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Missing working memory deficit in dyslexia: children writing from memory

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Abstract

This research focused on the fluency of writing processes of children with dyslexia, in order to examine the relationship between WM and writing. An experiment was used in which children with dyslexia, and chronological age-matched and reading age-matched children without dyslexia wrote 24 sentences. Sentences with existing words and non-words were used. The results show that there are no differences between children with dyslexia and their chronological age-matched peers during writing. This similarity is surprising and indicates that WM problems in children with dyslexia may have no impact on their writing. The results imply that when different components of WM interact with each other, a model in which visuospatial and verbal WM are separated is more appropriate than a model with a pooled WM.

Keywords: Temporal signal analysis, writing, working memory, dyslexia, sentences.

Introduction

The process of writing involves a large number of processes in different cognitive components. Therefore, understanding of how writers produce sentences includes an explanation of how activities are orchestrated in the cognitive system. Here, an important characteristic is the limited capacity of working memory (WM) to simultaneously maintain and process information (Olive, 2004). Children with dyslexia suffer from inefficient automatic information-handling processes (Turner, 1997), and have impaired WM (Berninger et al., 2006), and are therefore struggling with writing (Berninger, Abbott, Thomson, & Raskind, 2001).

Another explanation for writing problems in children with dyslexia, is that these children have difficulties with phonological representations that stems (partly) from a phonological core deficit. Specifically, these children have difficulties with constructing, maintaining, and retrieving phonological representations (De Bree, 2007).

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Working memory

According to Baddeley (2000), WM consists of several components which work together to enable the active processing and preservation of information in memory (Gazzaniga, 2002).

During writing, cognitive processes operate on different levels. For example, on a high level, visual WM stores the orthographic information of already written words, as an aid to catching spelling, or other errors (Kellogg, Olive, & Piolat, 2007). Also, WM is used to represent the physical layout of the text (Kellogg, Olive, & Piolat, 2007).

On a lower level of representation, for example, spelling involves a number of functionally distinct processing components. According to a spelling framework described by Tainturier and Rapp (2001), the ability to generate a spelling for words relies on the phonology to orthography conversion system. In this system, words are segmented into smaller units (e.g., phonemes, syllables). These smaller units are then converted into orthographic units which are assembled into a correctly sequenced abstract letter string. These abstract strings do not have a specific format. This means that a specific modality and format of output should be chosen, which is handwriting in this research.

Children with dyslexia are constrained by their WM limitations during writing, because they lack fluent text-generation processes (e.g., blending individual sounds to make a word) and writing-relevant knowledge (e.g., knowledge about which letter is associated to which sound). Therefore, these children may not have sufficient WM capacity to deal with the multiple demands imposed by the writing processes (McCuthen, 2000), causing the writing process to be slower and more laborious (Siegel, 2003). The writing process is even slower and more laborious in the case of sentences containing non-words, because the word identification process is more cumbersome. This is caused by the inability of children with dyslexia to rely on their mental lexicon during identification of a word (Siegel, 2003). Because of these increased processing demands, less capacity is left for storing words that should be written.

Phonological core deficit

Another problem reported in children with dyslexia is the phonological core deficit. According to this hypothesis, children with dyslexia code phonology in the brain less efficiently than children without dyslexia. This problem causes symptoms, such as difficulties with verbal short-term memory (STM), non-word repetition, phonological awareness, phonological learning of new verbal information, word retrieval, and rapid naming (De Bree, 2007). These problems in turn lead to slow literacy development, poor generalisation of word reading skills to non-word reading, and poor spelling development (e.g., Snowling 2001).

As there is more to phonology than just awareness and categorical perception, another aim of this research was to look at the production of speech sounds and sound patterns, as well as on-line operations on phonological representations (De Bree, 2007). The focus was on how quickly information stored in WM was processed and retrieved during writing. In an experiment, children rehearsed target sentences until they could verbally repeat them without errors, which eliminates some of the processing demands associated with encoding the stimulus but leaves the substantial demands of the writing process itself.

Graphical Protocol Analysis

The research method used in this research is called graphical protocol analysis (GPA) and was validated by Cheng and Rojas-Anaya (2005, 2006, 2007). They found that there is a strong and robust temporal chunk signal that reflects structure of chunks in WM and also measures how quickly chunks are processed in WM. Chunks are individual pieces of information grouped into larger units that increase our information retention (Carroll, 2004). Though chunks are formed at different levels (e.g., for experienced readers a letter is a chunk because it consists of different strokes, and a word is a chunk because it consists of several letters), in this research, the focus is on words as a chunk of different letters. To identify the structure of chunks in WM, writing has been shown to be useful (Cheng & Rojas-Anaya, 2007). This can be brought about by measuring the pauses between the end of writing one letter and the beginning of the next (Cheng & Rojas-Anaya, 2005). These pauses are specified by the amount of time that the pen is lifted from the paper. In previous research with adults on writing tasks, pauses were between 200 and 400 ms (Cheng & Rojas-Anaya, 2006).

This research will exploit the feature of GPA that determines how quickly information stored in WM will be processed during writing by comparing the overall pattern of pause lengths of all written elements. Because children with dyslexia have difficulties on tasks incorporating a verbal component, whereas they perform at the same level as children without dyslexia on comparable tasks without a verbal component (Tijms, 2004), a verbal task was used. Specifically, sentences were used, because children with dyslexia have problems with activation of phonological codes for naming and direct repetition of sequences of words (Tijms, 2004). In this research, a distinction was made between existing words and non-words, because children with dyslexia have problems with reading and writing non-words (Mann, 2003) which is even more salient in case of non-words with low phonotactic probability (Messer, Leseman, & Mayo, submitted). All sentences were aurally presented to the children, because children with dyslexia often have word identification problems with written language (Vellutino, 2004), which causes an incorrect encoding of representations (Tijms, 2004).

Research question and hypotheses

Focussing on the differences in WM performance during writing by children with and without dyslexia, the present research question is: To what extent do the working memory problems of children with dyslexia impact on their writing of sentences from memory?

To address this question, pause lengths between the written letters in sentences were compared between children with dyslexia and children without dyslexia. Poorer performance of WM was correlated to longer pauses, because the slower the rate of processing, the smaller the amount of information that can be processed in one unit of time (Conway, 2002). Here, poor performance is taken to indicate the inability to readily and properly process a sentence in WM.

Pause lengths in children with dyslexia (DYS) were expected to be longer than pause lengths in chronological age-matched (CA) as well as reading age-matched (RA) children without dyslexia, since processing in DYS children is slower due to the multiple demands imposed by the writing process (e.g., blending individual sounds to make a word, and keeping track of what should be written) (McCuthen, 2000). Memory performance for words is superior to non-words for all groups, thus longer pauses were expected in sentences containing non-words in all three groups. As DYS children have impaired WM for non-words (Wijsman et al., 2000), it was expected that the difference in pause length between DYS children and both groups of children without dyslexia in non-word sentences is larger than in familiar sentences.

Finally, a word-likeness effect was expected in sentences containing non-words. Specifically, non-words that sound like real words (i.e., non-words composed of highly frequent phoneme clusters, yet with a small neighborhood size) should be easier to recall than words that do not sound like real words (i.e., non-words composed of infrequent phoneme clusters, with a small neighborhood size) (Gathercole, Frankish, Pickering, & Peaker, 1999). This difference was expected to be larger in DYS children, because some language knowledge can still be used in non-words with high phonotactic probability, but to a lesser extent in non-words with low phonotactic probability (Messer, Leseman, & Mayo, submitted).

Methods

Participants

Participants in this study were 109 Dutch children between seven and ten years old, from nine primary schools and two dyslexia institutes in the Netherlands. Six of them had to be excluded from the analysis because they did not obey the instructions. The remaining 103 participants (*M* = 8.28 years, *SD* = .63 years) were 31 grade 3 DYS children, 35 grade 3 CA children without dyslexia, and 37 grade 2 RA children without dyslexia. All participants were native Dutch speakers without cognitive or neurological impairments. For example, children with ADHD or autism were excluded. To be classified as having dyslexia, children had received an official diagnosis from a dyslexia institute. School achievements of children without dyslexia in both grades were in the normal range.

Design and procedure

The experiment had a duration of 45 to 60 minutes per child. The session began with an acclimatisation period which allowed the participants to become familiar with a digital writing tablet by having them write their names and a dummy phrase on the tablet. After familiarization, the participant wrote 24 sentences, six of four different kinds of sentences. Familiar sentences were semantically easy sentences in order to facilitate remembering because of phonotactic, semantic, and syntactic knowledge in long term memory (e.g. 'Ik ben mooi' - 'I am pretty'). Jumbled sentences consisted of existing words in a jumbled order (e.g. 'Jij het hond' - 'You the dog') and were included to exclude the influence of syntactical information on recall and processing. Also sentences containing non-words with high phonotactic probability (e.g. 'Baam vus beg' - 'Rummer hoat barden') and non-word with low phonotactic probability (e.g. 'Knuk greupeg') were included to exclude to influence of semantic information on recall and processing. The level of difficulty of sentences was determined by pilot work to ensure that they were sufficiently demanding, but could nevertheless be remembered. All sentences were written on a paper containing a horizontal row of rectangles (width: 7 mm, height: 10 mm).

All sentences were presented in turn, alternating between familiar, jumbled and non-word sentences. After presenting a sentence, the experimenter checked recall accuracy by asking participants to repeat the sentence until they were able to recite it in a continuous unhesitating manner. Verbal recall was used to ensure that the content in WM was the same in all participants, which makes comparison of the output possible. A hash (#) was written at the beginning of each sentence to ensure that the writing process was well underway before the first letter was generated (Cheng & Rojas-Anaya, 2006).

WM and short-term memory performance of all participants was tested using two subtests of the Dutch version of the Automated Working Memory Assessment (AWMA) battery. In the digit span task, children were asked to remember series of numbers and had to recall these in the same order. Similarly, in the backward recall task, children had to remember an array of numbers, but had to recall them in reversed order. An additional test of the AWMA was administered to test memory for non-words with high phonotactic probability. In this test, series of non-words with high phonotactic probability were aurally presented, which had to be recalled in the same order.

Testing sessions were conducted by three experimenters, including one of the investigators, who trained the others by demonstration and the use of a video of one session. Also, a written protocol was provided to increase treatment integrity.

Data and analyses

A specially written program, TRACE, was used to record the writing actions and to extract the pen positions, times of points and pauses (Cheng & Rojas-Anaya, 2003). All files generated by TRACE were analysed using a special computer-program, written by the investigators. Because of the large amount of data (2472 sentences), automatic detection of letters and automatic calculation of pauses had to be applied. This involved identifying the horizontal position of strokes making up a letter and the horizontal separation between these strokes. Only in those cases where no automatic detection of letters was possible was manual calculation of the pauses applied. Data of 321 sentences (13%) scattered across participants were not included in the analyses, as in these sentences the instructions were not followed. Also, pause lengths larger than 3000 ms were excluded from the analysis, as they were found to be related to distraction and memory loss for the sentence. A threshold of 5000 ms did not change the results except for one minor case.

Results

WM and STM performance of children in the AMWA subtests was compared. The results of a one-way ANOVA on the backward recall task indicated that there were differences between the groups in WM performance ($F(2) = 45.61$; $p < .01$). The post-hoc test showed that the RA and CA groups differed ($p = .04$), also the CA and the dyslexics group ($p < .01$), but not the RA and dyslexics group ($p = .12$). The effects found were not large (see Table 1). Similarly, a one-way ANOVA on the digit span task indicated that there were no differences between the groups in short-term memory performance ($F(2) = .13$; $p = .88$).
To test whether there were performance differences in WM between children with and without dyslexia in the two different age groups, the means of the medians of the pauses for each kind of sentence were calculated.

Table 1: Group comparisons for AWMA backward recall subtest.

Group comparison	*n*	*M*	*SD*	*p*	*Cohen's D*
DYS	31	8.71	.51	< .01	.33
CA	35	11.11	.46		
DYS	31	8.71	.51	.12	
RA	37	9.78	.45		
CA	35	11.11	.46	.04	.18
RA	37	9.78	.45		

A one-way MANOVA revealed that there existed significant differences between different types of sentences in different groups (*Wilks' lambda* = 0.77, *F*(8;194) = 3.44; *p* < .01). The univariate results showed that these group differences existed for all sentence types (see Table 2). It was expected that the longest pauses would be found in DYS children, shorter pauses in RA children, and the shortest pauses in CA children. However, this turned out to be not the case (see Figure 2). A similar pattern was found for all types of sentences. Specifically, significant differences were found between the RA group and the other two groups, but no significant differences between the dyslexic and CA group. All significant effects between the RA group and CA or DYS group had a medium to large effect size (see Table 3).

Table 2: Univariate comparisons between sentence types.

Sentence type	*df*	*F*	*p*
Familiar	2	6.75	< .01
Jumbled	2	12.18	< .01
High phonotactic probability	2	6.51	< .01
Low phonotactic probability	2	6.08	< .01

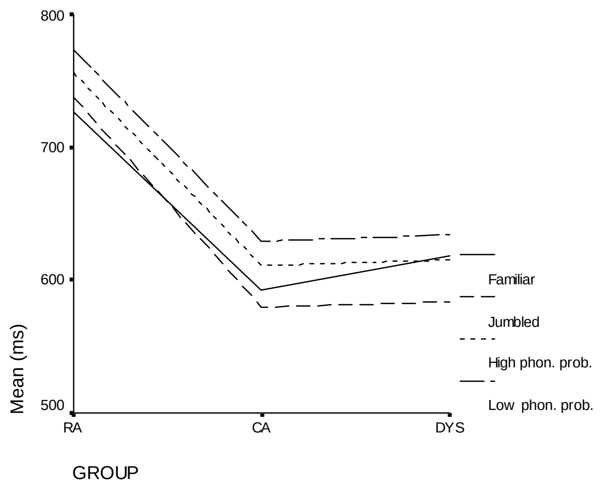

Figure 2: Patterns of mean pause lengths (ms) for different types of sentences for the different groups.

Table 3: Group comparisons for different types of sentences.

Sentence type	Group comparison	*n*	*M*	*SD*	*p*	*Cohen's D*
Familiar	DYS	31	617	123	.43	
	CA	35	587	109		
	DYS	31	617	123	< .01	.63
	RA	37	713	201		
	CA	35	587	109	.03	.83
	RA	37	713	201		
Jumbled	DYS	31	581	117	1.00	
	CA	35	581	95		
	DYS	31	581	117	< .01	1.01
	RA	37	733	206		
	CA	35	581	95	< .01	1.01
	RA	37	733	206		
High phonotactic probability	DYS	31	610	143	.98	
	CA	35	611	133		
	DYS	31	610	143	< .01	.74
	RA	37	743	236		
	CA	35	611	133	< .01	.74
	RA	37	743	236		
Low phonotactic probability	DYS	31	630	140	.88	
	CA	35	623	151		
	DYS	31	630	140	< .01	.70
	RA	37	758	238		
	CA	35	623	151	< .01	.73
	RA	37	758	238		

Finally, paired samples t-tests were conducted to test the word-likeness effect. The means of medians in sentences with non-words with high and low phonotactic probability were compared. The results indicated that there was no difference in pause length between these two kinds of sentences in general (*t* = -1.52; *p* = .13). This also applied for the individual groups (dyslexics: *t* = -1.08; *p* = .29; CA: *t* = -.77; *p* = .45; RA: *t* = -.79; *p* = .43) indicating that the word-likeness effect was not found in this experiment. (When the longer pause threshold was used (5000 ms) on pause length, a difference between sentences with non-words with high and low phonotactic probability was found (*t* = -2.46; *p* = .02), but again no effects were found in the individual groups (dyslexics: *t* = -1.88; *p* = .07; CA: *t* = -1.38; *p* = .18; RA: *t* = -1.00; *p* = .33).)

Discussion

The main aim of this research was to investigate the extent to which working memory (WM) problems of children with dyslexia impact on their writing of sentences from memory. It was expected that pause lengths in children with dyslexia (DYS) would be longer than pause lengths in chronological age-matched (CA) as well as reading age-matched children (RA) without dyslexia. However, the results show that there are no differences between DYS children and their CA peers, and that children in these groups perform better than RA children.

The difference between CA and RA children is as expected, because memory capacity increases when children get older (Alloway, Gathercole, & Pickering, 2006). However, the similarity between the CA and the dyslexics group in the writing task is surprising and indicates that WM problems in the latter group have no impact on their writing, which is in line with the absence of the word-likeness effect. This result is surprising, because the results of the backward recall test show that these groups differ in WM performance. It is difficult to imagine that no WM processes were involved in the writing task, and that demands involved in the writing task were small and of a level comparable to the recall of a sequence of digits. As Cheng & Rojas-Anaya (2008) propose, writing involves the planning and monitoring of graphical production at multiple representational levels, which puts high demands on WM. For example, while writing a sentence, words should be segmented into smaller units, these units should be stored and conversion rules should be applied to converse them into orthographic units, and finally the orthographic units should be conversed into graphemes. Therefore, a possible interpretation is that these results are consistent with a WM model in which separate WMs exist for visuospatial and verbal information (as originally proposed by Shah and Miyake (1996)). The added visuospatial demands seem to draw on a different resource than the verbal demands, because the added visuospatial aspects of writing do not seem to influence the performance of WM during writing. It seems as if an increasing amount of information can be processed, instead of information competing for a fixed amount of capacity.

These results are not consistent with the results of Alloway, Gathercole, and Pickering (2006). They investigated performance of children between four and eleven years old on different WM and STM tasks. They concluded that a model with separate STMs for visuospatial and verbal information, but a pooled WM is most appropriate in young children. However, the tasks they used were different from the task used in this research in several respects. First, the tasks they used measured visuospatial/verbal WM/STM performance separately, whereas in our task, these components continuously interacted with each other. Second, in their tasks, the stimulus was presented only once, whereas in our task, the stimulus was presented several times if necessary. This indicates that the memory trace in our research was stronger, influencing the ease with which information was recalled. Third, the output in their tasks was in general much shorter than the output in our research. For example, responses in their tasks involved stating 'true' or 'false', repeating a series of numbers, retracing the route through a maze, and identifying an odd-one-out shape and recall its location later. Compared to these tasks, writing of sentences is more complex.

Another interpretation could be that phonological processing is not intrinsically necessary in written language production. However, the present data discussed here does not address this interpretation. Further analyses will be conducted in order to address this possibility, by explicitly considering pauses between and within word chunks.

The results are not compatible with a general WM-capacity deficit as the primary cause of dyslexia or at least of dyslectics' difficulties with writing. However, the results do not provide unequivocal support for the alternative hypothesis. Expected effects such as a pause length difference between DYS children and CA children were not found. This may be due to the basic research procedure. As children were instructed and supported to rehearse the sentence as many times as needed, this enabled them to overcome possible weaknesses in phonological encoding and to use compensating mechanisms (e.g., semantic, syntactic, and phonotactic LTM knowledge). The results lead to more insight into the nature of the representation difficulties.

In conclusion, the findings from the present study indicate that WM problems in DYS children have little impact on their writing. This supports an interpretation that when different components continuously interact with each other, a WM model in which visuospatial and verbal WM are separated (Shah and Miyake, 1996) is more appropriate than a model with a pooled WM (Baddeley, 2000).

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