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What makes an excellent reader? Short-term memory contrasts between two groups of children

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Purpose: Research on the association of short-term memory (STM) and reading expertise are dominated by studies with typically developing children and children with reading impairment. Many studies confirmed the role of short-term memory in reading development and reading, especially in the case of verbal and phonological STM. The current study takes an unusual perspective by contrasting age-appropriate readers with excellent readers (reading performance with at least 1 SD above average) on three different short-term memory skills: phonological STM, verbal STM and visuospatial STM.

Methods: We identified and recruited six groups of children. Three groups performed at least one SD above average in two standardized reading tasks (excellent readers), the three control groups performed within the domain of ±0.5 SD on reading (age-appropriate readers). One group of excellent readers and one group of age-appropriate readers participated in a Phonological Short-Term Memory (STM) task, one pair of groups participated in a Verbal STM task, whereas the last pair participated in a Visuospatial STM task.

Results: Pairwise comparisons demonstrated that excellent readers outperformed age-appropriate readers in Visuospatial STM. Phonological STM only differed across the groups after controlling for age. No group difference was observed in Verbal STM.

Conclusion: Our results confirm the role of short-term memory in reading expertise. However, data highlights that visuospatial and phonological information becomes more relevant in above-average readers. Results are discussed along grain-size theory, and whether and how focused educational programs can build on visuospatial short-term memory training to achieve better reading.

KEYWORDS

word reading, pseudoword reading, excellent readers, phonological short-term memory, verbal short-term memory, visuospatial short-term memory

1 What makes an excellent reader? Short-term memory contrasts between two groups of children

Reading is among the most important academic skills. Especially Western societies rely heavily on written information: all agreements, all contracts must be documented in a written format, so literacy is inevitable to navigate within the society. In accordance, one of the major focuses of primary education is to support children in literacy development. Primary education is not only an opportunity, but most countries oblige their children to primary education. Since reading is such an important skill, it is necessary to understand how different cognitive factors support reading development, and how these underlying cognitive factors may be used to further enhance reading development. The current study is aimed to understand how different types of short-term memory underlie reading skills. While many previous studies have focused on children with deficient reading skills, our aim is to unravel how exceptionally good readers differ from their peers with age-appropriate skills. In accordance, the following study compares the short-term memory performance of excellent readers (more than 1 SD above average) and typical readers on three different short-term memory (STM) paradigms: a verbal STM task, a phonological STM task, and a visuospatial STM task.

The introduction below summarizes previous studies addressing the association between reading and working memory from various perspectives. On the one hand, research was aimed at identifying whether and how individual differences in reading are explained by underlying memory skills. On the other hand, research addressed how children with impaired reading skills differ from typical readers in working memory abilities. Reading is a complex skill during which the individual decodes visual stimuli into phonological information. Thus reading can in principle be associated with both visual and verbal short term memory functions. This is especially true due to the changing nature of reading throughout development.

In the earliest, pre-reading phase, children identify and recognize certain words, like their own names. These written words are not analyzed though, rather stored as complex visual images (Frith, 1985; Genisio and Bastien-Toniazzo, 2003). Next, children have to identify that letters and speech sounds correspond (Seymour and Elder, 1986; Morton, 1989; Froyen et al., 2009). This is the alphabetic principle, which is a prerequisite of reading (Byrne and Fielding-Barnsley, 1989; Liberman et al., 1989; Landerl et al., 2018). By the end of kindergarten years, children learn more and more letters, but mainly associate them with letter names (Thompson, 2009). Only during the early stages of primary education do children start to decode letters and combine the underlying phonological representations (Seymour and Elder, 1986; Ehri, 1991, 1997; Georgiou et al., 2020). Structured input helps them systematically identify the letter-speech sound correspondences, fine-tune their sensitivity to visual symbols appearing in their own languages (Brem et al., 2010; Froyen et al., 2010). At this point, children mainly decode the information sequentially. With practice, children develop and store orthographic representations of larger sublexical (Roembke et al., 2019) and lexical units (Goswami et al., 1998), which opens way to sight-word reading, which is the most optimal way of reading (Ehri, 2005, 2014). There could be certain differences due to educational policies: for example, school starts in England a year earlier than in Austria (Steiner et al., 2021).

Since reading is decoding visual symbols into phonological content, phonological abilities are among the best predictors of reading development (Castles et al., 2003; Farrar and Ashwell, 2008; Landerl et al., 2018), and they also serve as one of the best clinical markers of developmental dyslexia (Alexander et al., 1991; Ramus and Szenkovits, 2008). During the process of reading development, reading becomes a fairly automated skill (Froyen et al., 2009; Roembke et al., 2019), which leads to a decreasing role of phonological awareness. Children divert from sequential decoding and one-to-one mapping of letters and speech sounds, and rely more on a more holistic way of reading, that is word recognition (Ehri, 2014). Such an advanced process rather loads on access to orthographic representations and their associated phonological forms than manipulation of speech sounds (Moll and Landerl, 2009). Empirical studies indeed demonstrated that while the resolution of phonological awareness increases with age (Goswami, 1999, 2002), its explanatory power decreases with reading expertise (Hogan et al., 2005; Powell and Atkinson, 2021).

While children are expected to divert from the deployment of phonological knowledge with increasing reading experience, the role of verbal skills is not that obvious. While verbal short-term memory has also been identified as a clinical marker of dyslexia (Mann and Liberman, 1984; Brady, 1986), a causal relationship between reading and verbal short-term memory has not been fully supported (Melby-Lervåg, 2012; Melby-Lervåg and Hulme, 2013). That is, although children with dyslexia seem to have a below average verbal short-term memory capacity, individual differences in verbal STM do not seem to explain individual differences in reading within the typically developing domain. On the other hand, there can be an indirect effect, as verbal STM explains variance of the development of vocabulary (Gupta and Mac Whinney, 1997; Jarrold et al., 2004; Verhagen and Leseman, 2016), which in turn could translate into lexical quality, leading to better reading abilities (Perfetti, 2007).

The section above discussed why phonological and verbal skills may contribute to the development of reading. Not only spoken skills are relevant to reading, but also the processing of visual information. Visual input is neither invariant, nor noise-free. Letters, letter-clusters, words and scripts in general vary in numerous characteristics, like font, size, color or contrast. Despite this variance, orthographic units are still identified, at least when fonts are not dysfluent (Astley et al., 2023). The abstract letter units are assumed to be the smallest units of orthographic processing (Finkbeiner and Coltheart, 2009). These are common categories of letters with the same identity, regardless of their real physical appearance (Thompson, 2009; Carreiras et al., 2013). The existence of these abstract units demonstrate that certain visual features can be or are discounted when processing orthographic input.

Not only visual, but also spatial features can be disregarded during the process of reading. Individuals are able to activate the underlying orthographic representations even when certain letters are substituted with each other or with other letters. These are mostly known as transposed (Carreiras et al., 2007; Perea and Carreiras, 2008; Luke and Christianson, 2012) and substituted letter effect (Lété and Fayol, 2013; Varga et al., 2021; Hasenäcker and Schroeder, 2022). Research on these phenomena demonstrate that noise in letter identity as well as letter position can be disregarded during reading (flexibility was smaller in individuals with developmental dyslexia, e.g., Lété and Fayol, 2013; Kirkby et al., 2022). Since letter transposition is easier to overcome than letter substitution, it was proposed that certain sublexical orthographic units are stored and/or processed without an internal spatial structure. Open bigrams are combinations of two letters irrelevant of their order. The lack of spatial specification in these open bigrams, however, supports quick recognition and overcoming spelling errors, like the above-mentioned letter transposition (Grainger and Whitney, 2004; Lupker et al., 2015).

In sum, the above review suggests that during typical reading development, children should rely less and less on their phonological and visual processing abilities, while it is not clear whether reading experience qualifies the association verbal short-term memory and reading. Less is known about atypical readers, and even this knowledge is rooted in studies with developmental dyslexia, documenting decreased performance in all three domains, that is, phonological (Tiffin-Richards et al., 2008; Franceschini and Bertoni, 2019), verbal (Trecy et al., 2013; Majerus and Cowan, 2016), and visuospatial short-term memory (Smith-Spark et al., 2003; Bacon et al., 2013).

In the current study we take an unconventional perspective in examining how the contribution of phonological, verbal and visual short-term memory changes with reading expertise. We recruited excellent readers, that is, children who are at least 1 standard deviation above the age-appropriate level of reading, and compared their performance to children with age-appropriate reading skills (within the domain of ±0.5 SD). Excellent readers and typical readers were contrasted on their phonological, verbal and visuospatial short-term memory performance. It is important to note that Baddeley's working memory model does not differentiate between verbal and phonological short-term memory, since both load on the phonological loop. However, the two skills differ in their characteristics. Verbal STM is the memorization of known words based on their meaning, while Phonological STM requires an accurate coding of phonological input in the absence of semantic scaffolding, thus relying more on complex phonological processes (e.g., Dillon and Pisoni, 2006). We hypothesized two possibilities. On the one hand, if reading development requires relying less and less on phonological and visuospatial processing, we would expect no difference in visuospatial and phonological short-term memory between expert and age-appropriate readers. Whereas if results from developmental dyslexia are applicable on the other side of the spectrum, we should expect better performance of short-term memory in excellent readers in all three domains.

2 Methods

2.1 Participants

The current study is a part of the standardization of the Hungarian VOLT word and pseudoword reading test (Kemény et al., 2023). Within the standardization process, children from grade 1 s semester to grade 6 s semester were recruited. The aim was to collect age-norms across these 11 times points. The standardization process included data from 1952 children from various schools from western Hungary. Along with the reading tests, children did one of three memory tasks as well: the nonword repetition task measuring Phonological Short-Term Memory, the digit recall task measuring Verbal Short Term Memory, or the computerized version of the Corsi blocks task, measuring Visuospatial Short-Term Memory. Each child completed only one of the memory tasks. Out of the 1952 children, we filtered and report data of those children (1) who met the criterion of typical readers' or excellent readers', and (2) who had a completed memory task. Furthermore, each of the memory tasks had practice items. We only included participants who succeeded on the practice items. Altogether 319 children were included in the data analysis, one child had data from all three tasks, whereas all others completed only one of the memory paradigms. Since the different memory-tasks cannot be compared with each other, we present the results separately across the memory tasks.

Children were either typical readers or excellent readers. We defined the two groups based on reading performance. Typical readers are readers who perform between −0.5 and 0.5 standard deviations on both the word and pseudoword reading task of the VOLT (Kemény et al., 2023). Excellent readers perform above 1 SD on both subtasks. Descriptive data of participants are provided in Table 1. All children were Hungarian speakers. They were recruited and tested in their own primary schools. All schools were located in Western Hungary, in and around the city of Szombathely. Parents of all children provided a written informed consent in accordance with the declaration of Helsinki and the stipulations of the institutional ethics board. All children agreed to participate. The study received clearance from the Ethics committee of the Faculty of Psychology and Education of the Eötvös Loránd University.

2.1.1 Phonological STM group

There were 72 typical readers (31 boys and 41 girls) with full dataset. Their mean age was 9.89 years (Sd: 1.8, range: 7–13.08). There were 33 children among the excellent readers, with a mean age of 9.39 years (Sd: 1.813, range: 7.17–13.17). Their reading skills were on average 1.59–1.75 standard deviations above age-appropriate (considering a word and a pseudoword reading subtest).

2.1.2 Verbal STM group

Sixty-three children (32 boys and 31 girls) were included in the group of typical readers. Their mean age was 9.66 years with a standard deviation of 2.011. Typical readers' reading performance was around 0 on standardized values. There were 21 excellent readers (9 boys, 12 girls) with a mean age of 10.230 years (Sd: 2.128, range: 6.83–12.92). The reading skills of excellent readers were on average 1.78–1.8 standard deviations above age-appropriate.

2.1.3 Visuospatial STM group

We had 92 typical readers (45 boys and 47 girls) with 10.026 years of mean age (Sd: 1.9, range: 6.75–13.33). Their performance was compared to that of 40 excellent readers (20 boys and 20 girls) with a mean age of 10.05 years (Sd: 2.06, range: 6.92–13.17). Excellent readers were on average 1.7–1.74 standard deviations above age-appropriate reading level.

2.2 Methods

2.2.1 VOLT one-minute reading test

The VOLT is a standardized test for word- and pseudoword reading. The word reading subtest is composed of a list of 180 words. Children are asked to read the words one after the other as quick as possible within 60 s. The pseudoword reading subtest is identical with 180 pseudowords as reading stimuli. The test has been

TABLE 1 Descriptive statistics.

Panel A. Typical and excellent readers with data from verbal short-term memory task				
	Typical readers (*N* = 63, 32 boys, 31 girls)		Excellent readers (*N* = 21, 9 boys, 12 girls)	
	Mean (SD)	Range	Mean (SD)	Range
Age	9.657 (2.011)	6.75–13.25	10.23 (2.128)	6.833–12.917
Word reading[a]	58.27 (26.614)	18–101	95.476 (34.046)	38–146
Word reading Z[b]	0.016 (0.22)	−0.425 - 0.431	1.776 (0.604)	1.047–3.142
Pseudoword reading[a]	33.857 (12.197)	14–57	56.286 (17.757)	31–91
Pseudoword reading Z[b]	0.03 (0.28)	−0.479 - 0.494	1.801 (0.481)	1.072–3.087

Panel B. Typical and excellent readers with data from nonword repetition task				
	Typical readers (*N* = 72, 31 boys, 41 girls)		Excellent readers (*N* = 33, 18 boys, 15 girls)	
	Mean (SD)	Range	Mean (SD)	Range
Age	9.889 (1.796)	7–13.083	9.386 (1.813)	7.167–13.167
Word reading[a]	61.042 (25.623)	18–103	80.758 (30.69)	35–136
Word reading Z[b]	−0.009 (0.3)	−0.474 - 0.476	1.754 (0.58)	1.045–3.9
Pseudoword reading[a]	35.278 (11.228)	15–53	47.273 (15.758)	26–85
Pseudoword reading Z[b]	0.019 (0.267)	−0.479 - 0.494	1.589 (0.497)	1.009–2.711

Panel C. Typical and excellent readers with data from visual short-term memory task				
	Typical readers (*N* = 92, 45 boys, 47 girls)		Excellent readers (*N* = 40, 20 boys, 20 girls)	
	Mean (SD)	Range	Mean (SD)	Range
Age	10.026 (1.896)	6.75–13.333	10.046 (2.06)	6.917–13.167
Word reading[a]	63.38 (26.379)	18–107	92.175 (30.878)	37–136
Word reading Z[b]	−0.023 (0.292)	−0.498 - 0.497	1.738 (0.532)	1.014–3.9
Pseudoword reading[a]	36.5 (11.657)	15–57	54 (16.51)	27–88
Pseudoword reading Z[b]	0.029 (0.276)	−0.468 - 0.494	1.7 (0.559)	1.009–3.082

[a]Word and pseudoword reading scores are the number of words or pseudowords read within 60 s on the VOLT (Kemény et al., 2023) task, [b]normative, age-appropriate scores of word- and pseudoword reading. Panel A provides describes children with Verbal STM data, Panel B children with Nonword repetition data, Panel C children with Visuospatial STM data.

standardized for children from grade 1 spring semester to grade 6 spring semester. Separate age-norms have been reported for every semester. Data collection of all children of the current study took place in the spring semester (between April and May). The test–retest correlation of word- and pseudoword reading is 0.859–0.966 (varying across grades and subtasks). The correlation between word- and pseudoword reading is 0.677–0.897 (Kemény et al., 2023). The measure of reading was the number of words and pseudowords read within 60 s.

2.2.2 Phonological STM

We used the semi-computerized version of a standardized Hungarian pseudoword repetition task (Racsmány et al., 2005). Through headphones participants heard the pseudowords and had to repeat them with precision. The repetition was evaluated by a student assistant. Pseudowords increased in length, starting with monosyllabic pseudowords. Each length had four pseudowords. If a child was able to repeat at least two of the items, the task proceeded to the longer sequences. The task continued until the exit criterion was reached, that is, until the child was unable to repeat at least half of the pseudowords. Phonological STM is characterized by the number of correctly repeated pseudowords.

2.2.3 Verbal STM

Verbal STM was measured with the digit span task. Participants heard digits one after the other, and had to recall them when prompted. We used a computerized task programmed in E-prime (Psychology Software Tools Inc., 2016), in which digits were presented auditorily through headphones, and children had to enter the number sequence in an identical order using the computer's keyboard. Digits were recorded by a calm male voice. The length of the digits varied between 549 and 862 milliseconds. The recordings were stereo with 44.1 KHz sampling rate. Digits followed each other with a fixed 1,000 stimulus onset asynchrony. Although the task was automatized, a student assistant was always present to make sure the participant was not distracted and to assist entering the data.

The task started with two practice items to make sure children understood what they had to do. The practice trials were 2-digit sequences. The real items followed, starting from 3-digit-long sequences. There were four items from each length. The exit criterion was identical to the phonological STM task: children only proceeded to the next length if they repeated at least half of the items correctly. Verbal STM is characterized by the number of correctly repeated sequences.

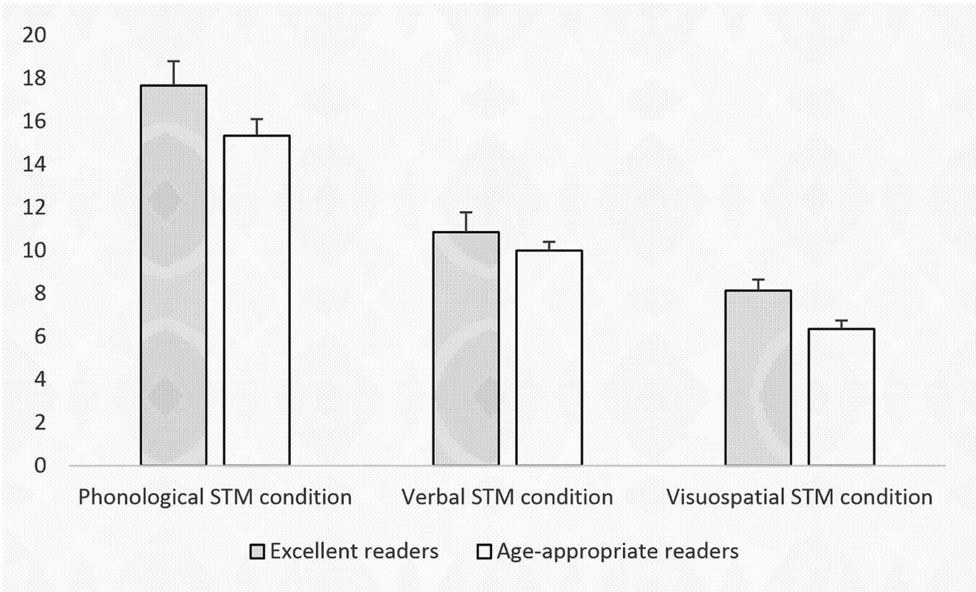

FIGURE 1
STM performance by group in the three conditions. Each bar represents the average number of correctly repeated sequence. Error bars represent SEM.

2.2.4 Visuospatial STM

Visuospatial STM was assessed using a computerized task analogous to the Corsi blocks, in which participants had to repeat a visuospatial sequence. The task was programmed and run in E-prime (Psychology Software Tools Inc., 2016). A 4 × 4 black array of rectangles appeared on a white screen. The screen resolution was set to 1,024 × 768, the array had a size of 341 × 341 pixels. During the items, one of the 16 rectangles turned red for 650 ms, then turned blank again for 500 ms, then another rectangle turned red. The aim of the participants was to remember the order of the rectangles turning red. After the sequence they were prompted to repeat the sequence using the mouse and clicking on the given rectangles.

There were two practice trials in the beginning with sequences of two locations. The real items started with three locations, and had four sequences with each length. The same exit criterion was used as before: the task only proceeded to the next length if at least half of the sequences were correctly repeated. Although the task was fully automated, a student assistant was always present to make sure the children complied with the task requirements, and helped them as required. Visuospatial STM is characterized by the number of correctly repeated sequences.

2.3 Results

2.3.1 Phonological STM – nonword repetition

Data from the three STM tasks by group are presented in Figure 1. We conducted an ANOVA with Nonword repetition as dependent and Group (Typical readers vs. Excellent readers) as between subject variable. The ANOVA revealed no significant main effect of group, $F(1, 103) = 2.868$, $p = 0.093$, $\eta_p^2 = 0.027$. Controlling for age, however, resulted in a significant group difference, $F(1, 102) = 4.058$, $p = 0.047$, $\eta_p^2 = 0.038$. Age was a significant covariate, $F(1, 102) = 5.354$, $p = 0.023$, $\eta_p^2 = 0.050$.

2.3.2 Verbal STM – digit span

We conducted an ANOVA with Verbal STM as dependent and Group (Typical readers vs. Excellent readers) as between subject variable. The ANOVA revealed no significant main effect of group, $F(1, 82) = 0.941$, $p = 0.335$, $\eta_p^2 = 0.011$. The groups did not differ even after controlling for age, $F(1, 81) = 0.286$, $p = 0.594$, $\eta_p^2 = 0.004$, whereas Age was a significant covariate, $F(1, 81) = 18.547$, $p < 0.001$, $\eta_p^2 = 0.186$.

2.3.3 Visuospatial STM

We conducted an ANOVA with Visuospatial STM as dependent and Group (Typical readers vs. Excellent readers) as between subject variable. The ANOVA revealed a significant main effect of group, $F(1, 130) = 6.902$, $p = 0.010$, $\eta_p^2 = 0.050$. This difference remained significant even after controlling for age, $F(1, 129) = 9.774$, $p = 0.002$, $\eta_p^2 = 0.070$. Age was a significant covariate, $F(1, 129) = 59.339$, $p < 0.001$, $\eta_p^2 = 0.315$.

3 Discussion

The aim of the current study was to unravel whether and how excellent readers differ from age-appropriate readers in their short-term memory abilities. In accordance, we have contrasted the short-term memory performance of excellent readers (reading performance at least 1 SD above average) and typical readers (reading performance within ±0.5 SD from average). The clearest effect was that excellent readers were significantly better in visuospatial STM than typical readers. Apart from that, they also outperformed typical readers in phonological STM, however, this was only observed after controlling for age. No difference was observed in verbal STM on the digit span task.

Results of the current study are not new in the sense that there is ample evidence for the substantial role of short-term memory in reading. It is a novelty though that the effect is not constraint to the verbal/phonological domain, and not even strongest in this domain. In the following section we will discuss why different types of memory processes may contribute to excellent reading, and what implications it has to further psychological research and educational development programs.

Several previous studies have identified the important role of phonological awareness as well as phonological skills in reading and developmental dyslexia (Alexander et al., 1991; Hogan et al., 2005; Ramus and Szenkovits, 2008; Landerl et al., 2018; Powell and Atkinson, 2021). Research has also documented that while phonological skills are a prerequisite for reading, its scope changes with age (Goswami, 2002), and its role decreases with development (Hogan et al., 2005; Powell and Atkinson, 2021). This is in accordance with reading development. Early readers rely heavily on letter-speech sound associations as they have to sequentially decode the observed written text. Later on, children associate visual and phonological word forms, developing orthographic representations in the individuals' orthographic lexicon (self-teaching, Share, 1995; Share and Shalev, 2004). These representations make way to sight-word reading, a process during which the reader recognizes visual word forms and retrieves the accompanying spoken word effortless (Ehri, 1991, 2014).

Other frameworks suggested that this shift toward sight word reading is not only supported by lexical representations (stored word forms), but also by the increasing grain size of orthographic information. That is, analytic levels start from letter-level, and increase toward larger and more consistent units (Ziegler and Goswami, 2005, 2006; Caravolas, 2006). Furthermore, Grainger and Ziegler (2011) suggested that orthographic information is processed along two parallel routes, the fine-grained route and the coarse-grained route. The fine-grained route puts a special emphasis on each individual unit, whereas the coarse-grained route is an approximate activation of the underlying patterns. During development, individuals rely less and less on fine-grained analyses and use more coarse-grained activations. The lack of focus on specific details makes individuals able to overcome noise, like transposed letters (Varga et al., 2021). The above models suggest that typical reading development involves a shift from specified to less specified visuospatial orthographic representations. This only seemingly contradicts the current results. Excellent readers may also decrease their reliance on visuospatial skills, however, their better visuospatial abilities may contribute to (1) the formation of orthographic representations, (2) access to orthographic representation.

The development of orthographic representations requires children to sequentially decode yet unknown words, and associate the observed visual forms with the produced phonological forms (Share, 1995; Share and Shalev, 2004). Sequential decoding is a slow and laborious process. Children have to remember the parse the letter sequence into decodable units, translate them into speech sounds and merge the speech sounds together. While this is enough to sound out the unknown word, children also have to store the new association, which load on visuospatial short term memory processes. This is in line with previous research suggesting that processing difficulties emerge with visual complexity, that is, visual complexity is a crucial factor in orthographic learning (Abdelhadi et al., 2011; Hsu et al., 2011; McBride-Chang et al., 2011).

The second possibility is that visuospatial skills affect access to orthographic representation. That is, the central effect relies not on the process of storing visual word forms, but on retrieving them. Better visuospatial short-term memory in this case would provide a spatially more precise cue for accessing the orthographic representation. This would be in line with previous research (Rao and Singh, 2015) highlighting the role of visual complexity in reading at the neural level. But such a hypothesis could also be integrated with the grain-size theory, suggesting that while it is beneficial to use larger grain-size, more detailed cues could enhance the dual routes in parallel (Grainger and Ziegler, 2011), leading to quicker phonological activation. This latter assumption suggests that visuospatial STM could support word recognition by making it more effective.

A similar pattern was observed in phonological short-term memory. As discussed above, since the role of phonological processing decreases with reading experience (Hogan et al., 2005; Powell and Atkinson, 2021), that the advantage of excellent readers is rather due to phonological skills being engaged in the development of the orthographic lexicon. That is, children who are better in their phonological STM will develop their orthographic lexicon quicker and easier than children with average phonological abilities. This hypothesis should, however, be analyzed in a longitudinal design. The lack of difference in verbal STM suggests that while verbal skills are necessary for typical reading (Trecy et al., 2013; Majerus and Cowan, 2016), they may not differentiate within the non-impaired region.

3.1 Enhancing visuospatial skills to support reading

While the current results show that excellent readers and typical readers differed most reliably in visuospatial STM, the educational challenge is whether one can integrate visuospatial trainings to support the reading development of children. The first question is whether one can train visuospatial STM, the second is whether such a training could be transferred to reading skills.

Several studies have recently addressed the effectiveness of working memory trainings. Some of these studies reported strong effects of training (Jaeggi et al., 2008; Morrison and Chein, 2011; Schwarb et al., 2016), while others argue for modest or no benefit after training (Melby-Lervåg and Hulme, 2013; Sala and Gobet, 2017; Kassai et al., 2019). Studies on visual short-term memory are even scarcer, but those that are available show a beneficial effect in both children (Caviola et al., 2009; Roberts et al., 2016) and older adults (McAvinue et al., 2013). Such beneficial effects, however, may be a result of changes in the strategies employed throughout memory processes (Gonthier, 2021). Whether or not a WM training leads to a development in a wider domain of cognition is only tangentially related to our theme, as we suggest visuospatial STM to be directly involved in the recognition of words and sublexical units.

The current study provides a plausible way to clarify controversial research results in gaming-based literacy trainings, suggesting that the beneficial effect may be mediated by visuospatial STM. A handful of studies provided evidence that computerized tasks enhance reading. Methods differ in a great range: some employing various games of executive functions (Pasqualotto et al., 2022) or action video games (Franceschini et al., 2013; Antzaka et al., 2017; Peters et al., 2021). These latter studies also highlight the importance of visual attention and executive functions. Analyzing the topic from a different perspective, studies have also shown visuospatial working memory and executive functions to be crucial in gaming (Hazarika and Dasgupta, 2020; Valls-Serrano et al., 2022), and video game-based visuospatial WM training to be highly effective – at least in older adults (Toril et al., 2016). Overall, it is plausible to assume that visuospatial working memory effects explain at least a part of the benefit by computerized EF training (Pasqualotto et al., 2022) and action video gaming (Franceschini et al., 2013) to reading. Testing such a hypothesis is, however, outside the scope of the current paper though.

3.2 Limitations and future directions

The most important limitation of the study is rooted in the study design. It would support interpretability if all children had data in all domains of short-term memory. It would allow us to contrast the effect of working memory measures on excellent reading. On the other hand, a longitudinal design would allow to examine if memory processes support the formation of orthographic representations or access to them. The current study, however, was designed as a side project of the standardization of a reading test, and was constraint to such design. It is also important to note that while the current study focused on short-term memory, short-term memory is also closely associated to intelligence, which in turn is often found to be related to reading and spelling (Peng et al., 2019; Zarić et al., 2021). Thus it would be interesting to explore whether and how differences in general cognitive abilities explain group differences between excellent and age-appropriate readers, and whether and how spelling abilities may covariate. A further possibility to consider is that although decoding and reading comprehension are highly correlated, reading comprehension does not equal decoding fluency (García and Cain, 2014). Using reading comprehension measures could further widen our knowledge on how STM is associated to reading skills. Finally, it is important to address the limitations of the current design. On the one hand, the quasi-experimental design does not allow causal inferences to be drawn, on the other hand, the small number of participants in our current setting we were only able to detect large effects (delta = 0.847 for the verbal STM comparison). Larger group sizes would allow a more fine-grained analyses of the STM differences.

3.3 Conclusion

In the current study we examined how excellent and age-appropriate readers differ from each other in terms of short-term memory. We reported an advantage of excellent readers in visuospatial and phonological short-term memory. We suggest that although the development of typical reading requires a diversion from spatial and phonological processes, the proper maintenance of these processes can support students in becoming excellent readers. However, we are yet to understand whether and how these processes could be utilized and integrated to primary school curricula.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving humans were approved by Ethics board of the Faculty of Education and Psychology, Eötvös Loránd University. The studies were conducted in accordance with the local legislation and institutional requirements. Written informed consent for participation in this study was provided by the participants' legal guardians/next of kin.

Author contributions

FK: Conceptualization, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Writing – original draft. GA: Writing – review & editing. OP: Conceptualization, Methodology, Writing – review & editing. EPR: Writing – review & editing. CL-H: Data curation, Investigation, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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