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Working memory capacity, and selective attention in older children with mathematics learning disabilities

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Abstract

Both verbal and visuospatial working memory adding to selective attention, have been examined in two groups (Mean age = 12.59 years old). One of the two groups displaying math learning disabilities (n=36), this group acts as an experimental group, and the other group without learning disabilities acts as a control group (n=36), the two groups were matched for age and IQ. The two groups presented with complex span tasks to assess working memory capacity (WMC), operation span task (OSPAN) used to assess verbal working memory capacity, symmetry span task used to assess visuospatial working memory capacity; the two previous tasks administrated automatically by using computers. Selective attention assessed in the two groups by using colored square task (CST) that used for assessing visual selective attention and it administrated automatically.

Results revealed that performance of children with MLD was lower than control group (typically achieving children) in both verbal and visuospatial working memory, moreover, the two groups differed in the number of correct responses (accuracy) in visual selective attention for typically achieved children, but there is no significant difference between them in response time (speed).

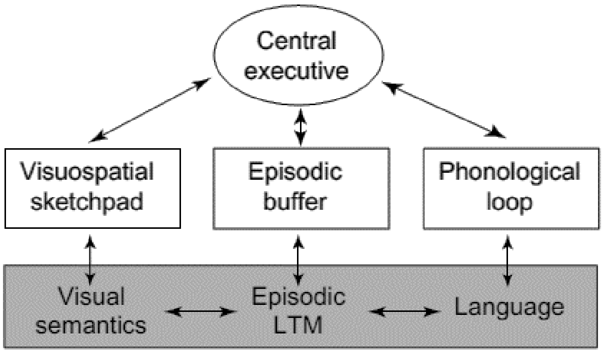
Keywords:

Working memory, working memory capacity, complex span tasks, selective attention, and mathematics learning disabilities.

1-Introduction

Mathematics play a great role in our daily life, and modern society; so acquiring basic mathematical skills is important for individual's future academic, and to do many common tasks in our life, such as: paying bills, developing a monthly budget and purchasing a house.(Bottge, 2001; McCloskey, 2007; Rotem & Henik, 2020). Therefore, any disability in mathematics will affect our life and goals. Many studies report a prevalence of mathematical learning disabilities between 3%-14%. (Badian, 1983; Barbaresi, Katuskic, Colligan, Weaver, & Jacobsen, 2005; Desoete, Praet, Titeca, & Deulemans, 2013; Geary, 2004; Geary, 2011; Geary, Hoard, Nugent, & Bailey, 2011; Mazzocco, Hanich, & Early, 2007; Mejias et al, 2012; Lewis, & Fisher, 2016; Shalev, 2007; Shalev, Manor & Gross-Tsur, 2005; Shin, & Byrant, 2016; Von Aster, & Shalev, 2007;). Mathematical learning disability refers to a specific learning disability affecting the normal acquisition of arithmetic skills (American Psychiatric Association, 2000). MLD characterized by a specific acquisition of mathematical skills such as basic numerical processing; learning arithmetic facts, applying arithmetic procedures, there is an agreement between researchers, that MLD has a neurobiological foundation, despite normal intelligence. (Berteletti et al, 2014; Butterworth & Laurillard, 2010; Geary, 2007; Landerl et al, 2009; Mazzocco, 2007; Rotzer et al, 2009; Temple, 1992). Many brain systems engaged in mathematical learning and consequently, any developmental deficit in any one of them should affect mathematical achievement. (Geary, 2010). Researchers try to determine the main cognitive aspects of MLD. (Berch & Mozzocco, 2002).

Working memory and executive functions play important roles in mathematical performance by providing flexible and efficient mental workspace, that necessary for processing and storing information simultaneously, inhibiting distractors to get access to working memory, and shifting between mental strategies. (Andersson, 2008; Fürst & Hitch, 2000; Logie, Gilhooly & Wynn, 1994; Seitz & Schumann-Hengsteler, 2000; Swanson, 2004). Working memory and working memory capacity (WMC) vary widely across people, and they predict higher-order cognitive abilities that influence academic achievement. (Engle, & Kane, 2004; Lawson, 2006). There is a consensus that working memory considered a core of human cognition. Over the last 40 years, working memory has aroused the most interest in cognitive psychology; so many models and definitions have proposed for it. Working memory generally refers to a cognitive system with a limited capacity, that responsible for active temporary storing, manipulation and retrieving of information in a simultaneous way in service of ongoing cognition. (Andrade, 2001; Ashcraft, 2002; Baddeley, & Hitch, 1974; Cowan et al, 2005; Downing, 2000; Geary et al, 2007; Little et al, 2014; Shipstead et al, 2014; Sigel & Ryan, 1989; Unsworth et al, 2009). Working memory consists of a supervisory component called central executive and (3) slave components served as storage buffers, phonological loop, visuospatial sketchpad, and episodic buffer. According to Baddeley's-Hitch multicomponent model, central executive considered as an attentional control system, it's also responsible for other regulatory functions such as control of action, problem-solving, coordinating between other slave components, regulating relationships between working memory and long term memory, the phonological loop (PL) store information with phonetic and verbal codes for a brief period, whereas visuospatial sketchpad (VSSP) is responsible for holding visual and spatial information, both PL and VSSP have limited capacity, episodic buffer a relatively new component is responsible for integrating of information from a variety of sources; to form meaningful chunks, it is assumed to be controlled by the central executive, and it forms an interface between long term memory (LTM) and the rest components of working memory (WM). (Baddeley, 86; 2000; 2007; Conway et al, 2001; Geary et al, 2007; Passolunghi & Mammarella, 2011; Srikon et al, 2012).



The Multi-component working model (Baddeley, 2000)

The term working memory capacity (WMC) has emerged in the past (30) years as a good predictor for many tasks (Conway et al, 2005). According to (Srikoon et al, 2012) WMC represents the ability to store, process, and access mental representation as need in order to support complex tasks. Nevertheless, (Shipstead et al, 2015) considered WMC as a reflection of individual differences in the system functions efficiently. (Minamoto et al, 2016) refers to WMC as proficiency in allocating limited attentional representation.

WMC predicts performance on a wide range of cognitive abilities, for example academic achievement (Cowan et al, 2005; Turner & Engle, 1989), imagery, reasoning and language comprehension (Bruyer & Scailquin, 1998; Engle et al., 1992; Kyllonen & Christal, 1990), emotion regulation (Kelider et al, 2009), problem-solving and decision making (Ash & Wiley, 2006; Copeland & Radvansky, 2004; Ricks et al, 2007; Shamosh et al, 2008), executive functions (McCabe, et al, 2010), predicts the ability to inhibit reflexive movements (Kane et al, 2001), attention focusing (Heirtz & Engle, 2007), ignoring powerful distractors (Conway et al, 2001), dichotic listening and stroop-effect (selective attention) (Colflesh & Conway, 2007; Kane et al, 2001, Kane & Engle, 2003), Furthermore WMC shares approximately 50% of its statistical variance with fluid intelligence (Kane et al, 2005).

In one of the first methodological attempt to measure working memory capacity, Daneman and Carpenter (1980) invented the reading span task. (Srikoon et al, 2012; Unsworth et al, 2009), recently many researchers using adding to reading ability, visuospatial ability and operated ability as a good measures for WMC that called complex span tasks (CST). Complex span tasks are highly predictive of an individual's performance across range of higher mental abilities. (Unsworth & Spillers, 2010; Unsworth et al, 2005). Complex span tasks reflect working memory system in a perfect way; because tasks contain two distinct components: (1) temporary storage (2) attention control (processing); so these tasks match with most famous and acceptable working memory model proposed by Baddeley and Hitch. (Baddeley, 1986; Conway et al, 2005; Pardo-Vazquez & Fernandez-Rey, 2008; Shipstead et al, 2015).

Building on the previous notions, a number of complex span tasks were subsequently designed and developed, initially, they administered individually and manually under the full supervision of the experimenter, recently these tasks have developed to be administered automatically by using computers; this allows applying on a group of subjects. For all of the different tasks, there are some basic common requirements of storage and processing, for example, complex span tasks require subjects to store and remember a series of serially presented items, the to be remembered (TBR) items is followed by a processing task and it must be finished before the presentation of the next item, processing tasks, and TBR items differ from one task to another, for instance, processing tasks include making logic judgments about reading or listening sentences, solving mathematical equations or judging on the symmetry of some patterns, also in the TBR items may include words, letters, digits, spatial locations or images, in all cases the TBR items have to be recalled in the same order in which they had appeared. (Mrazek et al, 2013; Sanchez et al, 2010; Shipstead et al, 2014; Unsworth et al, 2009).

In cognitive psychology, there is a constitutional question about how our brains selectively attend to certain aspects; allowing them for deeply processing while ignoring other aspects (Conway et al, 2001). The external environment contains vast dynamics; so our brain has to own flexible mechanisms to manipulate the intended information that necessary for our goal-directed tasks. (Elliott & Giesbercht, 2015). One of the most important flexible mechanisms in our brain is selective attention. Selective attention is the ability to focus awareness on relevant stimuli and ignoring distractors in the environment. (Butler, 1983; Gazzaly & Nobre, 2012; Hopfinger et al, 2001). Recently a growing literature of psychological and neurological studies has shown a great overlap between working memory and selective attention. (Chun, 2011; Cowan, 1995; Postle, 2006; Awh & Jonides, 2001; Awh et al, 2006). According to (Bengson & Mangun, 2011) they are closely related because they share the selection of task-relevant information, the both have limited capacities, for many years researchers considered attention as a gate that controls and determines sensory information that allowed to pass into working memory. But (Downing, 2000) tested this classical view and his results revealed that relationships between the two cognitive functions work in the two opposite directions, truly attention select the information that has to pass into working memory, but in the same time working memory determines the action of the attentional filter. One of the most widely accepted theories, that explains the relationships between working memory and attention is the controlled working memory theory of attention. (Engle & Kane, 2004; Kane, Bleckley, Conway, & Engle, 2001). According to (Colflesh & Conway, 2007) there is a domain-general component of working memory responsible for guiding and controlling attention. Working memory may operate in an environment contains a great number of irrelevant information; the ability to select goal-relevant information from the environment is driven by executive attention that equates working memory capacity. (Engle, 2002; Kane et al, 2007, shipstead, 2014).

A large number of studies investigate working memory in children with mathematics learning disabilities. (Passolunghi & Mammarella, 2011; D'Amico & Passolunghi, 2009; Passolunghi & Siegel, 2004; Geary, 2007; Rotzer et al, 2009). There are inconsistencies in the results of studies on the deficits in working memory for MLD. In the study of (Geary et al, 2007), the central executive was the fundamental source of deficits across math cognition tasks that applied to the sample, visuospatial sketchpad, and phonological loop participated in increasing math cognition deficits. In the study of (Passolunghi & Mammarella, 2011), results revealed that MLD children have lower scores than typically developed (TD) children in both simple and complex spatial WM tasks, but the two groups are similar in visual WM tasks, also MLD children performed poorly on complex span tasks than simple span tasks, whether TD children performance did not differ between the two-span tasks. (Mclean & Hitch, 1999; Lander et al, 2009) confirmed that MLD children have a normal phonological loop. In their review (Swanson & Jerman, 2006) analyzed studies published between 1983-2002 on the cognitive performance for MLD students beginning with kindergarten through adolescent compared to TD students, they revealed that MLD has many cognitive disorders in multiple cognitive functions including verbal working memory, visuospatial working memory, and short term memory words. (Andersson & Ostergen, 2012) Concluded that it is difficult to make confirmed conclusions about what aspect is impaired in working memory for MLD children.

Attention plays a great role in learning; so teachers and parents give it high importance especially in children with learning problems. (Ek et al, 2004). (Johnson, Altmaier, and Richman, 1999) proposed that LD can be accompanied by attention disorders, and at the same time, the attention problems complicate LD. Researches indicated that children with LD showed lower performance comparing with TD children in speed (response time) and accuracy (response error) of attention. (Aman & Turbott, 1986; Casco & Prunetti, 1996; Casco, Tressoldi, & Dellantonio, 1998; Lockwood, Marcotte, & Stern, 2001; Vidyasagar & Pammer, 1999;

Williams, Brannan, & Lartigue, 1987) In (Wang & Huang, 2012). In a neuroimaging study (Hari, Renvall & Tanskman, 2001) revealed that there is a functional selective attention deficit in dyslexic peoples. As for mathematics learning disabilities specifically, some studies indicate disorders in shifting ability and functions of attention. (Bull & Johnston, 1997; Bull، Johnston, & Roy, 1999; McLean & Hitch, 1999; van der Sluis, de Jong ، & Van der Leij, 2004). In (Anderson & Ostergen, 2012).Whereas other studies revealed that MLD children don't display deficits in processing speed (response time). (Chan & Ho, 2010; Van der Sluis et al, 2004; Willburger, Fussenegger, Moll, Wood & Lander, 2008) In (Anderson & Ostergen, 2012)

2- Current Study

The present study designed to explore working memory, and selective attention for MLD students, the study aimed to investigate:

1- Verbal (phonological) working memory for MLD students in order to solve paradoxes at this point.
2- Visuospatial working memory for MLD
3- Selective attention by measuring accuracy and speed for MLD students

3- Method

3.1. Participants

All students of grade 7 (n=266) with a mean age of 12.59 years old participated in raven's standard progressive matrices. 28 students which have IQ less than 88 (percentile rank less than 25) were excluded, also another 8 students have been excluded after examining the school psychologist records because of the presence of some health disorders, and some of the students belonged to families with socio-economical disadvantages; so the rest sample is (190) students. After that, students' scores obtained in the first math exam for the academic year 2019/2020 from the actual exam paper score, without adding degrees of activities to reflect the real student's achievement. The learning disabled students in mathematics diagnosed by subtracting the standard score of IQ (IQ Z- Scores) and standard scores of mathematics (math Z-Scores), the students diagnosed as MLD if the subtraction result (Discrepancy result) exceeded more than (1) standard score, this can conclude as MLD students = IQ Z-Score – Math Z-Score = more than (1) Z-Score. Finally (36) students diagnosed as MLD students, also (36) normal students were selected by matching them to MLD students in IQ; so we have (2) groups: experimental group (MLD) students (no=36) and control group or normal students (no=36), the total (72) students (44 boys and 28 girls).

3.2. Tests and materials

3.2.1. Automated Operation Span Task (AOSpan)

This task used for assessing verbal working memory, it consists of two simultaneous tasks, in the first participants solved a series of math operations, then indicate whether a presented answer is correct or not by clicking on the words yes or no (V.I the math operation presented in Arabic digits). For example 2+4-3= 2 Yes or No in Arabic ٢+٤-٣= ٢ نعم أم لا
The present time for each math operation is 3 seconds, after that, 10 they see an Arabic letter and try to store it, the letter presentation time is 1200 milliseconds. Three trials of each list length (2-5) were presented for total 42 tasks, after 2 to 5 such processing and storage presentations a recall grill is presented, and participants have to click on the letters they stored during the trial in the correct serial order, the recall grid consists of 12 unrelated Arabic letters (ي – ل – س – ص – ط – د - ر- ج – ف – ب – م - و), the order of list length varied randomly. The score computed automatically according to the sum of letters recalled in the correct serial position, regardless of whether the entire trial recalled correctly. There are three practice tasks before proceeding to the real tasks:
1-Storage task only
2-Processing task only
3-Processing-Storage task, that is identical to real tasks in its nature.
Presentations times for letters (storage) and math operation (Processing) is computed in an independent pilot study, statistical reliability and validity were calculated, Pearson's correlation coefficient between (AOSpan) and Raven's Standard Progressive Matrices (RSPM) is 0.685* (significant at 0.01 level), Kuder-Richardson formula

21 used for assessing reliability, the value is 0.925* (significant at 0.01 level). (Conway et al, 2001; Redick et al, 2012; Unsworth et al, 2009; 2013)

3.2.2. Automated Symmetry Span Task (ASymSpan)

This task used for assessing visuospatial working memory; it consists of two simultaneous tasks. In the first participants saw 8*8 matrix with some squares filled in black, and the rest are white (unfilled), participants have to decide whether this matrix is symmetrical about its vertical axis or not, the pattern was symmetrical half of the time, directly after that, participants were presented with 4*4 grid all of its squares is white (unfilled) except one filled with red, participants ordered to store the red square location, at recalling participants recalled the sequences of red square locations in the same order they appeared by clicking on the cells of an empty matrix. The presentation time for the processing task is 3 seconds, and the presentation time for the storage task is 1500 millisecond, these times were determined in an independent pilot study. Like operation span task three trials of each list length 2-5 presented for total 42 tasks, the order of list length varied in a random arrangement. There are three practice tasks before proceeding to the real tasks:

1-Storage task only

2-Processing task only

3-Processing-Storage task that is identical to real test tasks in its nature.

The Score is computed automatically according to the sum of red squares locations in the correct serial position regardless of whether the entire trials were recalled correctly. Statistical reliability and validity were calculated, Pearson's correlation coefficient between (ASymSpan) and Raven's Standard Progressive Matrices (RSPM) is 0.554* (significant at 0.01 level), Kuder-Richardson formula 21 used for assessing reliability, the value is 0.87* (significant at 0.01 level). (Shipstead et al, 2013; 2014; Unsworth et al, 2009; 2013)

3.2.3. Colored Square Task (CST)

This task used for assessing visual selective attention, the idea of this test depends on the presence of a target stimulus between irrelevant stimuli that called distractors, participants have to respond quickly as possible according to the target stimulus color by pressing on some keyboards keys. Practically on the computer screen, subjects see three-colored squares that equal in area, but they can differ in their colors, subjects ordered to focus on the middle square color and ignore the rest squares:

Subjects have to press on the right arrow key → in the keyboard if the target square is red or green, and if the target square color is blue or yellow, they have to pre ss on the left arrow key ← in the keyboard. The test consists of two parts (1) practice tasks (2) real tasks, in the practice task, participants have to finish two trials after that, they see a final screen showing the number of correct answers and false answers, also displaying the average response time (RT), the real tasks consist of three sessions, each session consists of (24) trials, each session separates from that follows by a break for (10) seconds and this break screen displays also the number of correct and false answers adding to the average response time (RT). Before beginning, the practice tasks and real tasks participants see a digital counter that counts down from 10 to zero to be steady. The presentation time for colored squares was calculated in a pilot study adding to the response time, the colored square presentation time was 600 millisecond and the response time was 1000 millisecond. Statistical reliability and validity were calculated, Pearson's correlation coefficient between CST and Raven's Standard Progressive Matrices (RSPM) is 0.518*(significant at 0.01 level), Kuder-Richardson formula 21 used for assessing reliability, the value is 0.94* (significant at 0.01 level). (Bundesen et al, 2012; Nieuwenthuis et al, 2006; Rouder, 2003)

3.3. Results

The collected data were analyzed by SPSS for both learned disabled and normal students by using one-way MANOVA

Table (1) Descriptive Statistics

	Groups	Mean	Std. Deviation	N
Number of Correct responses	learning disabilities	41.9444	14.42011	36
	normals	53.3333	13.86877	36
	Total	47.6389	15.17253	72
Response Time	learning disabilities	5.2489E2	137.64878	36
	normals	5.0033E2	164.99489	36
	Total	5.1261E2	151.37032	72
Verbal Working Memory Capacity	learning disabilities	26.8333	7.61390	36
	normals	32.0556	6.26530	36
	Total	29.4444	7.40553	72
Visuo-spatial Working Memory Capacity	learning disabilities	21.3889	9.05942	36
	normals	28.1111	5.88353	36
	Total	24.7500	8.30535	72

Table (2) Box's test of equality of covariance matrices

Box's M	34.364
F	3.224
df1	10
df2	2.343E4
Sig.	.000

P = 0.001; so the null hypothesis has to be rejected because the observed covariance matrices are equal

Table (3) Multivariate tests

Effect		Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared
Intercept	Pillai's Trace	.982	9.281E2[a]	4.000	67.000	.000	.982
	Wilks' Lambda	.018	9.281E2[a]	4.000	67.000	.000	.982
	Hotelling's Trace	55.408	9.281E2[a]	4.000	67.000	.000	.982
	Roy's Largest Root	55.408	9.281E2[a]	4.000	67.000	.000	.982
Groups	Pillai's Trace	.274	6.324[a]	4.000	67.000	.000	.274
	Wilks' Lambda	.726	6.324[a]	4.000	67.000	.000	.274
	Hotelling's Trace	.378	6.324[a]	4.000	67.000	.000	.274
	Roy's Largest Root	.378	6.324[a]	4.000	67.000	.000	.274

The table shows that groups (Normals vs. Learning disability) have a significant influence on the independent variables (verbal, visuospatial working memory, and visual selective attention)

Table (4) Leven's test of homogeneity of error variances

	F	df1	df2	Sig.
Number of Correct responses	.993	1	70	.322
Response Time	.500	1	70	.482
Verbal Working Memory Capacity	1.937	1	70	.168
Visuo-spatial Working Memory Capacity	3.875	1	70	.053

From this box, we can reject the null hypothesis for all tests because the error variances are not significant.

Table (5) Tests of between subjects effect

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	Number of Correct responses	2334.722[a]	1	2334.722	11.665	.001	.143
	Response Time	10853.556[b]	1	10853.556	.470	.495	.007
	Verbal Working Memory Capacity	490.889[c]	1	490.889	10.098	.002	.126
	Visuo-spatial Working Memory Capacity	813.389[d]	1	813.389	13.941	.000	.166
Intercept	Number of Correct responses	163401.389	1	163401.389	816.430	.000	.921
	Response Time	1.892E7	1	1.892E7	819.547	.000	.921
	Verbal Working Memory Capacity	62422.222	1	62422.222	1.284E3	.000	.948
	Visuo-spatial Working Memory Capacity	44104.500	1	44104.500	755.933	.000	.915
Groups	Number of Correct responses	2334.722	1	2334.722	11.665	.001	.143
	Response Time	10853.556	1	10853.556	.470	.495	.007
	Verbal Working Memory Capacity	490.889	1	490.889	10.098	.002	.126
	Visuo-spatial Working Memory Capacity	813.389	1	813.389	13.941	.000	.166
Error	Number of Correct responses	14009.889	70	200.141			
	Response Time	1615967.556	70	23085.251			
	Verbal Working Memory Capacity	3402.889	70	48.613			
	Visuo-spatial Working Memory Capacity	4084.111	70	58.344			
Total	Number of Correct responses	179746.000	72				
	Response Time	2.055E7	72				
	Verbal Working Memory Capacity	66316.000	72				
	Visuo-spatial Working Memory Capacity	49002.000	72				
Corrected Total	Number of Correct responses	16344.611	71				
	Response Time	1626821.111	71				
	Verbal Working Memory Capacity	3893.778	71				
	Visuo-spatial Working Memory Capacity	4897.500	71				

The table shows that the disability (normal vs. disabled) has a highly significant influence on the number of correct responses in selective attention but has no significant effect on response time; also, disability has a significant influence on both verbal working memory capacity and visuospatial working memory capacity.

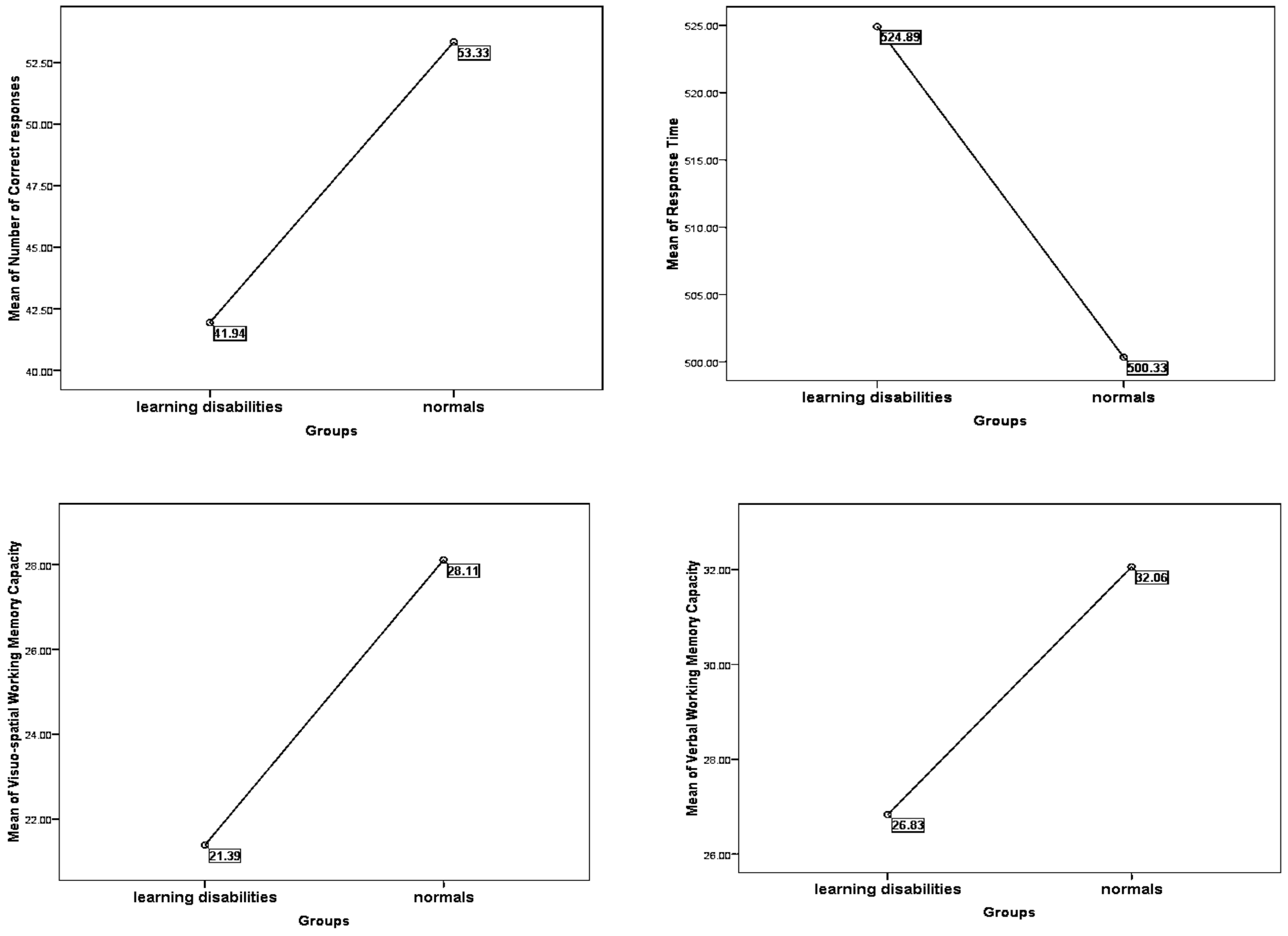


Figure (1) Profiles for learned disabled and normal in both WMC and visual selective attention

3.4. Discussion

Many types of research revealed that children with specific learning disabilities have deficits in working memory, and MLD students showed obvious deficits in central executive and the visuospatial sketchpad. (Mahler & Schundart, 2009). In addition (Narimoto et al, 2013) revealed that visuospatial working memory in non-verbal learning disabilities children has deficits in simple storage (passive storage) adding to deficits in complex span tasks (positive storage). According to (Masoura, 2006) MLD, children's central executive is unable to activate enough information from long-term memory to integrate between two passive stores in working memory (phonological loop and the visuospatial sketchpad. Deficits in visuospatial working memory for MLD students cause disabling of some cognitive processes such as information manipulation, storing, and allocating of attentional resources. (Swanson & Sigel, 2001). In the current study, results confirmed that MLD children have clear deficits in both temporary storage, and manipulation in visuospatial working memory and verbal working memory that measured by complex span tasks (symmetry and operation span tasks) comparing with their peers of typically achieved (TD) children who have efficient strategies to retrieve information from long term memory for integrating with temporarily stored information in working memory, also they have high working memory capacity in comparing with MLD children, and this gives them efficient ability to store items. In visual selective attention, TD (typically achieved) children have high working memory capacity; so they have more ability to suppress the irrelevant stimuli comparing with their peer children with low working memory capacity. (Ahmed & Defockert, 2012). It's known that MLD children have low working memory capacity, and a recent study confirmed that, so low working memory capacity affects negatively on visual selective attention efficiency because MLD children have deficits in the central executive that control attention and allocate attentional resources, so this allows irrelevant stimuli to make effective distortions and interference. (Peyrin, 2012) Confirmed that learned disabled students have visual attention span disorder that causes a decrease in the number of discrete visual elements that can be processed simultaneously in a visual scene.

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