RESEARCH ARTICLE

Intervention Targeting Reading and Working Memory among Struggling Readers in Primary School

Authors

Linda Fälth
Department of Pedagogy and Learning, Linnaeus University, Sweden
Irma Brkovic
Department of Pedagogical, Curricular and Professional Studies, University of Gothenburg, Sweden

Corresponding author:
Linda Fälth
Linnaeus University, Department of Pedagogy and Learning, P G Vejdesväg, 351 95, Växjö, Sweden,
linda.falth@lnu.se

Abstract

Working memory is one of our core cognitive functions. It allows us to keep information in mind for shorter periods of time, allowing us to process and work with that specific information. In this randomized control trial, the effects of a training program that combine reading training and working memory training among struggling readers aged 8-9 were investigated. 30 pupils were included in the intervention group and 17 were assigned to the control group. The intervention group received a total of 60 training sessions divided into two eight-week training periods with a four-week pause in between. The results show that children in the intervention group improved significantly better than children in the control group on eight tests: Reading comprehension, Word decoding, Nonsense-word reading, Short-term memory, Working memory, Visuospatial short-term memory, Visuospatial working memory and Working memory for words. The effect was not confirmed for Sight word seeing.

Keywords: Reading, reading difficulties, working memory, intervention, RCT

Introduction

Working memory (WM), the ability to process and remember information, has been described as a dynamic processing system with limited capacity that temporarily stores and processes information [1]. WM plays a crucial role during learning, including learning to read. This study investigated the influence of a combined reading and WM training on improving reading skills and WM. For the purpose of the current study, it is important to understand how deficits in WM impair reading skills. A poor WM capacity will affect the first crucial process when learning to read, the ability to recognize the correspondence between grapheme and phoneme, as well as holding the phonemes during the decoding process. Swanson and Beebe-Frankenberger [2] argued that WM is a resource that enables the learner to integrate information retrieved from long-term memory with current inputs. Thus, a poor WM may affect the child's ability to carry out important activities needed in the process of learning to read, especially reading comprehension. Given the importance of the WM system in reading development [3,4], it can be hypothesized that training WM abilities may affect the enhancement of reading skills. Research has found that training WM affected not only WM and attention abilities but also improved reading [5-8], decoding skills in adults with reading disability [9], decoding speed in adult dyslexic readers [10,11], and reading acquisition in children with special needs [12]. This area of research is growing rapidly. Many studies have found that training-related increases in WM capacity can lead to improvements in a range of important cognitive skills as well as improved cognitive function in clinical populations with known WM deficiencies [7].

As reading proficiency involves both cognitive abilities and skill acquisition, skill development and cognitive maturity will affect the relation between reading and WM. Studies have shown that children's reading skills can benefit from training focusing on phonological awareness, letter knowledge, language skills, speed of processing, and naming speed [e.g., 13,14]. In addition, Loosli et al [15]. showed that a computerized intervention with adaptive WM-training that monitored both processing and storage resources, conducted on typically developing children aged 9-11, significantly improved reading performance. A combination of training tasks targeting a variety of WM components is used in most of the studies on WM training for children with reading disabilities and/or dyslexia. This makes it difficult to determine whether WM training generates a general improvement in overall reading, or improves specific cognitive skills corresponding to the WM components that are targeted in training.

Low levels of WM performance are also widely reported in groups of children with difficulties in the areas of academic learning [e.g., 16,17]. These findings have led to assumptions that poor WM skills may contribute to problems in reading and mathematics. In children with reading difficulties and dyslexia, problems are mostly marked on verbal tasks that tap simple storage capacity (short-term memory or STM tasks) and more complex WM-tasks with verbal processing demands in addition to storage [18,19]. Weak storage in verbal STM also impairs the learning of novel phonological representations of new words [20,21]. It has been argued that close associations between deficits in WM and learning are simply common consequences of impairments in broader representational dimensions. Poor verbal STM and WM in children with language-related difficulties have been suggested to be a consequence of core impairments in either phonological processing or phonological representations that also impede mastery of the orthographic system [22,23]. In a review by Pennington and Bishop [24], a multifactorial model explains the existence of decoding difficulties, where the following cognitive abilities are identified as central: phonological awareness, short-term phonological memory, rapid automatized naming (RAN) and automation of reading. Research [e.g., 25,26]. also shows that the ability to focus is intimately associated with working memory as keeping the information in WM requires concentration.

In the context of reading, this means that to understand what is read, mental models are created in the WM and processed as we are reading. Reading is thus resource-intensive, concentration-intensive, and WM-intensive to varying degrees depending on the type of text, the purpose of reading, and what abilities the reader has [27]. A review by Peijnenborgh et al [28], focusing on whether WM training programs add value to children with learning disabilities, reports that most studies did not include decoding measures. However, the studies that did include decoding measurements showed a small but promising effect on decoding in children with language disorders that followed a WM training program compared to children who did not follow a WM training program. This is interesting as decoding skills were not a part of WM training and can be seen as far transfer effects. Two meta-analyzes [8,29]. and a study that included students with ADHD [30]. noted short-term effects, where students improved on the working memory tasks, they currently undertook but showed no long-term effects. Within the framework of the present study, working memory is trained in the context of reading training with the hypothesis that reading-related abilities should also be affected.

To alleviate children's difficulties resulting from poor WM, two approaches have been suggested. The first, an indirect approach aimed at minimizing failures in the classroom through effective classroom management of WM loads, a so-called bypass strategy where teachers are instructed to give simple task instructions or modify the time to fulfil a task [e.g., 31,32]. The consequence of this approach can be that children do not learn to internalize WM strategies. The second, a direct approach aimed to stimulate WM more explicitly as studies suggest that this direct approach using adaptive and extended training can improve WM capacity [25]. The effectiveness of both the implicit and explicit WM training methods is still under debate. A review study by Melby-Lervåg and Hulme [29] found that participants, after a course of four to five weeks of WM training, advanced in their performances on trained WM tasks. However, at a follow-up six months post-training, the positive effects were no longer found.

Gathercole et al [21], investigated the extent to which WM problems are present in individuals within a heterogeneous sample of pupils struggling academically in mainstream schooling. The pupils were referred to the research clinic by practitioners within education and community health services based on attention, learning, and memory problems. The majority of the pupils scored below the age-appropriate level on measures of literacy and mathematics. However, their mean vocabulary performance and nonverbal reasoning abilities were age-appropriate, although in the low average range. Classroom and teaching methods designed to compensate for, or avoid, WM- related learning failures such as minimizing WM loads, should be one key element in programs used in educational support for struggling learners [21,33,34]

One important responsibility for educators in primary school is to ensure that all pupils become competent readers. There is a need for effective instructional practices during this critical period as the achievement gap that may exist in students' abilities to read in early education tends to persist if no action is taken [35,36]. Early reading instruction has a well-established research base with a strong focus on the prevention of reading difficulties through early intervention [37]. The research base concludes that students with reading difficulties benefit from instruction that is explicit, purposeful and targeted. Many studies have suggested that pupils with dyslexia have deficient WM [38,39]. As a result, researchers have begun to focus on improving dyslexia through WM training. Within the framework of this study, a combination of reading training, reading comprehension and WM training was carried out to improve reading acquisition among the participants.

Research [40,41] has shown that structured training of phoneme/grapheme correspondence, with training from the simple to the more complex, has good effects on word decoding, spelling, phonological awareness and reading comprehension. There is also support for the so-called multi-component reading training programs to be more effective than those that are only intended to lead to the correct decoding of text [42]. Locascio et al [44] estimate that approximately 3% of students have reading comprehension difficulties while at the same time exhibiting an average word decoding ability. Their difficulties with reading comprehension are due to shortcomings in working memory, mainly the ability to plan, review and monitor their reading. Dahlin [44] conducted a study with 57 primary and middle school children who trained their working memory for 5 weeks using a computer- based program (Cogmed). The study showed that the children improved their working memory as well as significantly improving their reading comprehension. Dahlin [44] notes:" These results confirm the central role of working memory in reading comprehension, not only in the phonological loop, but in the central executive and the visuospatial working memory as well. This relation appears to be specific to reading comprehension tasks." (p. 488).

In a study, with a group of illiterate Portuguese women, different language abilities and working memory were tested at the same time as their brains were examined with PET cameras (positron emission tomography) [45]. The results showed that the illiterate participants underperformed both on tests measuring phonological awareness and tests measuring working memory in comparison with the literate participants in the control group. The researchers believed that one explanation may be that both phonological awareness and the habitual reader's knowledge of the word's visual form are tools for the brain to encode and retrieve verbal information from memory [45].

The aim of the present study was to test the effectiveness of a combined reading and WM intervention for working memory improvement among struggling readers in the lower grades of primary schools. Additionally, the effectiveness of the intervention on word decoding and reading comprehension was investigated.

Material and methods

Participants

To be included in the study, students A) should be identified by teachers as in need of extra support in Swedish and B) should score at least 1.5 SD below average on the word decoding test and reading comprehension test. Six of a total of 12 schools in a Swedish middle socioeconomic municipality were drawn to participate in the current study. The total number of pupils in the six schools was 789, and forty-seven pupils of them met the above criteria and were enrolled in the study, 27 boys and 19 girls. Their mean age was 8 years and 6 months. 30 pupils were randomly assigned to be part of the intervention group and 17 pupils formed a control group. The pupils were all native Swedish speakers. According to information obtained from homeroom teachers, they were all in need of extra support in reading and received special education in school. all guardians have given written permission to their child's participation in the study.

Measures

Reading comprehension. A reading comprehension test developed by Lundberg [46], *Which Picture Is Correct?,* which included 38 items consisting of four pictures accompanied by two or three sentences, was used. Only one picture corresponded exactly to the sentences. The task was to read the sentences and then mark the correct picture. The score was the total number of correct pictures subtracted by errors within 10 minutes. The comprising national norms for Grades 2 and 3 were used with a test–retest reliability of r = .88 [46].

Word decoding. Word decoding was assessed by the *Word-chains* test [47].The participant silently read chains of Swedish words where the blank space between words had been removed. Each chain consisted of three semantically unrelated words and the child was instructed to mark each word boundary with a pencil. The chains were constructed to have no ambiguities regarding boundary locations and had a large proportion of high-frequency words. The number of correctly marked word chains in 2 minutes was used as a measure of general word decoding skill. It was impossible to complete all 80 word-chains in 2 minutes. The *word-chain* test had test–retest correlations with an interval of 12 months between measurements of r = .80 to r = .90, in different groups of children in Grades 1 through 6 (47 Jacobson, 2014). Test–retest correlations between T1 and T2 in the present study was r = .88.

Sight word reading. The student was instructed to read as many words as possible from a list containing words with increasing difficulty and length (from 2 to 6 letters). Participants were asked to read simple words out loud as quickly as possible. The test was performed individually and the number of correctly read words was used as a measure of sight word reading, the maximum score being 100. The students were allowed to read for 45 seconds on each of the two test versions (A and B). Both results were summed up to increase reliability. Test–retest reliability for children aged 6–9 years was r = .97 [48].

Nonsense-word reading. The test had the same format as the Sight word reading test above but consisted of nonsense words instead of real words. The number of correctly read nonsense words was used as a measure of nonsense-word reading, with 100 as the maximum score. Test-retest reliability ranged from r = .84 to r = .86 in Grades 2 and 3 [48].

Short-term memory (STM). Short-term memory was assessed by *Digit Span*, a subtest from *Wechsler Intelligence Scale for Children–Fourth Edition* (WISC-IV) [49]. The task was to repeat digits (a span from two to nine) forwards in the correct order. Each correctly repeated digit span was scored.

Working memory. Working memory was also assessed by *Digit Span* from WISC-IV [49]. The task was to repeat digits (a span from two to eight) backward in the correct order. Each correctly repeated digit span was scored.

Visuospatial short-term and working memory. Corsi block span was used to assess visuospatial short-term and working memory. The participants were informed that they would be presented with a pattern consisting of blank squares that would be marked one at a time with Xs. They were asked to remember the position of each of the marked cells as well as the order in which they were marked. There were 12 positions, placed on the computer screen in a Corsi-type fashion [50], available for marking. The number of positions marked increased gradually to the maximum limit of six. There were three trials at each level of the task. The participants were requested to continue until the end of the task even if they could not manage to recall all the items. The total number of right answers was scored, the maximum was 63.

Working memory for words. We applied the same procedure as Siegel and Ryan [17]. The participants were presented sentences orally with the final word missing. The task was to supply the missing word and then to repeat all the missing words from the set. There were three trials at each set size or level (2, 3, 4, and 5). For example, "In summer it is very... ," "People go to see monkeys in a ... ," "With dinner we sometimes eat bread and ..." The child was then required to repeat the three words that he or she selected, in this case, hot, zoo, and butter, in the same order that the sentences had been presented. Task administration was stopped when the child failed all the items at one level. To minimize word-finding problems, the sentences were chosen so that the word was virtually predetermined. None of the children experienced any difficulty in supplying the missing word.

Training Program

The reading training program Omega-IS (Omega-Interactive Sentences) [51], uses a top-down strategy including both word- and sentence-level processing of written language. By clicking on text buttons with words or phrases, the child constructs a sentence, for example, “The lion chases the swan.” The child then hears the sentence being read by prerecorded human speech, followed by the meaning of the sentence being illustrated by an animation. The program offers correspondence between text, speech, and animations thus providing semantic comprehension and training of text material. The lessons included in the program went from two- (noun + verb) and three-word sentences (noun + verb + noun) to events where the child constructs its own stories. In total, it is possible to construct more than 1,900 different sentences, with feedback in the form of speech and animations, as described previously. By giving children the opportunity to create animations, through choosing different actors and scenarios, the program offers motivational literacy training. Also, as the language material of the program is meant to be explored by the pupil in interaction with a teacher, it gives an opportunity for conversations where the pupil can express his or her thoughts and imagination. In this study, Omega -IS was also used the other way around, i.e., the computer constructed an event/animation that was displayed on the screen. The pupil had to memorize this and create the sentence that best represented what he/she had just viewed. Immediate feedback with the number of correct words per sentence was obtained. During every session of the intervention, the instruction was to spend the same amount of time on these two parts of the program.

Procedure

Prior to the intervention, the trainers (N = 11 special education teachers) were instructed in the Omega-IS application by the authors during a one-day training in group settings. They also received individual consultations during the intervention.

There were three test occasions in total: one test session pre-intervention, one in the middle of the intervention (after 30 sessions) and a final test session after completion of the intervention. The participants received two eight-week training periods, with a four-week pause in between. Both training periods included a total of 30 one-to-one training sessions, 4 sessions per week for approximately 8 weeks. The special education teachers were instructed that the minimum time for a session was 15 minutes but that longer times were preferred. Most sessions lasted 15 to 20 minutes resulting in an average total training time of 491 minutes/participant (SD = 36, N = 30). After the 30 sessions, all participants received a pause for 4 weeks before the next training period. During the second training period, each participant received a total of 30 training sessions, 4 sessions per week for approximately 8 weeks. The average total training time was 498 minutes/participant (SD = 42, N = 30). There were no dropouts and all pupils received 60 training sessions within two eight-week periods. The number of sessions per week varied from 2 (two pupils had at least one training week with only 2 sessions) to 5 sessions per week (21 pupils had at least one training week with 5 sessions).

The pupils in the intervention group did not receive any additional special education in addition to the intervention. The pupils in the control group received treatment as usual i.e., they received the teaching that the class teacher and the special education teacher planned for the whole class. 15 of the 17 students in the control group were taught in small groups, 2 to 3 occasions per week. The other two students in the control group received no special education outside the classroom. In addition, a special education teacher was available in the classroom on 5 occasions per week, one lesson per day.

Results

Descriptive statistical indicators are shown in Table 1, for all investigated outcomes. There were three test occasions: one test occasion pre-intervention (Pretest), one in the middle of the intervention (after 30 sessions, Intermediate test) and one after the completion of the intervention (Posttest). All 47 participants were tested at all three test occasions and are included in the tables and figures as well as in the corresponding statistical analyses.

Table 1: Descriptive statistics for nine outcomes, at three test occasions, for Intervention and Control group.

		Intervention group (*N* = 30)		Control group (*N* = 17)	
Outcome	Test occasion	*M*	*SD*	*M*	*SD*
Reading comprehension	T 1	5.93	2.50	6.76	1.71
	T 2	11.20	3.91	9.35	1.22
	T 3	14.67	4.29	10.88	0.49
Word decoding	T 1	7.30	3.52	7.82	3.54
	T 2	11.93	4.37	9.94	2.95
	T 3	15.30	4.39	10.76	3.11
Sight word reading	T 1	22.80	8.58	22.00	7.80
	T 2	22.90	6.49	22.24	8.95
	T 3	28.10	9.46	25.35	7.66
Nonsense-word reading	T 1	15.20	5.49	17.06	6.81
	T 2	22.43	7.90	19.29	5.51
	T 3	26.23	9.51	20.35	5.10
Short-term memory	T 1	6.57	1.92	6.94	1.64
	T 2	7.07	1.57	7.06	1.68

	T 3	7.73	1.28	7.00	1.58
	T 1	3.87	1.57	4.41	1.54
Working memory	T 2	4.47	1.63	4.88	1.36
	T 3	4.97	1.50	4.76	1.25
	T 1	5.50	0.86	5.65	1.12
Visuospatial short-term memory	T 2	6.43	1.17	5.82	1.24
	T 3	8.43	1.01	6.35	1.00
	T 1	14.30	4.74	14.47	3.94
Visuospatial working memory	T 2	17.50	4.63	15.29	3.20
	T 3	19.57	4.61	15.59	3.10
	T 1	23.03	4.57	24.06	3.96
Working memory for words	T 2	28.03	5.39	24.41	4.20
	T 3	29.20	4.69	24.12	3.71

Note. T 1-Pretest, T 2-Intermediate test, T 3 -Posttest

The effects of the intervention were tested on nine different outcome tests. Nine separate two-way repeated ANOVA (2x3) analyses were conducted, with group (Intervention, Control) as between-subjects and Test occasion (Pretest, Intermediate test, Posttest) as within-subject factor. Where Mauchly´s test indicated that sphericity assumption was violated, results are reported for corrected degrees of freedom. Depending on the size of sphericity statistic (Greehouse-Geisser Epsilon) the Greehouse-Geisser correction (where $\varepsilon < .75$), or Huynh-Feldt correction (where $\varepsilon > .75$) was calculated. A summary of all analyses is presented in Table 2. Figures 1 shows results for each outcome separately. The main effect of Group (Control, Intervention) was not significant for any outcomes apart from Visuospatial short-term memory. The main effect of Test occasion (Pretest, Intermediate test, Posttest) was statistically significant for all outcomes, indicating an increase in results over time (Table 2).

Table 2: Results of two-way repeated ANOVA´s for nine outcomes

	Main effect - Test occasion	Main effect -Group	Group X Test occasion interaction	η_p^2 for interaction effect
Reading comprehension	*F*(1.450, 65.246) = 135.82 *p* < .000	*F*(1, 45) = 4.02 *p* = .082	*F*(1.450, 65.246) = 17.39 *p* < .000	.279
Word decoding	*F*(1.807, 81.318) = 67.48 *p* < .000	*F*(1, 45) = 3.85 *p* = .560	*F*(1.807, 81.318) = 14.17 *p* < .000	.239
				.297

Sight word reading	$F(2, 90) = 19.01$ $p < .000$	$F(1, 45) = .365$ $P = .55$	$F(2, 90) = 1.07$ $p = .346$	
Nonsense-word reading	$F(1.271, 57.190) = 63.42$ $p < .000$	$F(1, 45) = 1.36$ $p = .249$	$F(1.271, 57.190) = 18.39$ $p < .000$	.290
Short-term memory	$F(1.763, 75.047) = 6.71$ $p = .003$	$F(1, 45) = .073$ $p = .788$	$F(1.763, 75.047) = 5.66$ $p = .007$	.112
Working memory	$F(1.591, 71.576) = 13.70$ $p < .000$	$F(1, 45) = .35$ $p = 556$	$F(1.591, 71.576) = 3.85$ $p < .035$	.079
Visuospatial working memory	$F(1.682, 75.671) = 29.46$ $p < .000$	$F(1, 45) = 2.79$ $p = .102$	$F(1.682, 75.671) = 12.25$ $p < .000$	.214
Working memory for words	$F(2, 90) = 28.45$ $p < .000$	$F(1, 45) = 3.92$ $p = .054$	$F(2, 90) = 25.46$ $p < .000$	. 361

To answer the research questions, the central focus of analyses is the analysis of Group X Test occasion interaction effect. The significant interaction effect indicates that the increase in result is different for Intervention and Control group, suggesting a positive outcome of the intervention. As seen in Table 2 and Figure 1, the interaction between Group and Test occasion was significant for all but one outcome. The change between test occasions, for Sight word seeing, was not significantly different for Intervention and Control group. For all other outcomes (Reading comprehension, Word decoding, Nonsense-word reading, Short-term memory, Working memory, Visuospatial short-term memory, Visuospatial working memory and Working memory for words) the intervention group improved significantly better, compared to the control group from Pretest (pre-intervention) over Intermediate test (after the first intervention period) to Posttest (after the second intervention period). The direction of changes is shown in Figure 1.

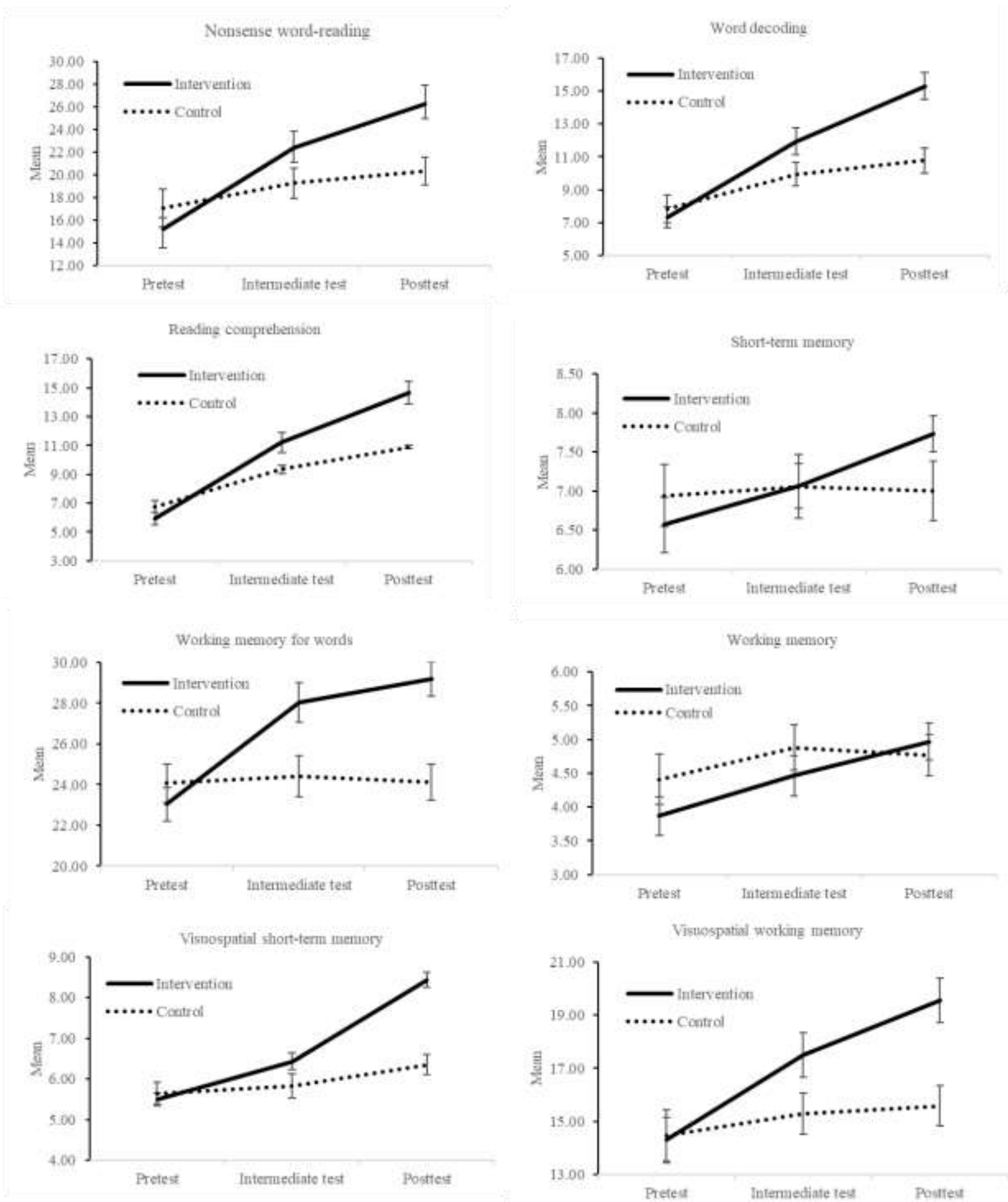

Figure 1: The change in average results for Control and Intervention group, between Pretest, Intermediate and Posttest, on 8 short-term memory and language tests. Error bars represent Mean *SE*s. Note. All means are calculated for same children in Intervention (N = 30) and Control (N = 17) group.

Discussion

On average, there will be about four pupils in a class of 30 who have WM abilities as low as the participants in this study, and they will typically be making poor academic progress [52]. This study provides a demonstration that these commonplace deficits and associated reading difficulties can be ameliorated by intensive adaptive training over a training period of eight plus eight weeks. In the present study, a combination of reading training and WM training is examined among children with reading difficulties. Results showed that pupils in the intervention group show statistically better improvement than control group children on several tests of working memory (Short-term memory, Working memory, Visuospatial short-term memory, Visuospatial working memory, Working memory for words), as well as on tests measuring reading comprehension and word decoding.

Educators in primary school need to ensure that all pupils become competent readers. There is a need for effective instructional practices during this critical period as the achievement gap that may exist in students' ability to read in early education tends to persist if no action is taken [34-36]. The majority of the children who participated in this combined training improved their WM as well as decoding scores substantially. Our data further indicated that training programs combining reading and WM training improved word decoding compared with the untrained group. These results are in line with those of Loosli et al [15] and Nevo and Breznitz [4] who found gains in performance in the reading of text and words in 9- to 11-year-olds. They claimed that the transfer reading performance task shares important features with the training task that was found to be related to reading speed.

When reading, working memory and long-term memory interact. To achieve automated reading, the reader needs to find the phonemes in the long-term memory and process and retain them in the working memory, as phonemes are learned components of words. Reading and writing thus require flexibility and error-free activity of the memory functions. The short-term phonological layer, which according to Baddley [1] is part of the working memory, can retain phonological material for a few seconds. Thereafter, the information disappears from memory if it has not been further processed and transferred to the subvocal repetition component, which can "bind" the material for a longer period [20] The ability to capture completely new words you hear is probably to a large extent dependent on our phonological short-term storage as well as on how rich our network of connections in the long-term memory dictionary is. When the student hears a new word for the first time, there is already a phonological representation for several parts of the word in the long-term memory dictionary. Semantic representations for parts of the word also exist. If the student has learned to read, there is also an orthographic representation for parts of the word that makes the word easier to perceive. The training program used in this study contains a word bank with 200 words which allows pupils to create 1936 sentences. The aim was to use both simple and well-known words as well as words that are not common, perhaps completely new to the student. The training program provides a correspondence between text, speech, and animations. This provides semantic comprehension of text material, which supports the understanding of what is read, and thus eases the load on the working memory.

Daneman and Carpenter [53] proposed a so-called "Reading span task" to measure complex working memory. Students are given the task of reading a sentence and remember the last word. After a series of sentences, the test person must repeat the last words in all sentences in the order in which they are presented. The student must thus simultaneously process and store information. The number of words that can be repeated in the correct order is seen as a measure of working capacity. The present study contains a variant of this type of task (Working memory for words) and the results show that a significant improvement in the intervention group, compared to the control group, occurred. Both Just and Carpenter [54] and Waters and Caplan (1996) argue that "reading span tasks" provide a measure of working memory capacity. However, Just and Carpenter [54] see this capacity as central to language comprehension, while Waters and Caplan [55] suggest that "reading span tasks" test conscious attention control in working memory.

This study, a relatively brief intervention including reading and reading comprehension linked to working memory tasks, improved abilities that are important in everyday life and thus contributes to the scholastic achievement of children in elementary school. These abilities include working memory and short-term memory, both on verbal and visuospatial tasks. The current study provides more evidence of the positive transfer effects of WM training on reading in the context of pupils with reading difficulties in early grades. Studies show that the ability to focus is intimately associated with working memory. This is another way of linking working memory to reading ability [25, 34] as information can be kept in the working memory through concentration. This can thus be applied to reading, as to understand what is read, you have to think while reading. We must constantly create mental models, keep them in mind, and relate them to each other while we read. According to this reasoning, a strong working memory can have a positive effect on the ability to concentrate, which in turn can have a positive effect on the ability to read. The results from the present study show that students who have difficulty with reading can increase their word decoding ability and reading comprehension, by combining training of the working memory ability with reading training. Several factors can be linked to the contribution of students' development: a successful intervention, in this case, a combined working memory and reading training, students' increased motivation due to the extra attention received whilst taking part in a research project, and the feeling of success as students, within the framework of a training program, become aware of their own progress. To understand how this type of intervention affects reading ability in the long term, more studies in the field are needed. Also, as transfer effects between WM training and increased reading ability [56] as well as other cognitive abilities are difficult to study, future studies will need more explicit clarifications of the specific mechanisms that generate training gains.

Limitations

Some important limitations of the study must be noted. First, this study consists of pre- and post-tests. In order to comment on how the results stand over time, long-term longitudinal studies are needed to follow up the effects. Second, the number of participants in the control group is lower than in the intervention group, which affected statistical assumptions for conducting mixed ANOVA analysis.

CRediT author statement

Linda Fälth: Conceptualization, Methodology, Data collection, Writing- Original draft preparation. **Irma Brkovic**: Statistical analyses, Writing- Reviewing and Editing.

References

1. Baddeley, A. (2003). Working memory: looking back and looking forward. *Nature reviews neuroscience*, *4*(10), 829-839. http://dx.doi.org/10.1038/nrn1201
2. Swanson, H. L., & Beebe-Frankenberger, M. (2004). The relationship between working memory and mathematical problem solving in children at risk and not at risk for serious math difficulties. *Journal of educational psychology*, *96*(3), 471. http://dx.doi.org/10.1037/0022-0663.96.3.471
3. Gathercole, S. E. (2006). Nonword repetition and word learning: The nature of the relationship. *Applied psycholinguistics*, *27*(4), 513. http://dx.doi.org/10.1017/S0142716406060383
4. Nevo, E., & Breznitz, Z. (2013). The development of working memory from kindergarten to first grade in children with different decoding skills. *Journal of experimental child psychology*, *114*(2), 217-228. http://dx.doi.org/10.1016/j.jecp.2012.09.004
5. Brehmer, Y., Westerberg, H., & Bäckman, L. (2012). Working-memory training in younger and older adults: training gains, transfer, and maintenance. *Frontiers in human neuroscience*, *6*, 63. http://dx.doi.org/10.3389/fnhum.2012.00063
6. Burns, M. K., Davidson, K., Zaslofsky, A. F., Parker, D. C., & Maki, K. E. (2018). The relationship between acquisition rate for words and working memory, short-term memory, and reading skills: Aptitude-by-treatment or skill-by-treatment interaction?. *Assessment for Effective Intervention*, *43*(3), 182-192. http://dx.doi.org/10.1177/1534508417730822
7. Klingberg, T., Fernell, E., Olesen, P. J., Johnson, M., Gustafsson, P., Dahlström, K., ... & Westerberg, H. (2005). Computerized training of working memory in children with ADHD-a randomized, controlled trial. *Journal of the American Academy of child & adolescent psychiatry*, *44*(2), 177-186. http://dx.doi.org/10.1097/00004583-200502000-00010
8. Peng, P., Barnes, M., Wang, C., Wang, W., Li, S., Swanson, H. L., ... & Tao, S. (2018). A meta-analysis on the relation between reading and working memory. *Psychological bulletin*, *144*(1), 48. http://dx.doi.org/10.1037/bul0000124
9. Shiran, A., & Breznitz, Z. (2011). The effect of cognitive training on recall range and speed of information processing in the working memory of dyslexic and skilled readers. *Journal of Neurolinguistics*, *24*(5), 524-537. http://dx.doi.org/10.1016/j.jneuroling.2010.12.001
10. Gray, S., Fox, A. B., Green, S., Alt, M., Hogan, T. P., Petscher, Y., & Cowan, N. (2019). Working memory profiles of children with dyslexia, developmental language disorder, or both. *Journal of Speech, Language, and Hearing Research*, *62*(6), 1839-1858. http://dx.doi.org/10.1044/2019_JSLHR-L-18-0148
11. Horowitz-Kraus, T., & Breznitz, Z. (2009). Can the error detection mechanism benefit from training the working memory? A comparison between dyslexics and controls an ERP study. *PloS one*, *4*(9), e7141.
12. Dahlin, K. I. (2011). Effects of working memory training on reading in children with special needs. *Reading and writing*, *24*(4), 479-491. http://dx.doi.org/10.1007/s11145-010-9238-y
13. Morris, R. D., Lovett, M. W., Wolf, M., Sevcik, R. A., Steinbach, K. A., Frijters, J. C., & Shapiro, M. B. (2012). Multiple-component remediation for developmental reading disabilities: IQ, socioeconomic

status, and race as factors in remedial outcome. *Journal of Learning Disabilities*, *45*(2), 99-127. http://dx.doi.org/10.1177/0022219409355472

14. Otaiba, S., & Fuchs, D. (2006). Who are the young children for whom best practices in reading are ineffective? An experimental and longitudinal study. *Journal of Learning Disabilities*, *39*(5), 414-431.
15. Loosli, S. V., Buschkuehl, M., Perrig, W. J., & Jaeggi, S. M. (2012). Working memory training improves reading processes in typically developing children. *Child Neuropsychology*, *18*(1), 62-78. http://dx.doi.org/10.1080/09297049.2011.575772
16. Archibald, L. M., & Gathercole, S. E. (2006). Short-term and working memory in specific language impairment. *International Journal of Language & Communication Disorders*, *41*(6), 675-693. http://dx.doi.org/10.1080/13682820500442602
17. Siegel, L. S., & Ryan, E. B. (1989). The development of working memory in normally achieving and subtypes of learning disabled children. *Child development*, 973-980. http://dx.doi.org/10.2307/1131037
18. Kudo, M. F., Lussier, C. M., & Swanson, H. L. (2015). Reading disabilities in children: A selective meta-analysis of the cognitive literature. *Research in developmental disabilities*, *40*, 51-62. http://dx.doi.org/10.1016/j.ridd.2015.01.002
19. Swanson, H. L., Zheng, X., & Jerman, O. (2009). Working memory, short-term memory, and reading disabilities: A selective meta-analysis of the literature. *Journal of learning disabilities*, *42*(3), 260-287. http://dx.doi.org/10.1177/0022219409331958
20. Baddeley, A., Gathercole, S., & Papagno, C. (1998). The phonological loop as a language learning device. *Psychological review*, *105*(1), 158. http://dx.doi.org/10.1037/0033-295X.105.1.158
21. Gathercole, S. E., Woolgar, F., Kievit, R. A., Astle, D., Manly, T., Holmes, J., & CALM Team. (2016). How common are WM deficits in children with difficulties in reading and mathematics?. *Journal of applied research in memory and cognition*, *5*(4), 384-394. http://dx.doi.org/10.1016/j.jarmac.2016.07.013
22. Metsala, J. L. (1999). Young children's phonological awareness and nonword repetition as a function of vocabulary development. *Journal of educational psychology*, *91*(1), 3. http://dx.doi.org/10.1037/0022-0663.91.1.3
23. Ramus, F., Marshall, C. R., Rosen, S., & Van Der Lely, H. K. (2013). Phonological deficits in specific language impairment and developmental dyslexia: towards a multidimensional model. *Brain*, *136*(2), 630-645. http://dx.doi.org/10.1093/brain/aws356
24. Pennington, B. F., & Bishop, D. V. (2009). Relations among speech, language, and reading disorders. *Annual review of psychology*, *60*, 283-306. http://dx.doi.org/10.1146/annurev.psych.60.110707.163548
25. Klingberg, T. (2013). *The learning brain: Memory and brain development in children*. Oxford University Press.
26. Singer, B. D., & Bashir, A. S. (2018). Wait… What??? Guiding Intervention Principles for Students With Verbal Working Memory Limitations. *Language, speech, and hearing services in schools*, *49*(3), 449-462. http://dx.doi.org/10.1044/2018_LSHSS-17-0101

27. Kamhi, A. G., & Catts, H. W. (2013). *Language and Reading Disabilities: Pearson New International Edition*. Pearson Higher Ed.
28. Peijnenborgh, J. C., Hurks, P. M., Aldenkamp, A. P., Vles, J. S., & Hendriksen, J. G. (2016). Efficacy of working memory training in children and adolescents with learning disabilities: A review study and meta-analysis. *Neuropsychological rehabilitation*, *26*(5-6), 645-672. http://dx.doi.org/10.1080/09602011.2015.1026356
29. Melby-Lervåg, M., & Hulme, C. (2013). Is working memory training effective? A meta-analytic review. *Developmental psychology*, *49*(2), 270. http://dx.doi.org/10.1037/a0028228
30. Chacko, A., Bedard, A. C., Marks, D. J., Feirsen, N., Uderman, J. Z., Chimiklis, A., ... & Ramon, M. (2014). A randomized clinical trial of Cogmed working memory training in school-age children with ADHD: A replication in a diverse sample using a control condition. *Journal of Child Psychology and Psychiatry*, *55*(3), 247-255. http://dx.doi.org/10.1111/jcpp.12146
31. Alloway, T. P., Gathercole, S. E., & Elliott, J. (2010). Examining the link between working memory behaviour and academic attainment in children with ADHD. *Developmental Medicine & Child Neurology*, *52*(7), 632-636. http://dx.doi.org/10.1111/j.1469-8749.2009.03603.x
32. St Clair-Thompson, H., Stevens, R., Hunt, A., & Bolder, E. (2010). Improving children's working memory and classroom performance. *Educational Psychology*, *30*(2), 203-219. http://dx.doi.org/10.1080/01443410903509259
33. Elliott, J. G., Gathercole, S. E., Alloway, T. P., Holmes, J., & Kirkwood, H. (2010). An evaluation of a classroom-based intervention to help overcome working memory difficulties and improve long-term academic achievement. *Journal of Cognitive Education and Psychology*, *9*(3), 227-250. http://dx.doi.org/10.1891/1945-8959.9.3.227
34. Johann, V., Könen, T., & Karbach, J. (2020). The unique contribution of working memory, inhibition, cognitive flexibility, and intelligence to reading comprehension and reading speed. *Child Neuropsychology*, *26*(3), 324-344. http://dx.doi.org/10.1080/09297049.2019.1649381
35. Gersten, R., Compton, D., Connor, C. M., Dimino, J., Santoro, L., Linan-Thompson, S., & Tilly, W. D. (2009). Assisting students struggling with reading: Response to intervention and multi-tier intervention in the primary grades. *A practice guide.*
36. Snow, C. E., Burns, S. M., & Griffin, P. (1998). Predictors of success and failure in reading. *Preventing reading difficulties in young children*, 137-171.
37. National Reading Panel (US), National Institute of Child Health, & Human Development (US). (2000). *Teaching children to read: An evidence-based assessment of the scientific research literature on reading and its implications for reading instruction: Reports of the subgroups*. National Institute of Child Health and Human Development, National Institutes of Health.
38. Hernandez, N., Andersson, F., Edjlali, M., Hommet, C., Cottier, J. P., Destrieux, C., & Bonnet-Brilhault, F. (2013). Cerebral functional asymmetry and phonological performance in dyslexic adults. *Psychophysiology*, *50*(12), 1226-1238. http://dx.doi.org/10.1111/psyp.12141
39. Smith-Spark, J. H., & Fisk, J. E. (2007). Working memory functioning in developmental dyslexia. *Memory*, *15*(1), 34-56. http://dx.doi.org/10.1080/09658210601043384

40. Hatcher, P. J., Hulme, C., & Snowling, M. J. (2004). Explicit phoneme training combined with phonic reading instruction helps young children at risk of reading failure. *Journal of child Psychology and Psychiatry*, *45*(2), 338-358. http://dx.doi.org/10.1111/j.1469-7610.2004.00225.x
41. Suggate, S. P. (2016). A meta-analysis of the long-term effects of phonemic awareness, phonics, fluency, and reading comprehension interventions. *Journal of learning disabilities*, *49*(1), 77-96. http://dx.doi.org/10.1177/0022219414528540
42. Melby-Lervåg, M., Lyster, S. A. H., & Hulme, C. (2012). Phonological skills and their role in learning to read: a meta-analytic review. *Psychological bulletin*, *138*(2), 322. http://dx.doi.org/10.1037/a0026744
43. Locascio, G., Mahone, E. M., Eason, S. H., & Cutting, L. E. (2010). Executive dysfunction among children with reading comprehension deficits. *Journal of learning disabilities*, *43*(5), 441-454. http://dx.doi.org/10.1177/0022219409355476
44. Dahlin, K. I. (2013). *Does it pay to practice?: a quasi-experimental study on working memory training and its effects on reading and basic number skills* (Doctoral dissertation, Department of Special Education, Stockholm University).
45. Castro-Caldas, A., & Reis, A. (2003). The knowledge of orthography is a revolution in the brain. *Reading and Writing*, *16*(1), 81-97.
46. Lundberg, I. (2001). Vilken bild är rätt? Stockholm: Natur och kultur.
47. Jacobson, C. (2014). *Läskedjor 2 Handledning*. Stockholm: Hogrefe.
48. Elwér, Å., Fridolfsson, I., Samuelsson, S., & Wiklund, C. (2013). LäSt-Test i läsförståelse, läsning och stavning. *Stockholm: Hogrefe Psykologiförlaget AB.*
49. Petermann, F., & Petermann, U. (2011). Wechsler Intelligence Scale for Children®–Fourth Edition. *Frankf. M Pearson Assess.*
50. Corsi, P. (1973). *Human memory and the medial temporal region of the brain*. Dissertation Abstracts International, 34(2-B), 891.
51. Heimann, M., Lundälv, M., Tjus, T., & Nelson, K. E. (2004). *Omega–Interactive Sentences, a multimedia software for language exploration and play*. Göteborg: Topic Data & Språkbehandling HB.
52. Gathercole, S., & Alloway, T. P. (2008). *Working memory and learning: A practical guide for teachers*. Sage.
53. Daneman, M., & Carpenter, P. A. (1980). Individual differences in working memory and reading. *Journal of verbal learning and verbal behavior*, *19*(4), 450-466. http://dx.doi.org/10.1016/S0022-5371(80)90312-6
54. Just, M. A., & Carpenter, P. A. (1992). A capacity theory of comprehension: Individual differences in working memory. *Psychological Review*, *99*, 122-149. http://dx.doi.org/10.1037/0033-295X.99.1.122
55. Waters, G. S., & Caplan, D. (1996). The measurement of verbal working memory capacity and it's relation to reading comprehension. *The Quarterly Journal of Experimental Psychology*, *49A*, 51-79.
56. Sala, G., & Gobet, F. (2017). Does far transfer exist? Negative evidence from chess, music, and working memory training. *Current directions in psychological science*, *26*(6), 515-520. http://dx.doi.org/10.1177/0963721417712760.

