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Investigation of differences in a new electronic test to detect working memory deficits of students with and without learning difficulties of secondary school

E Dimitriou [1, 2], A Ekonomou [1], P Roussos [1] and A Drigas [2, *]

[1] *Department of Psychology, National and Kapodistrian University of Athens.*
[2] *NetMediaLab Mind-Brain R&D, IIT, NCSR «Demokritos.*

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Abstract

The term "working memory" refers to our ability to retain and manipulate information in our minds for short periods. Recent research has linked its function to school performance, and it is strongly supported that deficits in working memory hinder the learning of some students, who are likely to face significant learning difficulties in both primary and secondary education. The purpose of this study is to investigate the differences in working memory functions of secondary school students with and without learning difficulties through the administration of a new electronic test developed for this purpose. A total of 262 secondary school students, 217 without learning difficulties and 45 with learning difficulties, who attended schools in Athens participated in the survey. The results showed that students with learning difficulties performed significantly worse on the tests than students without learning difficulties. The reliability and validity tests showed that the developed test is a valid and reliable tool.

Keywords: Intervention; Diagnosis Investigation; Electronic test; Working memory; Deficits; Learning difficulties; Secondary school

1. Introduction

"Working memory" refers to our ability to retain and manipulate information in our minds for short periods (Baddeley, 1986; Baddeley & Hitch, 1974; Gathercole & Alloway, 2004). According to Cowan (2017), this ability involves the temporary storage of a small amount of information for future access, including retaining information temporarily, renewing memory space, and managing information. It is a cognitive mechanism present in almost every daily activity and changes gradually from preschool to adulthood (Alloway & Alloway, 2013; Gathercole et al., 2004).

Various models have been developed by space researchers for interpreting the function of working memory. Instead of conflicting, these models complement each other. One influential model in cognitive psychology is the multilateral theoretical model of Baddeley & Hitch (1974). This model proposes that working memory is a system for temporarily retaining and manipulating information when performing cognitive tasks such as understanding, learning, and reasoning (Baddeley, 1986). The term "working memory" was introduced by Baddeley & Hitch (1974) to address the shortcomings of previous theoretical models and suggest that short-term memory functions as working memory.

Initially, Baddeley and Hitch's model of working memory included three components—the phonological loop, the visuospatial sketchpad, and the central executive which controls the other two subsystems. In later years, Baddeley added another system to the model called the episodic buffer to explain the influence of long-term memory on working memory contents (Baddeley 2000, 2021). The phonological loop processes verbal and auditory information and language production (Roussos 2011). The visuo-spatial sketchpad holds visual and spatial information (Baddeley,

* Corresponding author: A Drigas

2021). The episodic buffer is a system that integrates information from various sources into unified units of visual, spatial, and verbal information in chronological order (Baddeley, 2000).

In recent years, working memory has been a major focus for researchers in the field of cognitive psychology and has become one of the most discussed terms (Cowan, 2017). It is generally accepted that working memory plays a central role in various cognitive functions, including language comprehension, mental mathematical operations, reasoning, and programming (Oberauer et al., 2018). Working memory appears to impact the ability to learn, as learning requires retaining and accessing various information in memory (Porpodas, 2002). Most scholars agree that working memory is closely related to the learning process (Masoura, 2010), and while memory and learning are not identical, they are closely interconnected concepts (Sumrall et al., 2016).

Recent research suggests a link between working memory and school performance (El-Mir, 2019; Gathercole et al., 2006; Maehler & Schuchardt, 2016; Swanson et al., 2009). Working memory seems to be crucial for a wide range of school skills, such as reading and math, which heavily rely on working memory (Swanson & Kim, 2007). Given that the school environment is a space for learning and working memory is essential for almost all forms of classroom learning, deficits in working memory significantly impact a child's learning abilities (Masoura, 2010).

Based on Masoura's research in 2006, various studies have consistently shown a strong link between children's academic performance and their working memory function. Alloway & Alloway's 2010 study also suggests that working memory may be a more accurate predictor of academic learning in early school years compared to a child's IQ. Children with deficits in working memory require more time to store and manage complex information necessary for school learning, which could lead to learning difficulties and poor performance in primary and secondary school. Gathercole's 2014 research indicates that most students with poor working memory experience difficulties in reading, mathematics, and science throughout their primary and secondary education. Children with various learning disabilities often exhibit limited working memory, leading to issues in language (Alloway & Archibald; 2008 Ralli, 2021), reading (Gathercole et al., 2006), writing (Barreyro et al., 2009), mathematics (Chen et al., 2023; Deng et al., 2020; Wong et al., 2021), and other areas such as Attention Deficit Disorder (Ferreira, 2011), motor coordination disorder (Alloway, 2007), and the autistic spectrum (Alloway et al., 2009). About 70% of children with a specific learning disability in reading score very low on working memory tasks (Gathercole & Alloway, 2007)

Furthermore, studies by Swanson & Berninger in 1996 and others consistently show that children with learning disabilities demonstrate poor performance in working memory tests (Hulme & Mankenzie, 2014; Masoura, 2006; Zakopoulou al., 2019). According to Alloway et al. (2006), working memory continues to develop in children until mid-adolescence, but those with working memory problems experience a widening gap between their capacity and that of their peers, leading to increased learning difficulties.

1.1. Working memory and learning disabilities

The primary function of working memory is to facilitate and enhance the ability to encode, store, and retrieve information, which are necessary for learning and processing higher-level information. Working memory tasks require the person to retain one important piece of information while processing others. For example, when trying to solve a mathematical problem mentally, such as a two-digit multiplication, one should remember the two numbers, apply multiplication rules, store intermediate results simultaneously, and proceed to the next stage of the calculation. The project can only be completed if we manage to meet both the storage and processing requirements of the activity (Gupta & Sharma, 2017).

It is a fact that individuals have different memory capacities (Drew & Vogel, 2009). These differences in working memory capacity seem to have important implications for children's ability to learn and acquire new skills (Alloway et al., 2005). Information stored in working memory is easily lost due to overload or distractions. For instance, attempting to retain too much information or engaging in a demanding task may exceed the limits of working memory, leading to information loss. Similarly, distractions from irrelevant thoughts or external stimuli can also cause information to be lost. As a result, individuals with poor working memory abilities may struggle to meet the demands of working memory in various situations, such as in the classroom (Gathercole & Alloway, 2007). Consequently, students with working memory deficits may have difficulty remembering classroom instructions and performing tasks that require storing and processing information while keeping track of complex tasks (Gathercole & Alloway, 2008; Gathercole, et al., 2006).

Alloway et al. (2005) found that the severity of children's working memory deficits varies depending on the level of special educational needs. Children with significant learning disabilities were found to have larger deficits compared to those with mild learning disabilities. Therefore, specific learning difficulties are associated with deficits in working memory, especially in children with complex learning difficulties compared to children who only have numerical or reading difficulties (Chen et al., 2023; Deng et al., 2020; Gathercole, 2015; Van der Sluis et al., 2005; Wong et al., 2021).

Swanson and Siegel (2001) believe that the main cause of learning disabilities lies in the inherent limitations of working memory. The problems of students with learning disabilities are mainly rooted in the executive part of working memory. They struggle with self-regulatory mechanisms such as self-control, planning, testing, revision, and active effort for memory function. Furthermore, they face difficulties in projects that require general control and problem-solving strategies. The general limitations in control and monitoring hinder the effective use of working memory, leading to difficulties in processes such as selective attention, organization, and phonological coding (Swanson, 1999). Gathercole & Alloway (2008) theorize that the learning disabilities faced by these children arise because they are unable to meet the memory requirements of many structured learning activities. As a result, their working memory becomes overloaded, leading to the loss of critical information needed to continue an activity. They cannot proceed with the activity and complete it successfully unless they can access the critical information they need again (e.g. start a multiplication from scratch)which in turn, affects their ability to complete activities successfully and may result in mistakes. These failed attempts represent missed learning opportunities for a child, and the more frequent they are, the longer their progress in one or more areas will be delayed.

Individuals with learning disabilities often experience difficulties with working memory due to both neurobiological constraints and inefficient use of memory resources (Swanson, 2000). The strong connection between working memory deficits and various learning disabilities indicates that working memory assessment should be a standard practice when evaluating children for potential learning disabilities. Research findings suggest that working memory performance is a reliable tool for distinguishing between individuals with learning disabilities and those who may simply be slower learners (Swanson et al., 1990).

1.2. The necessity of our research

For the assessment of the working memory functions in secondary school students with learning difficulties in Greece, there is currently no specialized electronic tool available. Most existing tools focus on primary school students, have not been tested with the Greek population, or are not suitable for use by teachers. For example, the Working Memory Rating Scale (WMRS) has been tested only on primary school students (Alloway et al., 2016; Polytimou and Masoura, 2013). The Automated Working Memory Assessment (AWMA) is the first standardized tool for non-specialist evaluators, such as classroom teachers (Alloway et al., 2008; Drigas et al., 2015; Drigas et al., 2017), and has been used for research purposes (Polytimou, 2012; Chrysochoou et al., 2013). However, it has not been tested with the Greek population. Additionally, the WISC V test, which includes a working memory scale, is only administered by psychologists for intelligence assessment.

This research effort aims to address this gap by investigating the differences in the working memory functions of secondary school students with and without learning difficulties. It involves the administration of a new electronic test specifically designed for this purpose as part of a broader research initiative.

1.3. Research objectives and research questions

The main objectives of our research were:

- Constructing and carefully weighing a new electronic test to assess the working memory of secondary school students, both those with and without learning difficulties.
- Investigating the differences in performance between secondary school students with and without learning difficulties in the new electronic test.
- Verifying the reliability and validity of the test under construction.

1.4. The main research questions raised are as follows:

- Is the test we developed reliable and valid?
- Are there differences in the performance of secondary school students with learning difficulties (in reading and/or writing and/or mathematics and/or ADHD) and those without, specifically concerning their working memory functions?

We anticipated that the Working Memory Deficit Detection Test (W.M.D.D.T.) we developed would demonstrate good reliability and validity. Additionally, we expected that students with learning disabilities would perform less well on the tests compared to students without learning disabilities.

2. Material and methods

2.1. Participants

The total number of participants in our survey was 262 secondary school students from the Attica region. Of these, 217 students had no diagnosis of learning disabilities (LD), while 45 students had a diagnosis of LD (in reading and/or writing and/or mathematics and/or ADHD) by a recognized diagnostic body. The sample of participating students is considered as symptomatic as their participation was voluntary. For the participation of students, apart from their consent, we also secured the written consent of their parents. The average age of students without learning difficulties was 15.06 years (ranging from 12-18 years), while that of students with learning disabilities was 14.93 years (ranging from 13-18 years). There were 106 boys without learning disabilities and 111 girls without learning disabilities. In total, there were 24 boys with learning disabilities and 21 girls with learning disabilities.

2.2. Tools

2.2.1. The Test for the Detection of Working Memory Deficits

A new electronic tool called the Working Memory Deficit Detection Test (W.M.D.D.T.) has been developed for the purpose of our research. It is designed to assess the working memory functions of secondary school students. The test is accessible on a special platform and students need a specific code to log in. It consists of 20 subtests and is constructed based on the multistructural model of working memory proposed by Baddeley & Hitch (1974). Specifically, the W.M.D.D.T. includes subtests to evaluate the 3 dimensions of working memory: the phonological loop, the visuospatial sketchpad, and the central executive. However, it does not assess the episodic buffer added to the model by Baddeley (2000).

Especially:

These subtests can be categorized based on the specific dimension of working memory they target as follows:

- Visuospatial sketchpad dimension can be estimated using subtests 1 (Shape selection), 3 (Recall of dot position), 8 (Number of shapes - visual patterns with successive shapes of the same or different color), 9 (Dot count range), and 10 (Snap symbol order and compare order).
- The phonological loop dimension can be estimated using subtests 4 (Distinction of sounds), 5 (Retention of order of sounds), 6 (Retention of order of letters and comparison of order), 7 (Word recall), 12 (Retention of a similar word in text), 14 (Holding a sentence and choosing the right one from similar sentences), 15 (Retention of proposal and written withdrawal), 16 (Recognition of pseudowords), 17 (Word order retention), 18 (Fill in a correct missing letter from a word), and 19 (Number order retention).
- The central processor dimension can be estimated using the Stroop test, which is listed as test 2.
- The dimension of the phonological loop and the central executive can be estimated using subtests 11 (Word letter count), 13 (Word frequency count range in text), and 20 (Computational range).

Each subtest includes several tasks presented to the examinee sequentially in the form of visual or acoustic cards of increasing difficulty. In total, the W.M.D.D.T. includes 145 tasks, with the test-taker being asked to choose the correct answer each time.

Below is a brief description of W.M.D.D.T.:

- Shape selection (short-term optical memory)

The task aims to assess short-term retention and shape recall. It includes 6 different tabs with shapes.

- Stroop assay (attention control-central executive)

The Stroop test requires a person to read a list (17 total) of colored words printed in ink colors that are not related to the printed word.

- Recall dot position (visuospatial memory)

The task aims to assess short-term retention and recall of dot position in frames with cells. It includes 6 different tabs with cells and bullets.

- Sound discrimination (auditory short-term memory)

In this task, the participant needs to remember a sound they hear on the computer for a short period. After that, they will hear more sounds and must identify the one that is similar to the original and the different one. There are 6 consecutive sets of sounds.

- Sound range retention (auditory short-term memory)

In this task, the participant will hear a series of sounds through the computer and will be asked to remember them for a short period. Subsequently, the examinee will be prompted to recall the order of the sounds and determine if they are the same or different.

- Letter order retention (phonological short-term memory)

This task requires the participant to hold a series of digits for a short time, followed by recall and comparison of the correct order. There are 6 tabs of increasing difficulty.

- Word recall (phonological short-term memory)

The participant is required to read, remember and recall six lists of words of increasing difficulty (e.g. increase in syllables, difficult words, etc.) presented in 6 different tabs and reproduce them in a blank tab that will appear on the computer.

- Number of Shapes (Visual Patterns with Successive Shapes - Optical Memory) The task involves identifying visual patterns with shapes of the same or different color in 9 tabs and responding accordingly.
- Dot count range (Optical Short-Term Memory) The participant is asked to count a series of dots of different colors in 4 tabs and recall their total number.
- Snap string of symbols and compare order (visuospatial memory)

The task requires remembering and comparing the order of a series of symbols in 9 tabs.

- Word letter count range (phonological memory, central executive)

The test taker listens to small lists of words and calculates the number of letters in each word in 9 consecutive tabs.

- Retention of identical word in text (phonological memory)

The task involves identifying and repeating a specific word that is repeated in a given text. It consists of 3 tabs with 3 different texts of increasing difficulty (increase in the number of words and sentences).

- Word frequency count range in text (phonological memory, central executive)

In this task, the participant needs to listen to a series of short audio clips and simultaneously calculate the frequency of certain words being heard. There are 6 tabs.

- Sentence retention and selection of correct from similar sentences (phonological memory)

In this task, the individual is required to read a sentence on one card and then choose the correct match from 4 similar sentences on the next card (i.e. the one that was read on the previous card). There are 4 similar options to choose from

- Sentence retention and written recall (phonological memory, central executive)

In this task, the participant is required to read a set of sentences, memorize them, and then accurately recall and write them. There are four consecutive tabs with suggestions.

- Pseudoword recognition (phonological memory)

In this task, the individual is required to differentiate between real words and pseudo-words from a list of 16 pseudo-words provided.

- Word series retention (phonological memory)

This task involves listening to a string of words on the computer and then recalling and comparing the correct order, which will be written on a card. There are 5 levels of increasing difficulty with word orders.

- Fill in a correct missing letter from a word (phonological memory)

In this task, there are 3 tabs with different word lists. Each word that appears is missing a letter, and the examinee is asked to fill in the missing letter in each word.

- Series of numbers retention (phonological memory)

This task involves briefly memorizing a series of numbers displayed on one tab, and then recalling and comparing the correct order of the numbers shown on another tab. There are 5 tabs with number series included.

- Mental calculation (Computational range-acoustic memory, central executive)

This task involves the simultaneous retention and processing of information. The the participant hears simple verbal addition and subtraction problems and fills in the answers in the corresponding boxes. There are 7 tabs included, each presenting increasing difficulty.

2.2.2. The Working Memory Scale of the WISC-V intelligence test, which was used to test the convergent validity of the W.M.D.D.T.

2.3. Procedure of research

The survey was conducted from May to December 2023. After contacting schools in the Municipality of Athens area, we sent a consent form to the parents/guardians of the students. The school principals then distributed the form to the parents/guardians and collected the completed forms from those who consented. We scheduled our visits to each school unit during the survey. It's important to note that the students were given the choice to participate. Those who agreed to participate went to their school's computer room and followed our instructions to access the electronic platform where our test was posted. The platform not only recorded their answers but also the total time taken by each student to complete the test, as well as the time for the STROOP (subtest 2) and Word recall (subtest 7). For some tests, there was already a set time limit due to the nature of the test. Each student's answers were exported to an Excel file, which was then stored on the computer. Additionally, a small group of 40 students from the initial sample of 262 participants were given the test a second time within two months to check the reliability of our tool. Furthermore, a psychologist administered the working memory scale of the WISC-V intelligence test to a small group of 48 students from the initial sample of 262 participants to test convergent validity.

2.4. Statistical analysis of research

The survey data was analyzed using the statistical program SPSS 25. The students' test responses were collected in Excel files, which were then merged into a database and imported into SPSS. The original answer values were converted to a binary system: correct answers were assigned a value of 1, while incorrect answers were assigned a value of 0. However, for the Dot position, Recall words, and Sentence writing tests, partially correct answers were assigned a value of 1 and entirely correct answers were assigned a value of 2. The sum of correct answers for each subtest was calculated, as well as a grand total for all subtests, which created 20 additional variables for data processing. Frequency distributions were then calculated for each subtest and the overall performance.

The reliability and validity of the W.M.D.D.T. were assessed separately for each group of students (with and without learning difficulties) using Cronbach's Alpha internal consistency coefficient and by calculating correlation coefficients for the test-retest. The convergent validity of the W.M.D.D.T. was tested by administering it alongside the WISC-V working memory scale and correlating the initial W.M.D.D.T. values with the baseline values on the specific WISC-V scale.

Hypothesis testing on differences in W.M.D.D.T. averages between students with and without learning disabilities for subtests with a normal distribution was conducted using the t criterion for independent samples and Cohen's d effect size. For subtests with a non-normal distribution, the non-parametric Mann-Whitney U test was applied, and the effect size was calculated using the r-index

3. Results

3.1. Check the reliability and validity of W.M.D.D.T.

Reliability and validity are the fundamental psychometric characteristics of a test. Reliability refers to the consistency with which a psychometric tool evaluates what it measures, while validity is its ability to accurately measure what it has been designed for (Vamvoukas, 1993; Alexopoulos, 1998; Koulakoglou, 2017).

Table 1 Correlation coefficient values between the first and second administration of W.M.D.D.T. (test-retest)

Subtests	Correlation coefficient Pearson r	Spearman's rho correlation coefficient
Shape selection 1 & 2	0.70**	
STROOP 1 & 2		0.85**
Dot position 1 & 2	0.93**	
Distinction of sounds 1 & 2		0.92**
Sound series 1 & 2	0.78**	
Letter series 1 & 2	0.86**	
Recall words 1 & 2	0.91**	
Number of shapes 1 & 2	0.90**	
Number of dots 1 & 2	0.81**	
Symbol series 1 & 2		0.91**
Number of word letters 1 & 2	0.93**	
Identical word in text 1 & 2		0.90**
Word count in text 1 & 2	0.90**	
Recognition of sentence 1 & 2		0.85**
Writing sentence 1 & 2	0.96**	
Pseudoword recognition 1 & 2		0.91**
Word series 1 & 2	0.86**	
Missing letter 1 & 2		0.96**
Series of numbers 1 & 2	0.92**	
Mental calculation 1 & 2	0.97**	
Total test score 1 & 2	0.97**	

**P<0,01

For the reliability assessment of W.M.D.D.T., two methods were employed. Firstly, Cronbach's Alpha coefficient was utilized to determine the overall reliability index and assess the internal consistency of the test. Additionally, each question was individually validated (Alexopoulos, 1998). Secondly, the test-retest method involved readministering W.M.D.D.T. to a sample of 40 pupils approximately two months after the initial administration in order to evaluate its stability over time.

The Cronbach's Alpha coefficient of the W.M.D.D.T. for students without learning difficulties is 0.90, while for students with learning disabilities it is 0.94. To determine the relationship between the first and second administration of the test (test-retest), we calculated the correlation coefficients. We used the Pearson r coefficient for subtests with values close to a normal distribution, and Spearman's rho coefficient for the others. The data analysis shows a statistically significant positive correlation between the first and second administrations of the test for all subtests. The magnitude of each correlation indicates a strong correlation. Table 1 presents the corresponding correlation coefficient values between the first and second administrations of the W.M.D.D.T. (test-retest).

Convergent validity was tested by simultaneously administering the WISC-V Working Memory Scale to a small sample of 48 students (12 students with learning disabilities and 36 students without learning difficulties) out of a total of 262 participants in the main study and calculating the correlations with W.M.D.D.T.

Spearman's rho correlation coefficients were calculated for the memory variables (Auditory Working Memory, Visual Working Memory, and Total Working Memory) of WISC-V and the corresponding variables of W.M.D.D.T. because there is no normal distribution simultaneously in both tools. The correlations were found to be statistically significant and moderate, as shown in Table 2. According to the result, it appears that W.M.D.D.T. It is a valid tool.

Table 2 Spearman's rho correlation coefficients between WISC-V and W.M.D.D.T. memory variables

	Acoustic Working Memory W.M.D.D.T.	**Visual Working Memory W.M.D.D.T.**	**Total Working Memory W.M.D.D.T.**
Audio Working Memory *WISC-V*	0.38**		
WISC-V optical working memory		0.40**	
Total Working Memory *WISC-V*			0.56**

**p<0,01

3.2. Differences between students with and without learning disabilities

Table 3 below shows means and SDs of each of the 20 subtests and total score of the W.M.D.D.T. for students with and without learning disabilities. Subtests for which statistically significant differences were found between pupils with learning difficulties and without learning difficulties are marked with an asterisk.

Table 3 M(SD) of W.M.D.D.T. for students with (N=45) and without L.D. (N=217)

Subtests	**M(SD)**	**M(SD)**
*Shape selection	4.47 (1.44)	5.04 (1.00)
*STROOP	15.16 (3.63)	16.29 (2.15)
*Dot position	9.6 (2.05)	10.72 (1.53)
*Distinction of sounds	4.58 (1.62)	5.26 (1.21)
*Sound series	0.64 (0.48)	0.86 (0.35)
*Letter series	4.96 (1.28)	5.47 (0.88)
* Recall words	8.31 (2.95)	9.8 (1.79)
*Number of shapes	2.36 (2.79)	3.88 (3.38)
*Number of dots	2.13 (1.63)	3.01 (1.29)
*Symbol series	6.31 (2.52)	7.52 (1.51)
*Number of word letters	6.02 (3.27)	8.14 (1.32)
*Identical word in text	1.6 (1.21)	2.56 (0.66)
* Word count in text	2.47 (1.88)	4.77 (1.35)
* Recognition of sentence	2.78 (1.28)	3.38 (0.84)

* Writing sentence	4.02 (2.60)	5.69 (2.02)
*Pseudoword recognition	10.56 (5.48)	14.34 (1.85)
*Word series	2.58 (1.45)	3.66 (1.02)
*Missing letter	10.78 (5.55)	14.58 (1.83)
*Series of numbers	3.16 (1.64)	4.03 (1.04)
*Mental calculation	2.04 (2.40)	5.02 (1.94)
*Total test score	104.51 (23.18)	134.02 (13.23)

Before comparing the performance of students with and without learning disabilities on the test, we first made sure that the two groups did not differ in age. The average age for students without learning disabilities was 15.06 (SD=1.75), and for students with learning difficulties, it was 14.93 (SD=1.47). The age distribution of students was normal, and the difference in averages was statistically insignificant [t(260)=0.47, p=0.639]. This means that the two groups of students do not differ in age, and we can proceed to further testing.

To check for statistically significant differences between students with and without learning disabilities, we used the t-test for independent samples for variables that showed a normal distribution and could apply parametric criteria. Our analysis found statistically significant differences in the averages of the two groups for several subtests: Shape selection [t(53.164)=2.55, p=0.014, d=0.53]. Dot position [t(54.649)=3.48, p=0.001, d=0.69]. Word recall [t(50.9693)=3.26, p=0.002, d=0.73]. Number of figures [t(73.531)=3.21, p=0.002, d=0.46]. Number of dots [t(55.897)=3.39, p=0.001, d=0.65]. Symbol series [t(50.757)=3.09, p=0.003, d=0.70]. Word to text count [t(53.726)=7.82, p<0.001, d=1.59]. Sentence recognition [t(52.195)=3.02, p=0.004, d=0.65]. Sentence writing [t(55.504)=4.06, p<0.001, d=0.79]. Pseudoword recognition [t(46.104)=4.58, p<0.001, d=1.34]. Word series [t(53,332)=4,75, p<0,001, d=0,98]. Missing letter [t(46.008)=4.55, p<0.001, d=1.35]. Series of numbers [t(51.540)=3.43, p=0.001, d=0.75]. Mental calculation [t(56,463)=7,81, p<0,001, d=1,47]. Overall test score [t(50,102)=8,27, p<0,001, d=1,92]. Studying the averages of the two groups, we found that students without learning difficulties performed better in all subtests of the W.M.D.D.T. and for the overall score compared to students with learning difficulties.

For variables where parametric criteria were not met, and to check for statistically significant differences in value distributions between students with and without learning disabilities, we used the nonparametric statistical criterion Mann-Whitney U. Our analysis found statistically significant differences in the mean ranking values of the two groups for all variables and for time of test 2, but not for the time of test 7 and for the total time. Specifically for the subtests: STROOP [U=3880.50, p=0.004, r=0.18]. Distinction of sounds [U=3690.00, p=0.003, r=0.18. Sound series [U=3821.50, p=0.001, r=0.21]. Letter series [U=3675.00, p=0.002, r=0.19]. Number of word letters [U=3127.00, p<0.001, r=0.25]. Same word in text [U=2725.50, p<0.001, r=0.33]. From the study of the data, we found that students without learning difficulties performed better than students with learning difficulties in these subtests.

4. Discussion

In this study, a new electronic test was developed to assess the working memory of secondary school students, including those with and without learning difficulties. A total of 262 students participated in the online test, with 217 students without learning difficulties and 45 students with learning difficulties. Initially, the reliability and validity of the test were assessed separately for each group of students using Cronbach's Alpha internal consistency coefficient. Additionally, correlation coefficients between the first and second administrations of the test (test-retest) were calculated for a small group of 40 students from the initial sample. To evaluate convergent validity, the working memory scale of the WISC V psychometric tool was administered to a small sample of 48 students from the initial group, and their performance was correlated with their performance in the electronic test developed for this research. Furthermore, differences in performance in all tests of the electronic test between the two groups of students with and without learning difficulties were investigated.

The results of the reliability analysis using Cronbach's Alpha coefficient indicate that the W.M.D.D.T. is highly reliable. The test's internal consistency, as measured by the Cronbach's Alpha coefficient, confirms the conceptual validity of the test. This is important as internal consistency is now considered a measure of structural validity (Aiken, 1996). Additionally, in a test-retest with a sample of 40 students, strong positive correlations between the first and second administrations of W.M.D.D.T. for all subtests were observed, indicating result stability and therefore reliability.

Furthermore, statistically significant correlation coefficients were found between W.M.D.D.T. and the working memory scale of WISC V, a widely accepted intelligence test. This confirms the validity and reliability of the tool, making it suitable for teachers to assess their students' working memory functions. This assessment can help identify students with working memory deficits and provide them with appropriate support.

The study revealed significant differences in performance between students with and without learning difficulties. Students with learning disabilities performed significantly worse on all subtests compared to students without learning disabilities. The overall test score showed a large difference between the two groups, with a Cohen's d effect size of 1.92. It appears that secondary school students with learning disabilities exhibit deficits in all three dimensions of working memory: phonological circuit, central executive system, and visuospatial notebook. These findings were expected, as the role of working memory in learning and school performance is well-established and supported by previous research (Hulme & MacKenzie, 2014; Masoura, 2006; Zakopoulou et al., 2019).

The largest difference in Cohen's d effect size for the individual tests was found in Word to Text Count, Sentence Writing, Pseudoword Recognition, Word Series, Missing Letter, Number Series, and Mental Calculation. These tests mainly check the operation of the phonological circuit and the central processor. Researchers have varying opinions on this, depending on the type of difficulty. Although the visuospatial notebook is thought to play a role in reading, a significant deficit has been observed mainly in the phonological circuit and the central executive system in cases of specific learning disability in reading (Baddeley, 1999). On the other hand, studies by Swanson in 2006 and by Swanson et al. in 2009 showed that students with reading difficulties performed poorly on all tasks assessing working memory, whether visuospatial or verbal in nature. Their reading problems likely reflected a generalized malfunction of working memory, affecting overall system performance (Swanson, 1993, 1999). Gathercole and Alloway (2006) investigated the relationship between working memory and reading and math abilities and concluded that reading difficulty (dyslexia) is associated with deficits in phonological working memory and the central executive system.

In other studies, it has been found that children with dyslexia, when compared to their peers without dyslexia, also struggle with tasks involving recalling visual and spatial information (Swanson et al., 1993). Kibby et al. (2004) reported that children with reading difficulties may have a hard time with spatial tasks, reading, and following maps. Additionally, learning disabilities in mathematics were associated with deficits in both the phonological circuit (Dark & Benbow, 1994) and the visuospatial notebook (Fletcher, 1985; Siegel & Ryan, 1989), either separately or together (Clark & Campbel, 1991), as well as deficits in the central executive system (Wilson & Swanson, 2001; Masoura, 2007).

Research has also shown that poor working memory is strongly linked to both low academic achievement (Alloway et al., 2009; Gathercole & Alloway, 2008) and specific attention problems present in some children with subtypes of ADHD (Gathercole et al., 2008). It appears to be often associated with ADHD (Angelopoulou et al., 2021). Research conducted by Tillman et al. (2011) showed that poorer verbal short-term memory and central executive system, as well as poorer visuospatial short-term memory, were associated with higher levels of inattention, suggesting that ADHD symptoms are linked to several specific deficits in different components of working memory. Findings suggest that approximately 67%-71% of children with ADHD have impairments in at least one component of working memory (Fosco et al., 2020). However, the present study did not examine the differences between the various subgroups of students with learning disabilities who participated, due to their small number. This is one of the limitations of this research.

5. Conclusion

In conclusion our research findings demonstrate that the W.M.D.D.T. we developed is a reliable and valid tool. When administered, significant differences in performance were observed between students with and without learning difficulties. This test appears to be useful for identifying potential deficits in the working memory of secondary school students struggling with reading, writing, mathematics, and/or ADHD. This information is valuable for teachers as it enables them to plan and provide effective support to their students. However, it's important to note that our current survey has limitations, as the sample of students with learning disabilities was relatively small. In future research, we aim to include a larger sample size to test for differences between various subgroups of students with learning difficulties.

Compliance with ethical standards

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Disclosure of conflict of interest

The Authors proclaim no conflict of interest.

Statement of informed consent

Informed consent was obtained from all individual participants included in the study.

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