions in children with dyslexia and mixed learning disorder (MLD). Thus, 54 children (aged 8 to 12 years old) were recruited and divided into three groups; children diagnosed with dyslexia, MLD, and healthy controls. We assessed children's fluid intelligence, working memory, short-term and long-term object recognition memory, digit span, and reading speed. There was no significant difference between control and dyslexia groups in terms of their fluid intelligence scores, on the other hand the fluid intelligence scores of MLD group was significantly lower than both dyslexia and

Received: January 28, 2019; *Revised:* November 30, 2019; *Accepted*: December 6, 2019

[1] Bahçeşehir University Department of Psychology, Brain and Cognition Research Laboratory.
[2] Goethe-University Frankfurt am Main, Germany.

Correspondence to: Prof. Dr. Metehan Irak, Bahçeşehir University, Çırağan Cad. Osmanpaşa Mektebi Sok. No: 4 Beşiktaş, İstanbul, Turkey, 34353.
Phone: +90 212 3810449; E-mail: metehan.irak@eas.bau.edu.tr.

Authors Note: This study was carried out as a partial fulfillment of master degree of the fourth author (Z.O.). The authors have no financial conflicts to disclose and/or conflict of interest.

Acknowledgments: We thank the school principals and directors of the centers for data collection procedure. We also thank Matthew Rouse for proofreading.

control groups. Besides, the diagnosed groups showed significantly poorer performance on working memory, object recognition memory, digit span and reading speed than controls. Discriminant function analysis indicated that significant predictors for distinguishing the three groups are object recognition, forward digit span, and working memory, respectively. The lower performance on digit span and both verbal and non-verbal working memory tasks in dyslexic children can be evaluated as a general encoding strategy problem. We suggest that dyslexic children cannot properly encode verbal and nonverbal stimuli, and thus cannot maintain and retrieve them.

Keywords: Dyslexia; Mixed learning difficulties; Working memory; Object recognition; Digit span; Fluid intelligence.

1. Introduction

Specific learning difficulties (SLD) refer to when individuals have difficulties within specific rather than general cognitive functions, affecting their ability to learn, and achieve success in life. A large proportion of students with SLDs have reading difficulties, but SLDs are not solely an impairment in reading. Learning disorders are associated with significantly below average educational achievement levels, together with specific and continuous difficulties in academia, despite normal levels of intelligence, motivation, and adequate socio-cultural factors (Karande, Sawant, Kulkarni, Galvankar, & Sholapurwala, 2005).

SLDs have been grouped into four types: dyslexia (difficulty with reading), dyscalculia (difficulty with mathematics), dysgraphia (difficulty with writing) and mixed. People with SLDs experience significant difficulties developing the core skills of reading, writing, and arithmetic from their first days of school (Schuchardt, Maehler, & Hasselhorn, 2008). Dyslexia is the most frequent and the most commonly frequently studied SLD and is defined as a specific difficulty in reading and spelling. It is not related to low intelligence, insufficient educational facilities or neurological damage (Bishop-Liebler, Welch, Huss, Thomson, & Goswami, 2014). Most cases of dyslexia are identified at the end of the first academic year. Difficulties in reading single words accurately and fluently, persisting throughout school and therefore resulting in poor academic performance are common, affecting up to six percent school children (Luo, Wang, Wu, Zhu, & Zhang, 2013). Although recent studies have claimed that dyslexia arises from a phonological processing deficit (Fletcher, Lyon, Fuchs, & Barnes, 2007), there is an ongoing debate on the basis of dyslexia, whether it is related to impaired visual processing or impaired phonological processing.

1.1. Memory in Dyslexia

Dyslexia is a disorder without clear-cut boundaries or a given single cause (Snowling, 2012). As previously stated, one of the most debated questions is regarding whether the cause of dyslexia is of a linguistic nature, such as a phonological deficit (Ziegler & Goswami, 2005; Ramus & Szenkovits, 2008), or related to more general impairment, such as perceptual or visuospatial deficits (Romani, Tsouknida, di Betta, & Olson, 2011) or impaired working memory (WM) and executive function (Menghini, Finzi, Carlesimo, & Vicari, 2011).

It has also been claimed that SLDs are associated with impairments in WM (Schuchardt *et al.*, 2008). WM can be defined as the ability to simultaneously hold and manipulate information over a short period of time (Abd Ghani, 2013). As corresponding to Baddeley's WM model, which provides a global workspace which is responsible for rehearsal and choosing and operating strategies (Baddeley, Eysenck, & Anderson, 2009). In the original form of the model, introduced in 1974, the model has three systems; one controller and two slave systems (Baddeley & Hitch, 1974). The controller is a central executive which is basically responsible for general processing capacity, and issues that are not straight or assigned to slave systems within the model are evaluated and controlled. The phonological loop is one of the slave systems which deals with verbal content, and it has a phonological store to hold information for a short period of time, and an articulatory rehearsal component where memory traces can be revived. The other slave system is called the visuospatial sketchpad and deals with visual information. Another component, the episodic buffer, was introduced to the model later. The episodic buffer is thought to be controlled by the central executive, and can retrieve information through conscious awareness (Baddeley, 2000).

WM has a key role in the ability to follow information while engaging in effortful activities such as following instructions, sustaining attention, and complex reasoning. Memory deficits are strongly accompanied with reading difficulties (Kipp & Mohr, 2008). The coding, storage, and retrieval of stable associations between written language and speed are key processes in learning reading. There is a requirement to hold associations between sounds and letters, and subsequently build these new associations in order to be able to read. Thus, memory impairments are important when individuals who are poor at reading are required to decode complex words (Fuchs, Fuchs, & Compton, 2012). Problems on WM tasks tend to be greater in children who have problems in both decoding and reading comprehension (Swanson, Zheng, & Jerman, 2009).

Previous studies (Kibby, Marks, Morgan, & Long, 2004; Schuchardt *et al.*, 2008) have shown that younger students with a WM deficit typically experience dyslexia that is usually associated with impairments in the visuospatial sketchpad, phonological loop and central executive. WM is considered to be a component critical for word learning (Alt, 2011). According to McLoughlin, Fitzgibbon, and Young (1994), WM impairment is one of the major defining characteristics of dyslexia. Furthermore, WM and short-term memory (STM) have been the most widely investigated cognitive processes in the last 30 years in children with reading disabilities (Swanson *et al.*, 2009).

On the other hand, there is a controversy over the idea that WM deficits lead to dyslexia. The verbal component of WM, a system with limited capacity that stores information from various sources, has been found to be impaired in individuals with dyslexia (Menghini *et al.*, 2011). Visual processing is also thought to play a role in word recognition, whereas phonological processing is accepted as the main component affecting reading ability. Researchers have emphasized that impairments in phonological processing have a critical role in deficits in the development of dyslexia (Kibby *et al.*, 2004; Menghini *et al.*, 2011). Also, according to Baddeley, Gathercole and Papagno (1998), the phonological loop is responsible for learning language. This is because it is considered to be responsible for the encoding and rehearsal of novel information before creating long term memory.

It should also be mentioned that measuring WM using both visual and auditory tasks is important because of its nature and its relationship with SLDs (Baddeley & Hitch, 1974). Moreover, phonological stimulation appears during various levels of bottom-up and top-down processes that may impair performance on visual and auditory tasks (Kershner, 2016). In the current study, phonological processing was measured using digit span tasks. Whereas the performance of dyslexic children on visuospatial tasks has been ignored in previous studies, it is required to gain an effective understanding of visuospatial problems. According to Smith-Spark, Fisk, Fawcett and Nicolson (2003), studies of dyslexia should use visuospatial tasks to control for confounding phonological processes. It was found that long-term memory problems in children with dyslexia are not only caused by phonological deficits, but also comprise visuospatial problems (Menghini, Carlesimo, Marotta, Finzi, & Vicari, 2010). Moreover, visuospatial memory was found as a predictor of first grade mathematics achievement in children (Moll, Göbel, Gooch, Landerl, & Snowling, 2016). Pennington (2006) stated that dyslexia could be related with not only one but multiple cognitive dysfunctions. In the current study, the processing of visuospatial WM performance was measured in addition to the processing of phonological WM.

It has been claimed that children with learning difficulties are a heterogeneous group, and they should be evaluated in subgroups. Even though there are studies examining the differences between verbal and numerical domains of WM in children with learning disabilities, the results are still unclear (Peng & Fuchs, 2016). Phonological representations are fundamental in order to be able to read successfully (Melby-Lervåg, Lyster, & Hulme, 2012), and failure in these representations may be the main cause of the difficulties experienced by dyslexic children when they learn to read (Hulme & Snowling, 2009). Even though previously underlying cognitive deficits should be distinguished from reading disorder (RD) and mathematics disorder (MD), risk factors could be shared between these disorders (Moll *et al.*, 2016).

Evidence from neuropsychological research has revealed that the numerical domain differs from the verbal domain amongst children with learning disabilities (Cappelletti, Butterworth, & Kopelman, 2001). According to Woodward and Baxter (1997), children who have poor numerical ability generally are lacking from mental representations of problems, and this situation leads to more constant problems in areas of mathematics. To manage this situation, children need to change the structure of visual imagery to phonological stimuli, however this can be difficult. Moreover, children with RDs display verbal and numerical deficits in their WM and their verbal deficits same as children MDs. However, children with MDs reveal more severe numerical WM deficits (Peng & Fuchs, 2016). Identifying the brain structures associated with specific deficits in WM found in dyslexic children is not easy and it is open to discussion (Menghini *et al.*, 2011).

1.2. Intelligence and Dyslexia

Another key issue in dyslexia research is its association with the concept of intelligence. The importance of WM lies behind not only memory, but also its various connections with other cognitive processes, for example the central executive and fluid intelligence (Sidles, MacAvoy, Bernston, & Kuhn, 1987). Even though the current literature indicates that children with reading difficulties and average intelligence have problems with memory tasks, there is no evidence regarding differences related to intelligence (Swanson *et al.*, 2009). Although intelligence is associated with the executive system, it is generally not accepted as a main indicator. The role of intelligence in reading and reading problems is an important topic, but discrepancy between measured and actual performance of intelligence is still controversial. The main difficulty is to verify reading failure that may be a consequence of such a particular deficit in an exceedingly standard operation, instead of a failure of general learning mechanisms underpinned by intelligence (e.g. Anderson, 2008; Anderson & Nelson, 2012). Fluid intelligence such as, is related to the management of complex memory span performances (Engle, Kane, & Tuholski, 1999), and Conway, Cowan, Bunting, Therriault, and Minkoff (2002) found strong relationship between WM and fluid intelligence. In addition, Engle and colleagues (1999) have clarified the distinction between WM and STM, pointing to a strong relationship between WM capacity and fluid abilities. Fluid intelligence is widely measured using Raven's Standard Progressive Matrices (RSPM) test. The RSPM has been demonstrated be a good measurement of fluid intelligence (Engle *et al.*, 1999; Conway *et al.*, 2002) and also it is a good indicator of general intelligence (Carroll, 1993). RSPM is a non-verbal fluid intelligence test where respondents are required to identify relevant visual features depending on spatial organization (Yuan, Qin, Wang, Jiang, Zhang, & Yu, 2012) and prevents language-based problems, as it is a culture and language-free measurement of intelligence (Raven, Raven, & Court, 2004). To illustrate, Sidles and colleagues (1987) found no significant differences between children from two different countries in terms of RSPM scores and concluded that RSPM is a "culture fair measure of non-verbal mental processing". Since RSPM is a non-verbal pattern-completion test, it is considered as a good test for dyslexia by also considering WM. Therefore, it is important to investigate the relationship between WM performance and dyslexia while controlling for non-verbal fluid intelligence performance.

1.3. The Goal of Study

Memory is a complex process, has different types and consists of subcomponents namely encoding, storage, and retrieval. When examining possible memory problem in a sample, an accurate approach is to examine whether the problem is specifically relates with a particular type of memory, and/or which subcomponent is problematic. As summarized above section role of the memory in SLD is still controversial. Thus, the main goal of this study was to determine, or rule out, role of memory functions in children with dyslexia and compared to MLD, and undiagnosed children (controls). It is important to investigate whether children with dyslexia are impaired at word recognition and recognition of other complex non-word visual objects. Based on a recent meta-analysis (Kershner, 2016), impaired word and also visual object recognition in children with dyslexia would be expected. Kershner (2016) also revealed that both children and adults with dyslexia display functional abnormalities within the left fusiform gyrus. The fusiform gyrus is a part of in the ventral visual stream and is associated with recognition of words, faces, and other objects. We assumed that reading difficulty of people with dyslexia might be associated with a general high-level visual deficit. Thus, we measured WM (with verbal material), object recognition memory (with non-verbal material) and digit span (with number) in children with dyslexia and compared performance with children with other MLDs, and healthy controls.

Previous literature suggests that the inclusion and diagnostic criteria of children with dyslexia has a crucial point to enlighten its nature. To solve this problem, the eligibility criteria and selection procedure aimed to be well-defined. Intelligence tests (e.g. Wechsler Intelligence Scale for Children – WISC) are the most commonly used method for assessing dyslexia. However, in the present study, other additional components are thought to be related to dyslexia and memory (Smith-Spark *et al.*, 2003) that were measured as control measures, such as reading speed (Menghini *et al.*, 2011) and fluid intelligence (Swanson *et al.*, 2009).

2. Method

2.1. Participants

Fifty-four children (28 male) were recruited for participation in the study. All participants were native Turkish speakers and they were split into three groups of equal number: participants diagnosed with MLD (n = 18; 10 male), participants with a dyslexia diagnosis (n = 18; 11 male), and participants with no diagnosis (controls, n = 18; 7 male). Participants were aged between 8 and 12 (M = 9.77, SD = 1.41) (see Tab. 1). These three groups were matched in terms of age and level of education and there was no significant difference between groups in terms of age (p = .19) and level of education (p = .12). Diagnosed groups were selected for research purpose from a group of children who suffered in school and were diagnosed with dyslexia or MLD (diagnosed with dyscalculia and dysgraphia) at special education centers and private clinics by child psychiatrists. They were diagnosed through standardized clinical psycho-educational assessments battery including: family interview, Wechsler Intelligence Scale for Children (WISC-R), Gesell Developmental Test, Bender-Gestalt tests, Visual additive digit span, Turkish reading and writing test, Mathematic assessment, Child Behavior Check List (CBCL), and clinical interview. WISC-R was used to differentiate learning disabilities of children as it was the latest version of the test which has been used in Turkey to diagnose dyslexia and learning difficulties at the time of data collection. Finally, children with dyslexia and MLD were diagnosed according to DSM-IV and ICD-10 standards. Comorbidities such as attention deficit hyperactivity disorder were excluded. Control group was recruited from public and private schools after official permission was obtained from school' principals. In addition, participants were eligible if they were right-handed to control the aliasing effect of hemispheric asymmetry on cognitive abilities, reported normal or corrected-to-normal vision, had no neurological or psychiatric disorders, and were familiar with using computers.

Table 1 - *Age distribution according to group status*

Group	Age	*f*	%
Dyslexia	8-10	12	66.6
	11-12	6	33.4
Mixed Learning Difficulties	8-10	13	72.2
	11-12	5	27.8
Control	8-10	11	61.1
	11-12	7	38.9

2.2. Materials

2.2.1. Fluid Intelligence

Raven's Standard Progressive Matrices (RSPM) was designed to assess general aptitude, WM, task switching, and visual-spatial perception (Raven, Raven, & Court, 2004). RSPM is typically a nonverbal task to minimize the impact of language skills on performance. The Turkish language version of RSPM was adapted by Karakas (2004). The test contains five 12-item subtests, which are progressively difficult. Each item in the test comprises a pattern with one piece missing. Participants were asked to identify the correct missing piece from a series of possible answers. All items were presented in black ink on a white background. The test was administered to participants without any intervention or time limit. Possible scores RSPM range from 0 to 60.

2.2.2. Working memory task

This task was adapted from Harkin and Kessler (2009). Capital letters were presented on a grey background in a 2×3 matrix covering an area of 300×420 pixels. The task consisted of 3 stages. In stage one, a fixation cross was displayed for 1000ms, followed by four letters displayed four of the six possible locations. The location of the letters was random. Participants were given 1000ms to encode the identity and location of each letter. In the second stage after 500ms, participants were required to identify the location of a specific letter. Participants used a computer mouse to indicate the letter's location and were given 2000ms to respond. In the third stage, participants were required to decide whether the letter had been part of the encoded set or not (probe-1). Whether the probe-1 letter had previously been displayed which determined whether a trial was resolvable or misleading (irresolvable). In a baseline condition, probe-1 this was omitted to measure WM performance on the primary task under ideal conditions.

A 5 inter-stimulus interval of 500ms duration separated Probe-1 and Probe-2. Since baseline trials did not include the intermediate Probe-1, a grey screen was displayed for 5500ms between encoding and Probe-2 (equaling the ISI between encoding and Probe-2 on the other trial types). Probe-2 was the actual memory test for each trial and required participants to identify if a letter was correctly located with respect to its location in the originally encoded set (2000ms). In all trials the Probe-2 letter had been part of the encoded set, but the probe location was correct on only 50% of the trials. Finally, a scale was displayed prompting participants to indicate their degree of confidence in their Probe-2 response (6 levels: 1 = totally certain to 6 = totally uncertain).

2.2.3. Object recognition task (ORT)

The ORT task (Arslan-Durna, 2015; Başer, 2015) consisted of three stages. In the first stage, 15 unfamiliar geometric shapes were displayed sequentially in the center of the computer screen, on a grey background. Participants had 1000ms to encode and memorize the shapes. Following the presentation of every shape, in the first phase (short term memory: STM) participants were shown a 4x4 matrix, with boxes filled with 15 distractor shapes and one target shape. Participants were asked to identify the target shape by using the computer mouse as quickly as they could in 2000ms. In the second phase (long term memory: LTM) 49 shapes were presented within a 7×7 matrix and participants were asked to identify the target shapes they had seen previously, using the computer mouse, with no time limit. The task lasted about 10 minutes. High response accuracy and short reaction times (RT) indicates higher performance on the task. The number of correct and incorrect responses and RT for each phase was recorded.

2.2.4. Digit span test

The Digit Span subtest of WISC-R comprises forward digit span (FDS) and backward digit span (BDS) tasks and was used to measure phonological WM performance. Participants were asked to repeat series of digits, with the number of digits increasing progressively. FDS was used to assess short-term auditory memory, sequencing, and simple verbal expression, whereas BDS was sensitive to deficits in WM. The test was validated in Turkish by Savaşır and Şahin (1995).

2.2.5. Reading speed

In order to assess reading ability, the reading speed of participants was assessed. Four different texts were chosen from participants' own Turkish lecture book and were matched to their age and level of education (Dağlıoğlu, 2010; Köksal, Demir, Bozbey, Oğan, Özkara, & Aktaş, 2010; Müftüoğlu & Bektaş, 2011; Bıyıklı & Öztaş, 2012). Children read the text aloud for one minute, and the number of correct words was recorded. There were 219 words for second class, 244 words for the third grade, 371 words for fourth grade and 421 words for fifth grade children. The number of correct words read aloud during the reading task was recorded.

2.3. Procedure

After the necessary approval were obtained from the Bahçeşehir University Ethics Committee, data were collected from schools, and private and public special education centers in Istanbul, Turkey. Data were collected between November, 2014 and January, 2015. Firstly, the researcher introduced the aim and the procedure of the study to both principals of the centers and parents of children. Following this, informed consent was obtained from the parents. After consent was gained, assessments were conducted in one session in an appropriate testing room. Assessments lasted approximately 90 minutes for each participant with small breaks between tasks. The socio-demographic form was completed first. In order to control for order effects, the order of tasks was counter balanced across participants.

3. Results

Prior to the statistical analyses, data were screened for missing values and outliers (Tabachnick & Fidell, 2007). Results revealed that there were no missing values, nor univariate ($|z| \geq 3.30$) or multivariate outliers (Mahalanob is distance: $p < .001$). In accordance with the hypothesis of the current study, analyses were conducted and reported below. As we mentioned at previous section, memory performances of three groups may contribute unique variance after controlling for their fluid intelligence and chronological age, even though participants' age were matched. Thus, to control this issue, we first compared three groups' RSPM total score, and then for all group comparisons RSPM and age were analyzed as covariates. Group comparison results were reported for each memory task separately at following sections. Although, MLD group consists of different type of diagnosis (e.g., dyscalculia and dysgraphia), due to lack of participant number, analyses were not conducted for these participants separately.

3.1. Fluid intelligence performance

One-way analysis of variance (ANOVA) was performed to investigate differences between the dyslexic, MLD, and healthy control groups on fluid intelligence performance (RSPM total score). ANOVA was conducted using RSPM total score as a dependent variable and group type as an independent variable. The results indicated that there was an effect of group type on RSPM total score, $F_{(2,51)} = 12.85$, $p < .001$. The control groups RSPM total score ($M = 39.17$, $SD = 6.44$) was significantly higher than the MLD group ($M = 29.44$, $SD = 5.90$); and dyslexic group's performance on RSPM total score ($M = 34.83$, $SD = 4.81$) was significantly higher than MLD group ($M = 29.44$, $SD = 5.90$). However, there was no significant difference between control and dyslexia groups on RSPM total score. Result indicated that MLD group's fluid intelligence score significantly lower than both dyslexia and control groups, on the other hand as expected, there was no significant difference between control and dyslexia groups in terms of fluid intelligence score. Thus, we decided to control for fluid intelligence scores by adding it as a covariate for further comparisons.

3.2. Working memory performance

To investigate the group effects on WM performance after controlling for fluid intelligence scores, a multivariate analysis of covariance (MANCOVA) was conducted. Numbers of correct and incorrect responses, confidence rates and RT on WM task were dependent variables, on the other hand group type was independent variable, and fluid intelligence scores and age were covariates. The results demonstrated that neither age nor fluid intelligence performance as covariates were not significant. Therefore, a multivariate analysis of variance (MANOVA) was conducted and the results showed the main effect of group type on number of correct and incorrect responses for Probe-1 and Probe-2 and RT during confidence rating was significant ($F \geq 5.55$, $p \leq .05$). Table 2 shows the between subject effects on WM task variables.

Table 2 - *Effect of group status on WM task variables: MANOVA results*

WM task variables	*F*	η^2	*Post Hoc*
Correct Probe-1	17.26***	.40	C > D > M
Incorrect Probe-1	10.89***	.30	M > D > C
Correct Probe-1 RT	2.07	.08	
Incorrect Probe-1 RT	.03	0	
Correct Probe-2	22.15***	.47	C > D = M
Incorrect Probe-2	10.79***	.30	D = M > C
Correct Probe-2 RT	.9	.03	
Incorrect Probe-2 RT	1.05	.04	
Confidence Accuracy	2.41	.09	
Confidence RT	5.55*	.18	D > C

* $p < .05$, *** $p < .001$
Abbreviations: RT = Reaction Time, C = Control, D = Dyslexia, M = Mixed Learning Difficulties

Table 3 displays mean and standard deviations of significant values. Post-hoc analysis (Tukey HSD) indicated that the number of correct responses in Probe-1 was significantly higher in the control group in comparison to the dyslexia and MLD groups. The number of incorrect responses in Probe-1 was significantly higher for the MLD group compared to dyslexia and control groups. The number of correct responses in Probe-2 was significantly higher in the control group, compared to dyslexia and MLD groups. The number of incorrect responses in Probe-2 was significantly different for control group compared to dyslexia and MLD groups. Lastly, the dyslexia group's RT for confidence accuracy was significantly higher than control group.

Table 3 - *Mean and standard deviations of reading speed, RAVEN, FDS, BDS, WM and ORT task performance according to group status*

Group	Variables	*M*	*SD*	Variables	*M*	*SD*
Dyslexia	Reading Speed	12.32	9.96	FDS	4.89	.26
MLD		10.43	7.26		4.00	.26
Control		25.98	18.77		6.28	.26
Dyslexia	Correct Probe-1	19.11	3.53	BDS	3.89	.21
MLD		15.28	3.25		2.94	.21
Control		22.61	4.37		4.72	.21
Dyslexia	Incorrect Probe-1	7.06	2.78	Correct Visual STM	15.78	.91
MLD		10.44	3.60		12.28	.91
Control		4.89	4.27		20.44	.91
Dyslexia	Correct Probe-2	12.39	3.91	Incorrect Visual STM	11.50	.87
MLD		11.00	3.14		12.22	.87
Control		19.11	4.55		7.33	.87
Dyslexia	Incorrect Probe-2	11.28	3.95	Correct Visual LTM	8.61	.84
MLD		10.28	2.70		6.61	.84
Control		6.39	3.24		16.22	.84
Dyslexia	Confidence RT	3563.30	259.29	Correct Visual STM RT	3507.14	121.13
MLD		3011.22	259.29		3896.58	121.13
Control		2343.05	259.29		3466.99	121.13
Dyslexia	Raven	34.83	4.84			
MLD		29.44	5.90			
Control		39.48	6.43			

Abbreviations: MLD = Mixed Learning Difficulties; FDS = Forward Digit Span, BDS = Backward Digit Span, STM = Short Term Memory, LTM = Long Term Memory, RT = Reaction Time

3.3. Object recognition, digit span, and reading speed performance

To investigate the group effects on ORT, digit span tasks and reading speed, a MANCOVA was performed. Numbers of correct and incorrect responses, confidence rates, and RTs on ORT, FDS and BDS tasks and reading speed were used as dependent variables, with group type as independent variable, while age and RSPM total score were covariates. The results demonstrated that except FDS score, neither age nor fluid intelligence performance as covariates were not significant. Results showed that there was a main effect of group type on numbers of correct and incorrect responses for ORT-STM; numbers of correct responses for ORT-LTM, RT for correct responses for ORT-STM, FDS, BDS and reading speed ($F \geq 3.84$, $p \leq .05$). Table 4 shows the between subject effects on ORT, FDS, BDS and reading speed variables. Table 3 shows mean and standard deviations of significant values. Post hoc analysis revealed that for all significant differences, the control group performed better than MLD and dyslexia groups.

Table 4 - *Effect of group status on ORT, FDS, BDS and reading speed performance: MANOVA results*

Dependent Variables	*F*	η^2	*Post Hoc*
Correct ORT-STM	20.41***	.44	C > D > M
Incorrect ORT-STM	9.24***	.27	D = M > C
Correct ORT-LTM	36.79***	.59	C > D = M
Incorrect ORT-LTM	.02	.00	
Correct ORT-STM RT	3.84*	.13	M > C
Incorrect ORT-STM RT	1.09	.04	
Correct ORT-LTM RT	1.08	.04	
Incorrect ORT-LTM RT	.19	.01	
FDS	19.09***	.43	C > D = M
BDS	17.16***	.40	C > D > M
Reading Speed	7.71***	.23	C > D > M

* $p < .05$, *** $p < .001$
Abbreviations: ORT = Object Recognition Task, FDS = Forward Digit Span, BDS = Backward Digit Span, STM = Short Term Memory, LTM = Long Term Memory, RT = Reaction Time, C = Control, M = Mixed Learning Difficulties, D = Dyslexia

3.4. Correlations among the study variables

Pearson correlations were calculated to investigate relationships between FDS, BDS, RSPM, ORT, and WM tasks. Results presented at Table 5.

Except the number of incorrect responses at ORT-LTM task, 53 correlations out of 60 were significantly correlated.

Table 5 - *Pearson Correlations among the cognitive variables*

	1	2	3	4	5	6	7	8	9	10	11	12
1. FDS	1											
2. BDS	.71**	1										
3. Raven	.58**	.53**	1									
4. Correct ORT-STM	.63**	.56**	.77**	1								
5. Incorrect ORT-STM	-.52**	-.39**	-.66**	-.83**	1							
6. Correct ORT-LTM	.46**	.52**	.46**	.64**	-.53**	1						
7. Incorrect ORT-LTM	-.15	-.09	-.30*	-.25	.18	.03	1					
8. WM-Correct Probe-1	.62**	.60**	.62**	.70**	-.57**	.51**	-.34**	1				
9. WM-Incorrect Probe-1	-.62**	-.50**	-.54**	-.68**	.54**	-.35**	-.35**	-.85**	1			
10. WM-Correct Probe-2	.48**	.49**	.46**	.58**	-.40**	.69**	-.19	.70**	-.56**	1		
11. WM-Incorrect Probe-2	-.39**	-.37**	-.26	-.42**	.30*	-.43**	.21	-.55**	.51**	-.71**	1	
12. WM-Confidence	.26	.37**	.22	.42**	-.32*	.24	-.19	.48**	-.49**	.44**	-.37**	1

* $p < .05$; ** $p < .01$
Abbreviations: FDS = Forward Digit Span, BDS = Backward Digit Span, ORT = Object Recognition Task, STM = Short Term Memory, LTM = Long Term Memory; WM = Working Memory

3.5. Discriminant function analysis

To investigate which memory performance is the best predictor for distinguishing the three groups a direct discriminant analysis was performed using nine memory variables namely, FDS, BDS, RSPM total score, ORT correct responses at STM and LTM, WM correct response at probe-1 and probe-2, and WM confidence as predictors of membership in three groups (dyslexic, MLD, and controls). Statistically significant homogeneity of variance-covariance matrices ($p < .01$) was observed, however, so a non quadratic procedure was used. The overall Chi-square test was significant (*Wilks* λ = .24, *Chi-square* = 67.82, *df* = 16, *Canonical correlation* = .847, $p < .001$). Two discriminant functions calculated but only one function was significant. The significant function extracted accounted (Eigenvalues) for nearly 93.5% of the variance in groups confirming the hypothesis. The structure (loading) matrix of correlations between predictors and discriminant functions as seen in Table 6 suggested that the best predictors for distinguishing the three groups (first function) is correct response for ORT-LTM, FDS, and WM correct response for probe-2, respectively. As seen in Table 6, prediction accuracy distinguishing three groups of ORT-LTM was 66%, FDS was 46%, and WM correct response for probe-2 was 25%. Reclassification of cases based on the new canonical variables was highly successful: 84.4% of the cases were correctly reclassified into their original categories.

Table 6 - *Results of discriminant function analysis*

	Correlations of Predictors with Functions		Predicted Group Membership			
Predictor variable	1	2	Groups	Dyslexia	MLD	Control
FDS	.46	-.39	Dyslexic	12 (67%)	3 (16.7%)	3 (16.7%)
BDS	.07	.54	MLD	4 (22.2%)	14 (77.8%)	0 (0%)
Raven	.10	.33	Control	1 (5.6%)	0 (0%)	17 (94.4%)
Correct ORT STM	.03	.02				
Correct ORT LTM	.66	-.21				
Correct Probe-1	.05	.75				
Correct Probe-2	.25	-.73				
Confidence Accuracy	-.03	.00				
Canonical R	.85	.39				
Eigenvalue	2.540	.177				

Abbreviations: ORT = Object Recognition Task, FDS = Forward Digit Span, BDS = Backward Digit Span, STM = Short Term Memory, LTM = Long Term Memory, MLD = Mixed Learning Difficulties

4. Discussion

The present study aimed to investigate cognitive dysfunction in dyslexia. Fluid intelligence, WM, short-term and long-term object recognition memory and reading speed performances of children with dyslexia were compared with children with MLD, and healthy controls. Results indicated that MLD group’s fluid intelligence score was significantly lower than both dyslexia and control groups, on the other hand as expected, there was no significant difference between control and dyslexia groups in terms of their fluid intelligence scores. However, dyslexia group's WM, object recognition memory and reading speed performance was significantly poorer compared to other groups. Children with MLD, on the other hand, performed poorer on RSPM, WM, ORT, digit span and reading speed compared to other children. We also found that correct response for ORT-LTM, FDS, and WM correct response for probe-2 (respectively) were the best predictors for distinguishing the three groups.

As mentioned earlier, our results showed that although MLD group's fluid intelligence score was lower than the other groups, children with dyslexia and control groups did not differ by their fluid intelligence scores. In line with this finding, using non-verbal tests with children with dyslexia may provide a better understanding of fluid intelligence, as children with dyslexia have verbal deficits. On the other hand, (Lobier, Zoubrinetzky, & Valdois, 2012) found that dyslexic children demonstrated an impairment for non-verbal categories and concluded that this finding should be explained as due to a visual processing deficit rather than a phonological one. Furthermore, it has been accepted that the basis of dyslexia stems from language problems. Some researchers have proposed that dyslexia is a linguistic-based problem, claiming that the poor cognitive performance of children with dyslexia is a result of difficulty in phonological processing (Ziegler & Goswami, 2005; Fletcher *et al.*, 2007; Ramus & Szenkovits, 2008). Menghini *et al.* (2011) suggested that dyslexia is due to an impairment in decoding written language and reducing in this capacity. Kramer, Knee and Delis (2000) also found that acquisition of novel information rather than retrieving it was main problem related with verbal memory difficulties in children with dyslexia. Therefore, it may be concluded that dyslexia is not an intelligence problem, but a primarily linguistic one.

The WM task (Harkin & Kessler, 2009) was used in our study was developed based on Baddeley's WM model, and required processing of both verbal and visual stimuli simultaneously. First, participants were asked to identify the location of a displayed letter (Probe-1) and secondly, to decide whether the displayed location was correct or not (Probe-2). Participants were required to both learn the identity of a letter and also needed to remember the location of the letter as corresponding to role of visuospatial sketch path and requiring the episodic buffer too. The visuospatial sketch pad and phonological loop have limited capacities in maintaining single items and integrate those items in terms of their color, orientation, phonemes, meanings and so on (Harkin & Kessler, 2009). In the WM tasks in current study, participants were required to maintain and integrate the letter itself and its location. Our results demonstrated that compared to controls, children with dyslexia performed significantly poorer in both identifying the location of letters, as well as deciding the accuracy of presented items. The dyslexic group made more incorrect responses than the control group. Additionally, the dyslexia group's RTs during confidence ratings for the recalled items were significantly longer than the control groups. In other words, individuals with dyslexia were slower than controls during the confidence decision. Jeffries and Everatt (2004) found that children with dyslexia (without comorbid difficulties) and children with comorbid difficulties had more problems with phonological tasks than controls, and children with dyslexia performed worse on rhyming tasks than both controls and children with comorbid difficulties. Another study also found that efficiency in word reading was affected by WM through phonological awareness (Knoop-van Campen, Segers, & Verhoeven, 2018). This result indicated that problems in WM affect phonological awareness which would be related to reading problems in children with dyslexia. Therefore, both WM and phonological awareness seem important in dyslexia group. Moreover, Maehler and Schuchardt (2011) found that children with dyslexia showed phonological loop problems (e.g. lower memory spans for images, numbers etc.), and central executive (e.g. counting span, backward span for words and digits), but children with dyscalculia revealed impairments with the visuospatial sketchpad (e.g. a lower memory span for patterns and locations). The authors also mentioned that there is a lack of evidence related to any differences between these groups in term of discrepant information processing. Jeffries and Everatt (2004) concluded that measures of phonological processing indicate most consistent differences between participants with dyslexia and controls. Therefore, WM impairments based on the phonological loop process tend to be greater for children with dyslexia and these impairments should be measured by investigating both phonological and visual stimuli due to the nature of WM.

In the light of the results of the current study, and given the paucity of the current literature, it can be concluded that the dyslexia group's poor performance on WM task arises from the nature of WM in general. WM demands phonological processing, and this phonological processing is a key feature of WM responsible for the temporary storage of verbal information

(Swanson *et al.*, 2009). The ability of children with dyslexia to use phonological processing has been found to be impaired, suggesting that the cause of dyslexia has a special linguistic nature such as a phonological deficit (Ziegler & Goswami, 2005; Ramus & Szenkovits, 2008), which leads to WM impairments (Menghini *et al.*, 2011). Children with dyslexia face phonological processing difficulties which are associated with more a general dysfunction comprising WM problems and its executive functions.

To assess short-term and long-term recognition memory for non-verbal stimulus, an ORT was used (Arslan-Durna, 2015; Başer, 2015). In the ORT, participants were required to encode and memorize nonsense shapes, and then their ability to recognize them was measured. The results demonstrated that children with dyslexia showed poorer performance on both short-term and long-term object recognition compared to the control group. Similar with the WM task in the ORT dyslexia group recognized less objects and made more errors than controls. It is important to evaluate the visuo-spatial performances of children with learning disabilities because although previous research has shown that children with dyslexia show impairment on visuospatial tasks, the importance of visuospatial function in dyslexia has been largely neglected (Smith-Spark *et al.*, 2003). While there are some studies that have demonstrated normal visuospatial WM ability in children with dyslexia (Jeffries & Everatt, 2004; Kibby *et al.*, 2004), others have found the direct opposite (Olson & Datta, 2002; Smith-Spark & Fisk, 2007).

According to domain-specific theories of dyslexia by Unsworth and Engle (2007), the performance of children with dyslexia on non-verbal memory tasks would not be expected to differ from controls. These tasks are assumed not to require phonological processes, and so if dyslexia is a language-specific problem rather than a deficit in general cognitive processes, including processing of non-verbal stimuli, then children with dyslexia would be expected to be as good as healthy controls at processing non-verbal materials. However, our results failed to support domain-specific theories about dyslexia. Also, Fostick and Revah (2018) found that both WM and auditory temporal processing are impaired in dyslexia. Therefore, they concluded that dyslexia is not caused by a single deficit, but it is related to a combination of parallel impairments on different levels. In that sense, dyslexia could be evaluated as a being a general deficit related to perceptual, attentional, and visuospatial processes, rather than a core phonological deficit.

Our discriminant analysis showed that in addition to FDS score, correct response during ORT and correct response during WM at probe-2 were significantly discriminate the three groups, and ORT score was the strongest predictors among them. According to Cowan (2011, 2016), domain-general factor, which should be considered, is related to attentional impairment and attention capacity. Previously showed that (e.g., Valdois, Bosse, & Tainturier, 2004; Lobier, Peyrin, Pichat, Le Bas, & Valdois, 2014; Perez, Poncelet, Salmon, & Majerus, 2015) during categorization of verbal or nonverbal stimuli, activations at brain areas related to visual attention and right superior parietal region reduced for a subset of children with dyslexia presented attentional deficits. These results suggest that the memory problem in dyslexia may be related to the problem in the coding phase. In conclusion, the previous studies and our findings indicated that the memory problem in dyslexia is a multi-component problem involving both verbal and non-verbal different types of memory, and the attention might mediate these problems.

Our results also showed that digit span performances were significantly lower for the dyslexia group compared to the controls. Digit span has been used to evaluate STM, WM and attention. The task has been found to be a good method of measuring verbal STM capacity due to relying on practiced strategies and skills such as rehearsal and chunking (Conway *et al.*, 2002). Digit span is considered to be a common method of evaluating phonological STM capacity (Maehler & Schuchardt, 2011). Children with different types of SLD diagnosis often suffer from an attention problem, and it has been mentioned that children with SLDs suffer from deficits related to different cognitive, attentional and behavioral components (Tabassam & Grainger, 2002). It had been accepted that verbal and numeric spans are decreased in children with dyslexia compared to healthy controls (for a review, Snowling, 2000).

Regarding attentional problems in dyslexia, it has been proposed that impairments in the central executive could be a common cause of learning disabilities (Peng & Fuchs, 2016). It is strongly suggested that atypical right hemisphere activation in dyslexia might be task-specific and linked to the enrollment of cognitive control attentional processes (Kershner, 2016). Additionally, according to Boden and Giaschi (2007), reading problems in dyslexia are related to a magnocellular system that is associated with both visual and visuo-spatial attention (Schulte-Körne & Bruder, 2010). Dyslexia is not a reading difficulty but it is related to the difficulties with decoding single words (Vellutino, Fletcher, Snowling, & Scanlon, 2004). Although these children show deficits in both domains of WM across, deficits in the central executive are more distinctive in children with dyslexia and are especially related to reading difficulty. Therefore, it could be stated that children with specific learning disabilities and dyslexia display attention deficits.

Reading speed has been a focus in dyslexia studies (Ziegler, Perry, Ma-Wyatt, Ladner, & Schulte-Körne, 2003; Spinelli, De Luca, Di Filippo, Mancini, Martelli, & Zoccolotti, 2005). Our results revealed that children with dyslexia were significantly slower than controls in a reading task. This finding was consistent with the existing literature regarding dyslexia and reading speed (De Luca, Borrelli, Judica, Spinelli, & Zoccolotti, 2002; Ziegler *et al.*, 2003; Spinelli *et al.*, 2005). Menghini and colleagues (2011) found that the average reading speed of children with dyslexia was slower than the compared to age-matched controls. In addition, it was found that readers with dyslexia are sensitive to the number of letters of words and pseudo words, and this indicates less effective use of orthographic knowledge (Marinus & de Jong, 2010). It has been shown that children with dyslexia perform much slower and make more errors than aged-matched participants with normal reading levels (Vellutino *et al.*, 2004; Marinus & de Jong, 2010).

The discussion above was particularly focused on the differences between dyslexic children and controls. On the other hand, our study investigated a third group consisting of children with MLD. Some of these children suffered from either specific mathematics problems, specific reading problems or both. We found that the MLD group's performances on WM, ORT, DS and reading speed were significantly poorer than both control and dyslexia groups. It had been expected that the lower performance on tasks was because of their heterogeneous features and their reporting of both mathematic and reading problems.

In conclusion, we found that children with dyslexia showed poor verbal and non-verbal WM compared to controls, although both groups' general intelligence score did not differ. More specifically, the present study found that children with dyslexia showed lower WM performance on both verbal and visual tasks compared to healthy controls. The lower performance on non-verbal tasks in the dyslexia group can be evaluated as being due to a general encoding strategy problem (Harkin & Kessler, 2009; Alt, 2011). Digit span scores of dyslexia group also supported the idea that encoding strategy problem is one of the critical features of dyslexia. It could be said that the ability to encode, and the short-term retention of temporal sequences of events are impaired for children with dyslexia (Menghini *et al.*, 2011). Successful memory performance requires successful encoding, as more encoded information enables more retrieval. We concluded that due to their problematic encoding strategies, children with dyslexia showed poorer memory performances than controls. We believe that children with dyslexia cannot properly encode various aspects of both verbal and non-verbal; stimuli, and thus they cannot maintain and retrieve them.

There are some limitations of the current study. First, the sample sizes used were relatively small due to strict inclusion and exclusion criteria, and a larger sample size is crucial to examine the relationships between the variables that measured in this study. Future studies should focus on reaction time measures during memory performance to gather more detailed results about the nature of memory processes in dyslexia and MLD. Second, participants' intelligence scores and their level of learning disability were measured by Raven and WISC-R due to cultural availability of standardized versions of the tests. However, future studies should consider measuring intelligence with different measurement tools to control more reliable indicators of intellectual ability. Lastly, future studies should consider to control the socio-economic status of the participants (e.g. monthly family income) which was not controlled in current study.

References

Abd Ghani, K. (2013). *Working Memory Performance, Learning and Study Strategies and Learning Styles of Dyslexic and Non Dyslexic Adult Learners* (Doctoral dissertation, University of York).

Alt, M. (2011). Phonological working memory impairments in children with specific language impairment: Where does the problem lie? *Journal of Communication Disorders*, *44* (2), 173-185. doi: 10.1016/j.jcomdis.2010.09.003.

Anderson, M. (2008). What can autism and dyslexia tell us about intelligence? *Quarterly Journal of Experimental Psychology*, *61* (1), 116-128. doi: 10.1080/17470210701508806.

Anderson, M., & Nelson, J. (2012). Individual differences and cognitive models of the mind: Using the differentiation hypothesis to distinguish general and specific cognitive processes. In J. Duncan, L. Philips & P. McLeod (Eds.), *Measuring the Mind Speed, Control, and Age* (pp. 89-112). New York: Oxford Press. doi: 10.1093/acprof:oso/9780198566427. 003.0004.

Arslan-Durna, H. K. (2015). *Effects of violent game addiction on executive functions, response inhibition, and emotional memory*. (Unpublished master's thesis), Bahçeşehir University Institute of Social Science, Turkey. doi: 10.1007/978-3-319-29904-4_1.

Baddeley, A. (2000). The episodic buffer: a new component of working memory? *Trends in Cognitive Sciences*, *4* (11), 417-423. doi: 10.1016/ S1364-6613(00)01538-2.

Baddeley, A. D., & Hitch, G. (1974). Working memory. *In Psychology of Learning and Motivation*, *8*, 47-89. Academic Press. doi:10.1016/S0079-7421(08)60452-1.

Baddeley, A., Eysenck, M. W., & Anderson, M. C. (2009). *Memory*. New York, NY: Psychology Press.

Baddeley, A., Gathercole, S., & Papagno, C. (1998). The phonological loop as a language learning device. *Psychological Review*, *105* (1), 158. doi: 10.1037//0033-295x.105.1.158.

Başer, N. (2015). *Effects of violent game addiction on working memory, object recognition and visuo-spatial perception and its relationships with psychological factors.* (Unpublished master's thesis), Bahçeşehir University Institute of Social Science, Turkey.

Bishop-Liebler, P., Welch, G., Huss, M., Thomson, J. M., & Goswami, U. (2014). Auditory temporal processing skills in musicians with dyslexia. *Dyslexia*, *20* (3), 261-279. doi: 10.1002/dys.1479.

Bıyıklı H., & Öztaş, Y. (2012). *İlköğretim Türkçe 2 Ders Kitabı.* Ankara: Doku Yayıncılık.

Boden, C., & Giaschi, D. (2007). M-stream deficits and reading-related visual processes in developmental dyslexia. *Psychological Bulletin*, *133* (2), 346. doi: 10.1037/0033-2909.133.2.346.

Cappelletti, M., Butterworth, B., & Kopelman, M. (2001). Spared numerical abilities in a case of semantic dementia. *Neuropsychologia*, *39* (11), 1224-1239. doi: 10.1016/S0028-3932(01)00035-5.

Carroll, J. B. (1993). *Human cognitive abilities: a survey of factor-analytic studies*. New York: Cambridge University Press. doi: 10.1017/cbo9780511571312.

Conway, A. R., Cowan, N., Bunting, M. F., Therriault, D. J., & Minkoff, S. R. (2002). A latent variable analysis of working memory capacity, short-term memory capacity, processing speed, and general fluid intelligence. *Intelligence*, *30* (2), 163-183. doi: 10.1016/S0160-2896(01)00096-4.

Cowan, N. (2011). The focus of attention as observed in visual working memory tasks: making sense of competing claims. *Neuropsychologia*, *49* (6), 1401-1406. doi:10.1016/j.neuropsychologia.2011.01.035.

Cowan, N. (2016). Working memory maturation: can we get at the essence of cognitive growth? *Perspectives on Psychological Science: A Journal of The Association for Psychological Science*, *11* (2), 239-264.10.1177/1745691615621279.

Dağlıoğlu, E. (2010). *İlköğretim Türkçe 4 Ders Kitabı.* Ankara: Cem Veb Ofset.

De Luca, M., Borrelli, M., Judica, A., Spinelli, D., & Zoccolotti, P. (2002). Reading words and pseudowords: An eye movement study of developmental dyslexia. *Brain and Language*, *80* (3), 617-626. doi: 10.1006/brln.2001. 2637.

Engle, R. W., Kane, M. J., & Tuholski, S. W. (1999). Individual differences in working memory capacity and what they tell us about controlled attention, general fluid intelligence and functions of the prefrontal cortex. In A. Shah, & P. Shah (Eds.), *Models of Working Memory: Mechanisms of Active Maintenance and Executive Control* (pp. 102-134). New York: Cambridge University Press. doi: 10.1017/CBO9781139174909.007.

Fletcher, J. M., Lyon, G. R., Fuchs, L. S., & Barnes, M. A. (2007). *Learning disabilities: From identification to intervention.* New York: The Guilford Press. doi: 10.1080/09297040701455171.

Fostick, L., & Revah, H. (2018). Dyslexia as a multi-deficit disorder: Working memory and auditory temporal processing. *Acta Psychologica, 183*, 19-28. doi:10.1016/j.actpsy.2017.12.010.

Fuchs, L. S., Fuchs, D., & Compton, D. L. (2012). The early prevention of mathematics difficulty: Its power and limitations. *Journal of Learning Disabilities, 45* (3), 257-69.doi: 10.1177/0022219412442167.

Harkin, B., & Kessler, K. (2009). How checking breeds doubt: Reduced performance in a simple working memory task. *Behavior Research and Therapy, 47* (6), 504-512. doi: 10.1016/j.brat.2009.03.002.

Hulme, C., & Snowling, M. J. (2009). *Developmental Disorders of Language, Learning and Cognition*. Chichester, UK: Wiley-Blackwell. doi: 10.1111/j.1471-3802.2010.01151_1.x.

Jeffries, S., & Everatt, J. (2004). Working memory: Its role in dyslexia and other specific learning difficulties. *Dyslexia, 10* (3), 196-214. doi: 10.1002/dys.278.

Karakas, S. (2004). *BİLNOT bataryası el kitabı: Nöropsikolojik testler için araştırma ve geliştirme çalışmaları.* Ankara: DizaynOfset.

Karande, S., Sawant, S., Kulkarni, M., Galvankar, P., & Sholapurwala, R. (2005). Comparison of cognition abilities between groups of children with specific learning disability having average, bright normal and superior nonverbal intelligence. *Indian Journal of Medical Sciences, 59* (3), 95. doi: 10.4103/0019-5359.15085.

Kershner, J. R. (2016). Network dynamics in dyslexia: Review and implications for remediation. *Research in Developmental Disabilities*, *59*, 24-34. doi: 10.1016/j.ridd.2016.07.014.

Kibby, M. Y., Marks, W., Morgan, S., & Long, C. J. (2004). Specific impairment in developmental reading disabilities a working memory approach. *Journal of Learning Disabilities, 37* (4), 349-363. doi: 10.1177/00222194040370040601.

Kipp, K. H., & Mohr, G. (2008). Remediation of developmental dyslexia: Tackling a basic memory deficit. *Cognitive Neuropsychology*, *25* (1), 38-55. doi:10.1080/02643290701836138.

Knoop-van Campen, C. A., Segers, E., & Verhoeven, L. (2018). How phonological awareness mediates the relation between working memory and word reading efficiency in children with dyslexia. *Dyslexia*, *24* (2), 156-169. doi:10.1002/dys.1583.

Köksal, K., Demir, E., Bozbey, S., Oğan, M., Özkara, M. & Aktaş, A. (2010). *İlköğretimTürkçe 3 DersKitabı.* Ankara: Özgün Matbaa.

Kramer, J. H., Knee, K., & Delis, D. C. (2000). Verbal memory impairments in dyslexia. *Archives of Clinical Neuropsychology*, *15* (1), 83-93.doi:10.1093/arclin/15.1.83.

Lobier, M. A., Peyrin, C., Pichat, C., Le Bas, J. F., & Valdois, S. (2014). Visual processing of multiple elements in the dyslexic brain: evidence for a superior parietal dysfunction. *Frontiers in Human Neuroscience*, *8*, 479. doi: 10.3389/fnhum.2014.00479.

Lobier, M., Zoubrinetzky, R., & Valdois, S. (2012). The visual attention span deficit in dyslexia is visual and not verbal. *Cortex*, *48* (6), 768-773. doi: 10.1016/j.cortex.2011.09.003.

Luo, Y., Wang, J., Wu, H., Zhu, D., & Zhang, Y. (2013). Working-memory training improves developmental dyslexia in Chinese children. *Neural Regeneration Research*, *8* (5), 452. doi: 10.3969/j.issn.1673-5374.2013. 05.009.

Maehler, C., & Schuchardt, K. (2011). Working memory in children with learning disabilities: Rethinking the criterion of discrepancy. *International Journal of Disability, Development and Education*, *58* (1), 5-17. doi: 10. 1080/1034912X.2011.547335.

Marinus, E., & de Jong, P. F. (2010). Variability in the word-reading performance of dyslexic readers: Effects of letter length, phoneme length and digraph presence. *Cortex*, *46* (10), 1259-1271. doi: 10.1016/ j.cortex.2010.06.005.

McLoughlin, D., Fitzgibbon, G., & Young, V. (1994). *Adult Dyslexia: Assessment, Counselling and Training*. London: Whurr Publishers Ltd.

Melby-Lervåg, M., Lyster, S. A. H., & Hulme, C. (2012). Phonological skills and their role in learning to read: a meta-analytic review. *Psychological Bulletin*, *138* (2), 322. doi: 10.1037/a0026744.

Menghini, D., Finzi, A., Carlesimo, G. A., & Vicari, S. (2011). Working memory impairment in children with developmental dyslexia: is it just a phonological deficit? *Developmental Neuropsychology*, *36* (2), 199-213. doi: 10.1080/87565641.2010.549868.

Menghini, D., Carlesimo, G. A., Marotta, L., Finzi, A., & Vicari, S. (2010). Developmental dyslexia and explicit long-term memory. *Dyslexia*, *16* (3), 213-225. doi: 10.1002/dys.410.

Moll, K., Göbel, S. M., Gooch, D., Landerl, K., & Snowling, M. J. (2016). Cognitive risk factors for specific learning disorder: processing speed, temporal processing, and working memory. *Journal of Learning Disabilities*, *49* (3), 272-281. doi: 10.1177/0022219414547221.

Müftüoğlu, A., & Bektaş, S. (2011). *İlköğretim Türkçe 5 Ders Kitabı.* İstanbul: FCM Yayınları.

Olson, R., & Datta, H. (2002). Visual-temporal processing in reading-disabled and normal twins. *Reading and Writing*, *15*, 127-149. doi: 10.1023/ A:1013872422108.

Peng, P., & Fuchs, D. (2016). A meta-analysis of working memory deficits in children with learning difficulties: Is there a difference between verbal domain and numerical domain? *Journal of Learning Disabilities*, *49* (1), 3-20. doi: 10.1177/0022219414521667.

Pennington, B. F. (2006). From single to multiple deficit models of developmental disorders. *Cognition*, *101* (2), 385-413. doi: 10.1016/ j.cognition.2006.04.008.

Perez, M. T., Poncelet, M., Salmon, E., & Majerus, S. (2015). Functional alterations in order short-term memory networks in adults with dyslexia. *Developmental Neuropsychology*, *40* (7-8), 407-429. doi: 10.1080/ 87565641.2016.1153098.

Ramus, F., & Szenkovits, G. (2008). What phonological deficit? *The Quarterly Journal of Experimental Psychology*, *61* (1), 129-141. doi: 10.1080/17470210701508822.

Raven, J. R., Raven, J. C., & Court, J. H. (2000, updated 2004). *Manual for Raven's Progressive Matrices and Vocabulary Scales* [Section 3: The standard progressive matrices]. San Antonio, TX: Harcourt Assessment.

Romani, C., Tsouknida, E., di Betta, A. M., & Olson, A. (2011). Reduced attentional capacity, but normal processing speed and shifting of attention in developmental dyslexia: Evidence from a serial task. *Cortex*, *47* (6), 715-733. doi: 10.1016/j.cortex.2010.05.008.

Savaşır, I., & Şahin, N. (1995). *Wechsler Çocuklariçin Zeka Ölçeği (WISC-R) El Kitabı.* Ankara: Türk Psikologlar Derneği Yayınları.

Schuchardt, K., Maehler, C., & Hasselhorn, M. (2008). Working memory deficits in children with specific learning disorders. *Journal of Learning Disabilities*, *41* (6), 514-523. doi: 10.1177/0022219408317856.

Schulte-Körne, G., & Bruder, J. (2010). Clinical neurophysiology of visual and auditory processing in dyslexia: a review. *Clinical Neurophysiology*, *121* (11), 1794-1809. doi: 10.1016/j.clinph.2010.04.028.

Sidles, C., MacAvoy, J., Bernston, C., & Kuhn, A. (1987). Analysis of Navajo adolescents' performances on the Raven progressive matrices. *Journal of American Indian Education, 27* (1), 1-8.

Smith-Spark, J. H., & Fisk, J. E. (2007). Working memory functioning in developmental dyslexia. *Memory*, *15* (1), 34-56. doi: 10.1080/09658210601043384.

Smith-Spark, J. H., Fisk, J. E., Fawcett, A. J., & Nicolson, R. I. (2003). Investigating the central executive in adult dyslexics: Evidence from phonological and visuospatial working memory performance. *European Journal of Cognitive Psychology*, *15*, 567-587. doi: 10.1080/09541440340000024.

Snowling, M. (2000). *Dyslexia: A Cognitive Developmental Perspective*. Oxford: Blackwell. doi: 10.1017/s0142716400008936.

Snowling, M. J. (2012). Seeking a new characterization of learning disorders. *Journal of Child Psychology and Psychiatry*, *53* (1), 1-2. doi: 10.1111/j.1469-7610.2011.02505.x.

Spinelli, D., De Luca, M., Di Filippo, G., Mancini, M., Martelli, M., & Zoccolotti, P. (2005). Length effect in word naming in reading: Role of reading experience and reading deficit in Italian readers. *Developmental Neuropsychology*, *27* (2), 217-235. doi: 10.1207/s15326942dn2702_2.

Swanson, H. L., Zheng, X., & Jerman, O. (2009). Working memory, short-term memory, and reading disabilities: A selective meta-analysis of the literature. *Journal of Learning Disabilities*, *42* (3), 260-87. doi: 10.1177/0022219409331958.

Tabachnick, B. G., & Fidell, L. S. (2007). *Using Multivariate Statistics* (5th ed.). Boston MA: Allyn & Bacon/Pearson Education.

Tabassam, W., & Grainger, J. (2002). Self-concept, attributional style and self-efficacy beliefs of students with learning disabilities with and without attention deficit hyperactivity disorder. *Learning Disability Quarterly*, *25* (2), 141-151. doi: 10.2307/1511280.

Unsworth, N., & Engle, R. W. (2007). On the division of short-term and working memory: an examination of simple and complex span and their relation to higher order abilities. *Psychological Bulletin*, *133* (6), 1038. doi: 10.1037/0033-2909.133.6.1038.

Valdois, S., Bosse, M. L., & Tainturier, M. J. (2004). The cognitive deficits responsible for developmental dyslexia: Review of evidence for a selective visual attentional disorder. *Dyslexia*, *10* (4), 339-363. doi: 10.1002/dys.284.

Vellutino, F. R., Fletcher, J. M., Snowling, M. J., & Scanlon, D. M. (2004). Specific reading disability (dyslexia): What have we learned in the past four decades? *Journal of Child Psychology and Psychiatry*, *45* (1), 2-40. doi: 10.1046/j.0021-9630.2003.00305.x.

Woodward, J., & Baxter, J. (1997). The effects of an innovative approach to mathematics on academically low-achieving students in inclusive settings. *Exceptional Children*, *63* (3), 373-388. doi: 10.1177/001440299706300306.

Yuan, Z., Qin, W., Wang, D., Jiang, T., Zhang, Y., & Yu, C. (2012). The salience network contributes to an individual's fluid reasoning capacity. *Behavioral Brain Research*, *229* (2), 384-390. doi: 10.1016/j.bbr.2012.01.037.

Ziegler, J. C., & Goswami, U. (2005). Reading acquisition, developmental dyslexia, and skilled reading across languages: a psycholinguistic grain size theory. *Psychological Bulletin*, *131* (1), 3-29. doi: 10.1037/0033-2909.131.1.3.

Ziegler, J. C., Perry, C., Ma-Wyatt, A., Ladner, D., & Schulte-Körne, G. (2003). Developmental dyslexia in different languages: Language-specific or universal? *Journal of Experimental Child Psychology*, *86* (3), 169-193. doi: 10.1016/S0022-0965(03)00139-5.