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Verbal working memory and reading abilities among students with visual impairment☆

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ABSTRACT

Aim: This study investigated the relationship between working memory (WM) and reading abilities among students with visual impairment (VI). Seventy-five students with VI (visually impairment and blindness), aged 10–15 years old participated in the study, of whom 44 were visually impaired and 31 were blind.
Methods: The participants' reading ability was assessed with the standardized reading ability battery Test-A (Padeliadu & Antoniou, 2008) and their verbal working memory ability was assessed with the listening recall task from the Working Memory Test Battery for Children (Pickering et al., 2001).
Results-Implications: : Data analysis indicated a strong correlation between verbal WM and decoding, reading comprehension and overall reading ability among the participants with VI, while no correlation was found between reading fluency and verbal WM. The present study points out the important role of verbal WM in reading among students who are VI and carries implications for the education of those individuals.

What this paper adds?

Learning to read comprises the achievement of two stages —that of decoding and that of text comprehension. Although decoding and reading comprehension are related skills, research data support the gradual dissociation of the second from the first and show that other factors, such as working memory (WM), affect comprehension more than decoding skills. However, limited research has been focused on the relationship of reading and WM in children with visual impairments. As an effort to address this gap in knowledge, the aim of this study was to examine the relationship between verbal WM and reading abilities among students with VI. Although visual retention and processing of information are also important for reading, when visual input is only partly available as in the case of VI individuals, the retention and process of verbal information should be important for reading. The following research hypotheses were set in present study: 1) verbal WM is related to decoding in children with VI and blindness, 2) verbal WM is related to reading fluency 3) verbal WM is related to reading comprehension. Based on the findings of the present study the relationship between reading comprehension and verbal WM in children with VI was strong. According to the present results it can be suggested that experimental studies are needed to be conducted to see if WM improves reading improves as well and then propose that children

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with VI may be benefited by a working memory training programme that may increase their working memory capacity improving their WM function and consequently their ability to read and most importantly to comprehend written texts.

1. Reading and working memory

Reading is a complex procedure if one considers the number of functions that need to be activated and applied for its achievement. Learning to read comprises the achievement of two stages—that of decoding and that of comprehension (De Jong and van der Leij, 2002). Although decoding and reading comprehension are related skills (Gough and Tunmer, 1986), several studies suggest the gradual dissociation of the second from the first (De Jong and van der Leij, 2002; Megherbi & Ehrlich, 2005; Muter, Hulme, Snowling, & Stevenson, 2004; Savage, 2006; Stothard & Hulme, 1996; Tunmer and Hoover, 1992). This tendency is mostly observed as the age of children increases. Studies such as those of Oakhill, Cain, & Bryant, 2003 showed that factors such as vocabulary, Working Memory and knowledge of the structure of the text, affect comprehension more than decoding skills. Perfetti and Hart (2002) and Landi (2005) found similar findings in various age groups. Finally, the fluency of reading ability intervenes in comprehension processes, but only during the first years of the child's reading efforts. The direct relation between word processing speed and comprehension is a crucial element of fluency in the total comprehension process (Allington, 2004; Jenkins, Fuchs, van den Brock, Espin, & Deno, 2003), which is necessary but not sufficient for the reader to comprehend the message communicated by the writer of the text (De Jong and van der Leij, 2002). Working memory (WM) is a memory system of limited capacity, which is responsible for retention and simultaneous processing of information over short periods of time (Baddeley and Logie, 1999 Just & Carpenter, 1992). WM is generally considered as a temporary storage system under attentional control that is the basis for our capacity for complex thought (Baddeley, 2012).

According to the multi-component model of WM suggested by Baddeley and Hitch (1974) and Baddeley (2003a, 2003b), WM consists of four subsystems: a) the phonological loop that allows the temporary storage of verbal and acoustic information, such as phone numbers and people's names, b) the visuospatial sketchpad that allows the manipulation and storage of visuospatial information. Research supports that the visual spatial sketchpad of WM involves two functions: i) one function responsible for the maintenance and storage of special categories of optical information (such as shapes and colors) and ii) one function responsible for retaining of spatial information in relation to the element of dimension in space (e.g., the course taken in a labyrinth, or the place of an object in space) (Gathercole and Baddeley, 1993; Logie, 1995; Pickering et al., 2001). iii) The third subsystem is the central executive system, a higher order attentional control system that is in direct contact with the phonological loop and the visual-spatial sketchpad and coordinates the activity among all subsystems and the forth system is iv) the episodic buffer: a limited capacity system that provides temporary storage of information held in a multimodal code and binds information from the subsidiary systems, and from long-term memory, into a unitary episodic representation (Baddeley, 2000).

Typically, with the term working memory we refer to the retention and the parallel processing of information. Thus we imply to the capacity of the central executive component of working memory, while with the term short-term memory we refer to the mere retention of information and thus, we mean the capacity of the phonological loop and visuospatial sketchpad. Several others models describing the structure of working memory have been suggested (see Miyake and Shah, 1999 for an overview) nevertheless the Baddeley and Hitch (1974) models remain a very widely used and influential in current literature. Also, it describes working memory capacity in full detail, suggesting distinctive components for different functions and activities. It has been used a lot with research among clinical populations (Gathercole and Pickering, 2000; Gathercole & Pickering, 2001) and in educational settings (Holmes and Gathercole, 2014 Dunning & Holmes, 2014).

As WM is responsible for the temporary retaining and processing of information, it appears to be necessary for transacting cognitive processes such as numeration (Logie and Baddeley, 1987) and logical inference (Cowan, Cartwright, Winterowd, & Sherk, 1987; Miyake and Shah, 1999). Furthermore, research has consistently demonstrated significant relationships between WM and many aspects of language development, such as vocabulary acquisition (Baddeley, Gathercole, & Papagano, 1998), learning of a foreign language (Service, 1992 Service & Kohonen, 1995) and reading (Daneman and Carpenter, 1980) with an emphasis on text comprehension (Oakhill, 1982; Oakhill, Yuill, & Parkin, 1986).

Al-Hamori and Khsawneh (cited in Al-Yaman, Al-Srour, & Al-Ali, 2013) explicitly examined the role of working memory capacity and gender in reading comprehension in a sample of 230 students in secondary school in Irbid city. In their study they found that reading comprehension is affected by the capacity of working memory, and that there was no interaction effect between working memory capacity and gender. Jincho et al. (2008) investigated the effects of verbal working memory (VWM) and cumulative linguistic knowledge (CLK) on reading comprehension among 62 students in Useda University in Japan. According to the results VWM and CLK were independent of each other, while verbal working memory and cumulative linguistic knowledge independently contributed to reading comprehension.

The embodiment of information from different parts of the text is very difficult and demands good memory skill. The limits of memory systems may impose problems in decoding, in recall and/or in the processing of new information in the text in relation to pre-existing knowledge (Cornoldi, de Beni, & Pazzaglia, 1996; Perfetti, Marron, & Foltz, 1996; Yuill, Oakhill, & Parkin, 1989). Theories that claim the necessity of accuracy and speed in word reading in order for comprehension to be successful are based on the function of an immediate memory system.

Initially, the capacity of WM was examined by a sentence-based reading span test developed by Daneman and Carpenter (1980, 1983).This task requires participants to read and make semantic judgments on sentences, while at the same time they asked to recall the last word of each sentence. Results showed that performance on this task correlates higher with measurements of reading comprehension rather than other memory tests. Over time this task was developed further and adapted to recent models of working memory. At its recent form the task consists of spoken sentences and requires the last words to be stored in memory. It seems that there are tremendous individual differences on working memory capacity and WM's function plays a major role in reading comprehension. Individuals with low WM capacity experience problems in reading comprehension (MacDonald, Just, & Carpenter, 1992). For example, Yuill and Oakhill (1991) assessed the WM of 84 children and showed that "poor" readers were not effectively using their WM. Further studies found a strong relation between reading comprehension and WM and they concluded that performance on WM tasks can predict performance in reading comprehension (Leather and Henry, 1994; Seigneuric, Ehrlich, Oakhill, & Yuill, 2000) observed. In general, research shows a strong relation between WM and children's reading comprehension based on different tasks (i.e. word- or sentence- or number based tasks) (Cain, Oakhill, & Bryant, 2004).

2. Working memory among individuals with visual impairments

It is a common conception that the loss of vision forces an individual to rely on his/her intact perceptual processes. Touch, memory and attention skills of individuals with severe visual impairments (VI) have been found to compensate for the absence of vision (Cattaneo and Vecchi, 2011; Warren, 1978). Furthermore, individuals with VI become more skilled, on average, in abilities of auditory monitoring (Benedetti and Loeb, 1972) and speech discrimination (Niemeyer and Starlinger, 1981; Roder & Rosler, 2003). The superiority of congenitally blind individuals (who were born blind or who lost their vision in infancy), has been reported on simple auditory discrimination tasks within the auditory modality (Roder, Rosler, & Neville, 1999), as well as on more complex tasks such as language processing (Roder and Rosler, 2003). In the absence of vision in persons with severe VI, there is considerable dependence on auditory-verbal information and thus the sequential processing of information may be particularly well developed. This finding is in line with the study of Raz et al., (2007), who suggested that individuals with severe VI have superior memory abilities because they have trained themselves in serial strategies to compensate for the absence of visual information. This superior ability is possible to be the result of actual brain reorganization in individuals with VI, whose brains become more adapted to spatial, sequential and verbal information (Cornoldi and Vecchi, 2000).

Recent studies showed that individuals with VI process speech faster (Roder, Rosler, & Neville, 2000) and discriminate speech in the context of a noisy room better when compared to persons with sight (Muchnik, Efrati, Nemeth, Malin, & Hildesheimer, 1991). The results of the above two studies indicate a possible relation between the two capacities studied (i.e., faster auditory processing and better discrimination), but they do not provide an explanation for some of the memory advantages reported in the following studies.

According to Raz et al. (2007) individuals with VI exercise their verbal memory abilities (STM) more heavily than persons with sight, as they need to compensate for missing information. In their study individuals with sight and individuals with VI heard a list of 20 words and were asked to recall them in serial order. The individuals with VI recalled more words than the participants with sight (indicating better verbal memory) and also they were better in serial recalling longer word sequences.

From a developmental perspective it seems that children with VI often learn to compensate for vision loss and achieve similar levels of intellectual and educational attainment as their sighted peers. Lacking sight, children with VI must develop serial strategies to identify objects in the environment and remember this information along with route information (Millar, 1994). In addition, some studies have reported more efficient perceptual processing in children with VI compared to children with sight on auditory discrimination tasks (Roder, Rosler, Hennighausen, & Nacker, 1996). The research findings for WM are inconclusive, with most researchers finding no differences between persons with sight and children with severe VI (Cornoldi and Vecchi, 2000 Rokem & Ahissar, 2009; Swanson and Luxenberg, 2009).

However, a study by Withagen et al. (2012) showed that children with VI outperformed their peers with sight on both short-term memory and WM tasks, which indicates that children with VI may further benefit from the fact that verbal input is sequential. Swanson and Luxenberg (2009) showed that children with VI outperformed children with sight on short-term memory tasks but not on WM tasks. They assumed that if persons with VI make increased use of the sensory features of to-be-remembered items, they should gain particularly from tasks that draw upon phonological information. In contrast, if their executive system of working memory is impoverished because of inabilities to access visual-spatial information, they should perform poorer than sighted individuals on WM tasks. This is because they do not have access to additional stores of information (i.e., the visual-spatial sketchpad). An alternative hypothesis is that WM performance may be comparable between sighted and blind participants because efficiently accessing resources from both the verbal (phonological loop) and visual-spatial system (i.e., visual-spatial sketchpad) are not necessary.

Reading comprehension and working memory among individuals with visual impairments

Children who have severe visual impairments use the Braille code for reading, which is based on the tactile sense. Like children who are sighted, children who are blind need to develop abilities such as the use of phonemes and word identification (Trent and Truan, 1997). However, visual information processing is faster and more efficient in relation to tactile information processing (Rogers, 2007). Furthermore, there are studies that show that memory works differently when it has to process verbal and tactile information (Warren, 1994).

As mentioned earlier WM has a close connection with reading and reading comprehension. Furthermore, de-codification fluency and its influence on reading comprehension have been put to doubt during the last years. However, little research has been focused on the relationship of reading and especially reading comprehension and verbal WM in children with VI. Gompel et al. (2002) showed that although children had diminished vision and displayed problems in decodification, they did not have decreased performance in comprehension. Furthermore, in the study by Gompel et al. (2004) processing of letter-order information was more difficult for children with low vision (moderate visual impairment combined with severe visual impairment are grouped under the term *low vision*, according to WHO definition, 2013) as they needed more time to identify the single letters and consequently they had to keep the identified letters longer in working memory.

As an effort to address this gap in knowledge, the aim of this study was to examine the relationship between verbal WM and reading in students with visual impairment. Specifically, the following research hypotheses were set in our study: 1) verbal WM is related to decoding in children with visual impairment (low vision) and blindness, 2) verbal WM is related to reading fluency in children with visual impairment (low vision) and blindness, 3) verbal WM is related to reading comprehension in children with visual impairment (low vision) and blindness.

3. Method

3.1. Participants

The participants of the current study were 75 students, with mean age $\bar{x} = 11.95$ years and $SD = 1.888$, from 36 primary and 6 junior high schools from all over the country of Greece. The participants' age ranged between 10 and 15 years old. Forty-four of the students had low vision (according to the WHO definition for visual impairment and blindness "Moderate visual impairment combined with severe visual impairment are grouped under the term *low vision*) and 31 students were blind (visual acuities of less than 20/400). All participants were identified as legally blind individuals (with central visual acuities of less than 6/60 in the better eye with the use of a correcting lens or visual fields of less than 20°). Fifty-eight were primary school pupils and 17 were junior high school students. Fifty-eight were primary school students, aged 10–12 years old, i.e. 4th–6th grade students according to the Greek school system, whereas 17 were junior high school students, aged 13–15, i.e. 7th–9th grade students. Thirty-one of the students (i. e. those who had severe visual impairments) read braille and the rest students ($N = 44$) could read large print and according to their records had low vision. All students started their education in reading by the age of six and according to their records they had no additional disabilities. The research was approved by the Greek Ministry of Education and the Institute of Educational Policy (IEP) in Athens. Finally, informed consent to participate in the study was obtained from all students and their parents.

3.2. Instruments

3.2.1. Reading ability

Test-A, a test which was developed by Padeliadu and Antoniou (2008) and assesses reading in children between 8 and 15 years old, was used in our study. Test-A consists of subscales that measure separately the core elements of reading i.e.,1) decoding, 2) fluency, 3) syntax, and 4) comprehension. The decoding section includes three tasks: a) non-semantic word reading, b) semantic word reading, and c) distinction between semantic and non-semantic words. The fluency section includes one task, i.e., to read a certain text aloud for sixty seconds. The syntax section includes four tasks, which was not used because it includes pictures and could not be used for children with VI. The comprehension section includes two tasks: a) identifying the two semantically equal sentences between five options and b) answering seven multiple-choice questions on three different reading texts. Test-A has been standardized for the Greek population using 1405 Greek students from all over the country. The depended variables that derived from Test – A are norm scores which yield an estimate of the position of the tested individual in comparison to the class average. The Test – A Indicator represents the percentile that the student belongs regarding his/her reading ability when compared to their peers of the same gender and age. It has to be mentioned here that this Test has not been standardized for students with visual impairments; for this it was adapted to fit the needs of students with VI and was provided in print braille for the students with severe VI and in four different font sizes of large print: 24, 36, 48, and 72pt for the students with low vision.

Verbal working memory abilities (A task tapping the function of the Central executive, component of working memory).

A translated version of the listening recall task from Pickering and Gathercole's (2001) Working Memory Test Battery for Children was used to examine verbal WM. The task comprises of short sentences that are read aloud by the examiner. Some of the sentences are meaningful and others are meaningless. Participants were asked to judge the veracity of every sentence (by replying 'true' or "false') and at the same time to maintain and recall the final word of each sentence in the order it was presented.

The task becomes gradually more difficult with consecutive trials of more sentences presented. The task consists of blocks of trials. Every block consists of six sentences of a particular difficulty level from 1 to 9. Testing ceased when participant failed after three trials in a particular block. The final score on the test is the sum of the total correct responses ($Min = 0$, $Max = 42$).

3.3. Data analysis

Braille reading constitutes a highly specific and active tactile process, through which fingers, arms, even elbows are involved (Millar, 1994). It seems that hand movements depend on (a) brain asymmetry, (b) sensitivity of each finger, and (c) training received at an early stage of learning (Lorimer, 2002). A very recent hypothesis suggests that the necessary level of tactile sensitivity for braille reading is already achieved during the beginning stages of reading but takes some time for the child with the severe visual impairments to develop accuracy in tactile spatial resolution (Veispak et al., 2013). Braille reading presupposes effective tactile spatial acuity, so that the reader will be able to identify the relative spatial position of the braille dots and eventually acquire the maximal amount of information of each braille character (Vakali & Evans, 2007). This delay may lead to the possibility of a possible floor-effect in the data and would also support the non-normality in the data. Thus, non-parametric statistics were used due to the fact

Table 1
Means and Standard Deviations of the variables in students with blindness.

	Type of vision loss	*N*	$\bar{x}$	*SD*
Variation of attendance grade–equivalent grade (Decoding)	Blindness	31	−1.81	3.94
Variation of attendance grade–equivalent grade (Fluency)	Blindness	31	−4.03	1.35
Variation of attendance grade–equivalent grade (Comprehension)	Blindness	31	−1.65	2.59
Variation of attendance grade–equivalent grade (in total)	Blindness	31	−1.65	2.59

Note: $N = 31$ in all cases.

that the variables tested for correlation were not normally distributed. The Spearman rho correlation was used since the variables were ranked, and also in order to examine if at each hypothesis the two existed variables covary, ie. if as one variable increases, the other variable tends to increase or decrease.

As mentioned above, Test-A is a test that assesses reading and it consists of three core elements: decoding, fluency and comprehension. Each student, based on his/her performance, gets a ranking in relation to students in his/her grade. More specifically, if a student's indicator Test-A is 0.69, it means that this particular student's performance in reading comprehension is better than 69% of the population on which the test was standardized on, i.e. sighted children of the same age and gender.

4. Results

Table 1 shows the means and standard deviations of the variables which are included in Test-A. In specific, the mean for decoding was$\bar{x} = -1.81$, which indicates that all students with blindness were on average two school grades behind their school year group.

The mean for fluency was$\bar{x} = -4.03$, which indicates that students with blindness were on average four school grades behind their school year group. In terms of reading comprehension Table 1 shows a mean $\bar{x} = -1.65$, which indicates that students with blindness were approximately two school grades behind their school year group. In total students with blindness were 1.65 (Table 1) school grades behind their current attendance grade.

Table 2 reports similar results regarding the variables as described above. In specific, the mean for decoding was$\bar{x} = -1.39$, which indicates that all students with low vision were on average 1.5 school grades behind their school year group. The mean for fluency was$\bar{x} = -3.18$, which indicates that students with low vision were on average three school grades behind their school year group and in terms of reading comprehension Table 2 shows a mean $\bar{x} = -1.55$, which indicates that students with low vision were approximately two school grades behind their school year group. In total students with low vision were 1.61 (Table 2) school grades behind their current attendance grade.

In total, it seems that the two groups did not have significant differences towards the variables of decoding, fluency, and comprehension. According to Tables 1 and 2, students with blindness lagged slightly behind their peers with low vision.

Table 3 provides information about correlations between Test-A variables (Test-A is a test that assesses reading and it consists of three core elements: decoding, fluency and comprehension) and verbal working memory for participants with blindness. Blind participants' verbal working memory function correlates with both their reading (r = 0.591, p = 0.01) and their comprehension ability (r = 0.642, p = 0.01), while it does not correlate with decoding (r = 0.296) and fluency (r = 0.025). In the same group, reading ability relates closely with comprehension (r = 0.665, p = 0.01) and decoding (r = 0.525, p = 0.01) but not with fluency, while fluency has a significant relation only with decoding (r = 0.453, p = 0.05) but not with comprehension (r = 0.183). Those findings are in line with data that dissociate components of reading and assume reading and comprehension abilities independent from fluency. It seems that individuals with blindness with good verbal working memory can read and comprehend texts, whereas at the same time they may not read with fluency. It appears that they use a route to reading through memory but not through decoding.

The same pattern with strong correlations among verbal working memory, comprehension and reading ability holds also for the group of the individuals with VI. In addition, Table 4 indicates the lack of relation between verbal working memory and fluency, and between reading ability and fluency, while reading relates closely with comprehension and decoding.

The most interesting finding is the difference between the two groups in the relation among verbal working memory and

Table 2
Means and Standard Deviations of the variables in students with low vision.

	Type of vision loss	*N*	$\bar{x}$	*SD*
Variation of attendance grade–equivalent grade (Decoding)	Low vision	44	−1.39	3.90
Variation of attendance grade–equivalent grade (Fluency)	Low vision	44	−3.18	1.62
Variation of attendance grade–equivalent grade (Comprehension)	Low vision	44	−1.55	2.35
Variation of attendance grade–equivalent grade (in total)	Low vision	44	−1.61	2.40

Note: $N = 44$ in all cases.

Table 3
Correlations between Test-A variables and working memory for participants with blindness.

Measures	1	2	3	4
1. Working Memory Performance	–			
2. Indicator Test-A: Reading Ability Performance	**0.591****	–		
3. Variation of attendance grade–equivalent grade (Decoding)	0.296	**0.525****	–	
4. Variation of attendance grade–equivalent grade (Fluency)	0.025	−0.185	**.453***	–
5. Variation of attendance grade–equivalent grad (Comprehension)	**0.642****	**0.665****	**.707****	0.183

Note: $N = 31$ in all cases.
* $p < 0.05$.
** $p < 0.01$.

decoding, that appears significant (r = 0.403, $p = 0.01$) only in the group with the participants with VI. It appears that verbal working memory, reading, decoding and comprehension interrelate only in this group. One more interesting difference among the groups is the strong relation between comprehension and fluency that emerge in the group with VI but is absent in the group with blindness (r = 0.183 *ns*).

Research hypothesis 1 (verbal working memory is related to decoding in reading among students with VI) is supported by the results described in Tables 3 & 4 respectively. The results indicate a relationship r = 0.403, $p = 0.01$) only in the group with the participants with VI and not for the group of students who were blind. For research hypothesis 2 (working memory is related to reading fluency in students with VI), evidence in both Tables 3 and 4 shows that verbal WM performance was not correlated with fluency.

Hypothesis 3 (working memory is related to reading comprehension in students with VI) is supported as shown in Tables 3 and 4. Verbal WM has a strong and positive correlation with the core element of comprehension in the group of students who had VI (r = 0.670, $p = 0.003$) as well as in the group of students who were blind (r = 0.642, $p = 0.003$).

Verbal Working memory is positively correlated with the overall Indicator Test-A for the group of the students who had VI ($r = 0.642$, p = 0.000) as well as for the group of students who were blind (r = 0.591, p = 0.000). More specifically, the students with higher performance on the verbal working memory task had better general reading ability.

5. Discussion

Based on the results of the study, significant correlations were identified between verbal WM decoding and reading comprehension, while no correlation was identified between verbal WM and reading fluency in students with VI.

For research hypothesis 3 the results of the present study support the well observed relationship between verbal working memory and reading comprehension and expanded to individuals with VI. Daneman and Carpenter (1980, 1983) were the first to link working memory and reading comprehension. Further studies also showed that WM performance differs tremendously among individuals and that individuals with low working memory capacity have difficulties in reading comprehension (MacDonald et al., 1992). Later research (Leather and Henry, 1994; Seigneuric et al., 2000) noted that working memory performance could also predict reading comprehension performance. Gathercole and Pickering (2000, 2001), observed a close link between the WM performance and the overall school performance in children in their early school years. They specifically investigated the central executive system of Working Memory, which is specifically linked with reading and reading comprehension. Present study also examined particularly the central executive system of WM in children with VI. According to the results of the present research verbal WM was correlated significantly with both reading comprehension and overall reading ability. We believe that one of the reasons of this finding is the fact that all participants with and without sight need to develop the same cognitive skills in order to master reading. According to Trent and Truan (1997) individuals with and without VI need to develop the same early reading skills, such as recognition of whole words, use of phonics and context clues and structural analysis of words, in order to achieve text comprehension. Harley, Truan, & Sanford (1997) agree suggesting that these early word-identification skills are parallel for both braille readers and print readers. These findings are in line with the results of the studies of Gathercole and Pickering (2000, 2001) who revealed that children who had low performance in tasks which examined the central executive system of WM, had difficulties and low performance in reading and reading comprehension.

Table 4
Correlations between Test-A variables and working memory for participants with visual impairment (low vision).

Measures	1	2	3	4
1.Working Memory Performance	–			
2.Indicator Test-A: Reading Ability Performance	**0.642****	–		
3.Variation of attendance grade equivalent grade (Decoding)	**0.403****	**0.382***	–	
4.Variation of attendance grade–equivalent grade (Fluency)	0.254	0.110	**0.790****	–
5.Variation of attendance grades–equivalent grade (Comprehension)	**0.670****	**0.545****	**0.521****	**0.487****

Note: $N = 44$ in all cases.

When it comes to hypothesis 1, the findings of this study showed a significant correlation between decoding and verbal WM only for the students who had visual impairment (Table 4) and not for those who were blind (Table 3). This can be explained on the assumption that for students with VI letter-order information was a daunting task as they needed more time to identify the single letters and consequently they had to keep the identified letters longer in working memory. On the other hand, it could be argued that the students who were blind had developed better memory abilities compared to the students who were visually impaired because they have trained themselves in tactile serial strategies to compensate for the absence of visual information (Raz, Striem, Pundak, Orlov, & Zohary, 2007). This ability is possible to be the result of actual brain reorganization as braille reading binds definitely the sense of touch as well as the somatosensory system of the brain (Darden and Schwartz, 2015).

Decoding and reading comprehension are key elements of reading and also there is a link between the two especially in the children's' first school years. Since reading comprehension is shown to have a link with WM there should also exist a relationship between WM and decoding. However, many studies support the disconnection of decoding and reading comprehension especially as children grew older (De Jong and van der Leij, 2002; Megherbi & Ehrlich, 2005; Muter et al., 2004; Savage, 2006; Stothard and Hulme, 1996; Tunmer and Hoover, 1992) as well as many studies stresses the importance of the involvement of other factors such as WM (Cain et al., 2004; Protopapas, Simos, Sideridis, & Mouzaki, 2012; Perfetti and Hart, 2002; Landi, 2005) which may lead to the disconnection of decoding and reading comprehension.

One interesting finding of the present study was the lack of relation between verbal working memory and reading fluency. Although one would expect a link between the ability to retain and process verbal information and fluency in reading, it appears that such a link is not readily observed among individuals with VI (either students with visual impairment or blindness). One explanation might be that other factors affect blind students' fluency in reading through braille (i. e. motor skills, established experience by using the Braille code and tactile skills), whereas for students with visual impairments the factors may refer to experience in using large print or assistive technology – such as cctv – which may increase the perceived fluency with which the information is processed (Abner and Lahm, 2002). The negative correlations between fluency and decoding suggest also that these two are distinctive abilities in individuals with VI. It is possible that while decoding requires holding information in memory, fluency depends on abilities, other than verbal working memory.

In the case of the current study, the majority of the participants (74.4%) were primary school children with VI. The participants' equivalent grade of attendance regarding decoding was between the first and third grade (58.7%). As a result, the participants were actually in their first school years in the area of decoding. In the first school years as mentioned before a link is being showed between decoding and reading comprehension. Since decoding is essential for reading comprehension in those school years and reading comprehension is affected by WM it is clear that decoding would also have a link with verbal WM.

Furthermore, reading comprehension is affected by secondary elements of decoding such as phonological awareness (Oakhill et al., 2003 Rausby & Swanson, 2003). This could also be another reason for the link that was shown between verbal WM and decoding in the present study. The ability of visual recognition of letters and the following identification of sounds and the skill of connecting sounds and letters to make words is essential for reading comprehension (Vellutino, Fletcher, Snowling, & Scanlon, 2004). We can assume that there is a circular link between WM, decoding and reading comprehension. Verbal WM affects reading comprehension and the latter is affected by decoding and its key element of phonological awareness and the latter is also linked with verbal WM.

The findings of the present study are in line with similar research on children without VI and the outcomes of the current study are of great significance considering the lack of studies, which examined the role of verbal WM in reading by students with VI. The relationship between reading comprehension and verbal WM in children with VI was strong and positive, showing the important role of WM in reading comprehension of students with VI. According to the presented results it can be proposed that children with VI may benefit from a working memory training programme that may increase their working memory capacity improving their WM function and consequently their ability to read and most importantly to comprehend. It is vital though to mention that the previous suggestion is correct under the condition that an experimental study has been conducted first to check if WM improves then reading process improves as well.

In addition, it has to be mentioned that print braille and large print have been traditionally used for making relevant content (e.g. curriculum) accessible to children with VI. However, studying through braille or through large print may be very time-consuming, while the above traditional media for studying do not allow for adequate access to all existing information. As a result, students with VI fall further behind their sighted peers (Kelly, 2009) in cognitive tasks, such as reading. In the future, there is a need for further studies that will examine the function of WM in reading for students with VI. A study that could identify if WM training programs are also beneficial for the reading comprehension of children with VI would also be of great interest. The application of additional measures and alternative data analysis methods as well as the involvement of more participants will provide more data regarding the role of WM and its relationship to reading performance of students with VI taking into account possible differences between the children classified as low vision and those classified as severely visually impaired.

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