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The specific relation of visual attention span with reading and spelling in Dutch

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A B S T R A C T

Visual attention span, the number of orthographic units that can be processed at a glance, has been shown to predict reading performance in orthographically opaque languages (i.e., French and English), independent from phonological awareness. Whether this relation is also found in Dutch, a more transparent orthography, was examined in two studies. Two unresolved issues are addressed. First, whether the contribution of visual attention span to reading was independent of rapid naming. Participants were 117 second graders and 111 fifth graders. Visual attention span was a significant predictor of both beginning and advanced word reading fluency, after controlling for rapid naming. Second, we examined the relation of visual attention span with spelling performance in a sample of 255 fourth graders. Visual attention span was a unique predictor of both orthographic knowledge and spelling performance. Based on the results we discuss the possibility of a slightly different interpretation of visual attention span.

1. Introduction

Reading requires mapping written word forms to spoken, phonological forms. Therefore, phonological skills have been put forward as the key factor determining reading performance (e.g., Ramus et al., 2003; Vellutino, Fletcher, Snowling, & Scanlon, 2004). Indeed, phonological awareness and rapid naming have been shown to predict reading performance in many languages, both concurrent and longitudinally, in typically developing children, as well as children with dyslexia (e.g., de Jong & van der Leij, 1999; Kirby, Parrila, & Pfeiffer, 2003; Landerl & Wimmer, 2008; Lervåg, Bråten, & Hulme, 2009; Moll, Fussenegger, Willburger, & Landerl, 2009; Torgesen, Wagner, Rashotte, Burgess, & Hecht, 1997; Vaessen & Blomert, 2010; Wolf & Bowers, 1999; Wolf et al., 2002; Ziegler, Bertrand et al., 2010).

However, there is by no means a perfect relation between phonological skills and reading. More recently, the role of visual rather than phonological processing in reading development has received more attention. This was, for example, stimulated by complaints of individuals with dyslexia that letters and words move around, blur and/or merge (e.g., Stein & Walsh, 1997; Vidyasagar & Pammer, 2010). Visual factors already featured prominently in the first description of reading difficulties, as *word blindness*, or a defective visual memory for words (Morgan, 1896). A more recent multiple case study also indicated that two classes of impairments contribute to reading disabilities, namely phonological and visual impairments (White et al., 2006).

A prominent visual theory is the visual attention span hypothesis. According to this hypothesis, the visual attention span, that is the number of orthographic units (e.g., letters, letter clusters or syllables) that can be processed simultaneously at a glance, is a core skill determining reading performance, independent from phonological skills (e.g., Valdois, Bosse, & Tainturier, 2004; Valdois et al., 2003). Theoretically, the visual attention span hypothesis is grounded in the multiple-trace memory model (Ans, Carbonnel, & Valdois, 1998; Valdois et al., 2004). In this model of the reading process, two successive reading procedures are distinguished. In the global procedure words are processed as a whole. Only if a word is not identified through the global procedure, the analytic procedure is activated and the word is read through serial activation of smaller orthographic units, such as syllables, letter clusters or letters, for which phonological outputs are successively generated and maintained in short-term memory. To enable processing through the global procedure, the visual attentional window, through which information from the orthographic input can be extracted, needs to extend over the entire letter string. If the visual attentional window does not cover the entire word, words cannot be processed in parallel, the analytic procedure is activated, and visual attention is focused successively on sublexical units. In other words, visual attention span, as a measure of the visual attentional window, plays a crucial role in parallel word processing.

Visual attention span has been shown to contribute to reading performance, independent from phonological skills in typically

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developing children (Bosse & Valdois, 2009; van den Boer, de Jong, & Haentjens-van Meeteren, 2013), and in children with dyslexia (Bosse, Tainturier, & Valdois, 2007). In the first grade visual attention span correlated with reading rate, as well as accuracy, of both words and pseudowords (Bosse & Valdois, 2009). These relations decreased in Grades 3 and 5, with the exception of irregular word reading accuracy, for which visual attention span remained a stable predictor across grades. These findings suggest that visual attention span, fostering parallel word processing, is especially important in reading irregular or exception words, for which serial analytic processing could result in incorrect pronunciations. Similarly, visual attention span has been linked to the acquisition of orthographic knowledge. If the visual attention span covers the entire word, a whole word orthographic representation can be acquired, enabling word identification through the global procedure. Indeed, it has been shown that orthographic learning benefits from the availability of whole-word orthographic forms (Bosse, Chaves, Largy, & Valdois, 2013).

Nevertheless, the effect of purely visual skills on reading development in general, and reading performance of children with dyslexia in particular, as proposed by the visual attention span hypothesis, is still widely debated (Hawelka & Wimmer, 2008; Lobier, Zoubrinetzky, & Valdois, 2012; Valdois, Lassus-Sangosse, & Lobier, 2012; Ziegler, Pech-Georgel, Dufau, & Grainger, 2010). On the one hand, Ziegler, Pech-Georgel, et al. (2010) showed that performance of children with dyslexia was impaired on a two-alternative forced choice task including letter and digit strings. When symbol strings were presented, however, their performance did not differ from that of average readers. Based on these results, the authors argued that only symbols that map onto phonological codes pose a challenge for children with dyslexia. In other words, their symbol-to-sound mapping is impaired. Similarly, Hawelka and Wimmer (2008) found that children with dyslexia and non-impaired readers showed similar performance on a visual target detection task of letters and pseudoletters when the task did not require verbal report of the letters. On the other hand, Valdois et al. (2012) argued that the verbal mapping account of a visual attention span deficit is incorrect, since performing a concurrent phonological task did not hamper letter-string report of children with dyslexia more than that of typically developing children. Furthermore, Lobier et al. (2012) showed that dyslexics with a visual attention span impairment performed worse than controls on a visual categorization task with both verbal and nonverbal stimuli. More specifically, the visual attention span impairment predicted performance on the nonverbal version of the task.

In the current paper we present two studies that further examine the nature of visual attention span and its relation with reading fluency. The work of Valdois and colleagues (Bosse & Valdois, 2009; Bosse et al., 2007; Valdois et al., 2003, 2004) clearly shows that visual attention span is an important predictor of reading performance. However, this relation has only been established for children learning to read an opaque orthography (i.e., French and English). Therefore, the joint aim of the two studies is to examine whether visual attention span is also a predictor of reading skills for children learning to read Dutch, a more transparent orthography, and thereby to establish whether visual attention span, similar to phonological awareness and rapid naming, can be considered a key predictor of reading performance across languages. In addition, the studies address two unresolved issues concerning visual attention span that could further specify the nature of its relation with reading.

First, the contribution of visual attention span has been shown to be independent of phonological awareness (e.g., Bosse & Valdois, 2009), but rapid naming, another important predictor of reading performance, has not been controlled for. Rapid naming, especially of letters, requires processes similar to those of visual attention span, which is typically measured as the ability to report back briefly presented strings of five letters (e.g., R H S D M). Both tasks require participants to quickly identify and name the letters. However, as argued by Bosse and Valdois (2009), there are also important differences between the tasks. For example, visual information is available only briefly in a visual attention span task, but remains available in rapid naming tasks. In Study 1 we examined the predictors of reading performance, and included both tasks to determine whether it is the similarities with or the differences from rapid naming that characterize the relation of visual attention span with reading performance. In a previous study (van den Boer, de Jong, & Haentjens-van Meeteren, 2013) we have shown that visual attention span is related to naming speed of single words, independent from rapid naming, in Grade 2 beginning readers. In the current study we aimed to extend this finding, by including both beginning (i.e., Grade 2) and advanced (i.e., Grade 5) readers, and by looking at the effects on a standardized continuous measure of word reading fluency.

In Study 2 the same variables were examined as predictors of both word and nonword reading performance in a large sample of fourth graders. Furthermore, this study addressed a second unresolved issue, that is the relation of visual attention span with spelling performance. To our knowledge this relation has not yet been studied, although it could be of importance in unraveling the nature of visual attention span. Given that in a spelling task phonological rather than orthographic word forms are presented, a relation of visual attention with spelling performance might not be expected if visual attention span reflects parallel visual processing of orthographic units within a fixation.

Alternatively, visual attention span could be related to spelling given that reading and spelling both rely on orthographic knowledge at a lexical as well as a sublexical level (e.g., Ehri, 2000; Tainturier & Rapp, 2000). Visual attention span has been shown to be related to the acquisition of orthographic knowledge (Bosse et al., 2013). Accordingly, a relation with spelling performance could be expected. This relation, however, is probably indirect, rather than direct. According to the self-teaching hypothesis (Share, 1995, 1999), orthographic representations are mainly acquired through phonological recoding of letter strings encountered during reading. Every time a word is successfully decoded into its phonological code, a link can be established between the written and spoken word forms, and an orthographic representation can be built or strengthened. In line with this theory, the relation between visual attention span and spelling could be mediated by reading skills. Visual attention span could affect reading and thereby the acquisition of orthographic knowledge, which in turn affects performance on spelling tasks.

2. Study 1 — method

2.1. Participants

One hundred and seventeen second-grade (52 boys, 65 girls), and 111 fifth-grade (51 boys, 60 girls) children from six schools in the Netherlands participated in the study. The mean ages of the children were 8 years (SD = 5.70 months) in Grade 2, and 11 years (SD = 5.86 months) in Grade 5. All children attended mainstream primary education. At the time of testing, second and fifth graders had received approximately one year five months and four years five months of instruction, respectively.

2.2. Measures

2.2.1. Word reading fluency

Word reading fluency was assessed with the One Minute Test (*Eén Minuut Test*; Brus & Voeten, 1995). This standardized reading test is regularly used as a measure of reading achievement in Dutch schools. The test consists of 116 words of increasing length and difficulty. Children were asked to read the words aloud as quickly and accurately as possible for 1 min. The score consisted of the number of items read correctly.

2.2.2. Nonverbal intelligence

Nonverbal intelligence was assessed with Raven's Standard Progressive Matrices test (Raven, 1960). Children were presented with 60 patterns from which a small part was omitted. They were instructed to identify the element that completed the pattern out of six to eight alternatives. They worked individually for 45 min to complete as many items as possible. The score consisted of the number of correct items.

2.2.3. Vocabulary

Vocabulary was assessed with the Vocabulary subtest from the RAKIT battery of intelligence tests (Bleichrodt, Drenth, Zaal, & Resing, 1984). Children were instructed to choose the picture that best matched the word read aloud by the experimenter from among four alternatives. The test included 45 items. The score consisted of the number of correct items.

2.2.4. Verbal short-term memory

Verbal short-term memory was assessed with a letter span task (e.g., Johnston, Rugg, & Scott, 1987). Children were presented with letter sequences (e.g., F L B S) increasing in length from two to seven letters, three sequences of each length. They were asked to repeat the letters in the correct order. After two consecutive errors within the same sequence length, the task was discontinued. The score consisted of the number of sequences repeated correctly.

2.2.5. Phonological awareness

Phonological awareness was assessed with an elision and spoonerism task (de Jong & van der Leij, 2003). The experimenter read aloud a nonword. Children were first asked to repeat the nonword. Next, the experimenter repeated the nonword and named a phoneme to be deleted. Children were then asked to repeat the nonword without this phoneme. A total of 27 items were administered. For the first 18 items children were asked to delete a single phoneme (e.g., 'tral' without 'r'), whereas in the next nine items the phoneme to be deleted was included twice (e.g., 'gepgral' without 'g'). Fifth graders who gave more than three correct responses to these last nine items, were presented with an additional six items. For these items, children were asked to switch the position of two phonemes and report the resulting nonword (e.g., 'larspos' switch 'l' and 'p'). The score consisted of the total number of correct responses.

2.2.6. Rapid naming

Rapid naming of digits (1, 3, 5, 6, and 8) was assessed. Children were presented with a sheet including five lines of ten digits each. They were asked to name aloud all digits as quickly as possible. The score consisted of the time needed to name all digits, converted to the number of digits named per second.

2.2.7. Visual attention span

The whole report visual attention span task as designed by Valdois and colleagues (e.g., Valdois et al., 2003) was administered. Children were presented with 20 five-letter strings (e.g., R H S D M). They were asked to repeat as many letters as possible, in the correct order. The strings were created from ten consonants (B, D, F, H, L, M, P, R, S, and T), all presented twice in each letter position. The task was programmed in E-prime version 1.0 (Schneider, Eschman, & Zuccolotto, 2002). To focus attention, a plus sign was presented for 1000 ms. Letter strings were then presented for 200 ms in bold 24-point Arial font. The score consisted of the number of letters repeated correctly (from a total of 100). Please note that although the task was identical to the task used by Valdois et al. (2003), the scores on the task were calculated slightly differently. Whereas in the studies of Valdois et al. (2003, 2004) scores were based on letter identity only, in the current study the identity as well as the order of the letters were taken into account. This scoring method was chosen because in reading it is important to perceive letters in the correct order in which they appear. Nevertheless, the correlation between the scores with and without taking order into account was high in Grade 2 ($r = .89$), as well as Grade 5 ($r = .89$).

2.3. Procedure

All children were tested in January/February. The vocabulary and nonverbal intelligence tasks were administered during a classroom session of about 45 min each. The other tasks were administered in a fixed order to each child individually in one session of about 30 min.

3. Study 1 — results

3.1. Descriptive statistics

Descriptive statistics are presented in Table 1. Thirteen children (eight in Grade 2, and five in Grade 5) were absent during classroom administrations of the vocabulary and nonverbal intelligence tasks. In addition, five scores (three in Grade 2, and two in Grade 5) were more than three standard deviations above or below the group mean. These outlier scores were coded as missing. As could be expected, children in Grade 5 obtained higher scores than children in Grade 2 on all tasks ($ps < .001$). Correlations between the variables for both grades are shown in Table 2. Nonverbal intelligence and vocabulary did not correlate significantly with word reading in Grade 2 nor in Grade 5. Verbal short-term memory, phonological awareness, rapid naming, and visual attention span correlated significantly with word reading fluency in both grades.

3.2. Visual attention span

The scores on the whole report visual attention span task were examined in more detail, especially for the poor readers. In Fig. 1 the proportion of letters recalled correctly for each letter position is shown for the second as well as the fifth graders. Performance is shown for poor and average readers separately. Above-average readers were kept out of this analysis to allow for a fair comparison. Norm scores on the One Minute Test ($M = 10$, $SD = 3$) were used to select both poor (norm scores ≤7) and average readers (norms scores 8 through 12).

Importantly, performance on the first and second letter positions was at ceiling for all groups. This indicates that the children did not have any difficulties with letter report per se. From the third position onwards, however, a drop in performance can be seen. On these letter positions, performance of advanced readers in Grade 5 was better than that of young beginning readers in Grade 2, $F(1,177) = 127.21$, $p < .001$, $\eta_p^2 = .42$, and importantly, performance of poor readers was worse than the performance of average readers, $F(1,177) = 33.57$, $p < .001$, $\eta_p^2 = .16$. The interaction between Grade and reading level was not significant.

3.3. Predictors of word reading

Hierarchical regression analyses were used to determine whether the predictor variables uniquely contributed to word reading fluency in Grades 2 and 5. For 15 children in Grade 2 and nine children in Grade 5 one or two scores on the predictor variables (mainly nonverbal intelligence and/or vocabulary) were missing, due to outlier scores or absence during task administration. These scores were imputed to avoid losing these participants for the regression analyses. Missing scores were estimated based on the relations among the predictor variables, using the EM algorithm (Tabachnick & Fidell, 2012). Little's MCAR test indicated that the data were missing completely at random, $\chi^2(24) = 18.583$, $p = .774$ in Grade 2, and $\chi^2(19) = 16.273$, $p = .639$ in Grade 5. The children with missing scores did not differ significantly from the children without missing scores on reading fluency and predictor variables both before and after imputation. Results were very similar when listwise deletion was used to handle missing data.

Table 1
Descriptive statistics for Grade 2 and Grade 5.

	Grade 2			Grade 5			
	N	*M* (*SD*)	Range	*N*	*M* (*SD*)	Range	*t* test
Word reading (raw)	117	39.59 (14.45)	12–81	111	68.34 (11.40)	41–99	16.723*
Nonverbal IQ	108	29.85 (8.24)	9–45	105	41.72 (7.25)	21–57	11.152*
Vocabulary	109	41.80 (3.94)	33–51	106	50.69 (3.41)	40–57	17.668*
Verbal short-term memory	116	6.87 (1.70)	3–11	111	9.30 (2.23)	5–15	9.186*
Phonological awareness	117	15.48 (6.00)	1–27	111	23.66 (4.47)	15–32	11.715*
Rapid naming	117	1.75 (.39)	.96–2.63	110	2.27 (.45)	1.06–3.33	9.331*
Visual attention span	116	55.19 (11.73)	31–92	111	76.24 (11.94)	42–100	13.401*

* $p < .001$.

In the first step the three control variables nonverbal intelligence, vocabulary, and verbal short-term memory were entered in the models. In the second step phonological awareness and rapid naming were added to the model. Visual attention span was entered in the third and final step, to examine its contribution to reading fluency, after controlling for both phonological awareness and rapid naming. The results are presented in Table 3. In Grade 2 the control variables did not account for any variance in word reading fluency. In Grade 5, however, the control variables accounted for 17% of the variance, mainly due to the effect of verbal short-term memory. Phonological awareness and rapid naming accounted for additional explained variance in both grades (32% in Grade 2 and 23% in Grade 5). Visual attention span, entered in the third step, also explained additional variance (2% in Grade 2 and 6% in Grade 5). Together the variables explained a substantial amount of variance in word reading fluency (40% in Grade 2 and 46% in Grade 5).

Standardized beta coefficients of the final model indicate the unique relation of each predictor with reading, when controlling for all the other variables in the model (see Table 3). Beta coefficients indicated that in both grades rapid naming appeared to be the strongest predictor of word reading fluency. In both Grades 2 and 5 phonological awareness and visual attention span were also significant predictors of reading fluency. Whereas in Grade 2 the coefficient of phonological awareness was slightly higher than that of visual attention span, in Grade 5 the opposite was found; visual attention span appeared to be a slightly stronger predictor than phonological awareness.

4. Study 2 — method

4.1. Participants

Two hundred and fifty-five fourth-grade children (133 boys, 122 girls) participated in this study, with a mean age of 9 years and 11 months ($SD = 5.41$ months). All children attended mainstream primary education at one of the 11 participating schools in the Netherlands, and had received approximately three years and five months of instruction at the time of testing.

Table 2
Correlations among all variables for Grade 2 and Grade 5.

	1	2	3	4	5	6	7
1. Word reading	–	.14	.00	.22*	.44**	.52**	.40**
2. Nonverbal IQ	.05	–	.21*	.21*	.26**	−.11	.25*
3. Vocabulary	−.07	.21*	–	.01	−.04	−.19*	.11
4. Verbal short-term memory	.38**	.26**	.17	–	.37**	.13	.30**
5. Phonological awareness	.35**	.30**	.06	.43**	–	.32**	.33**
6. Rapid naming	.51**	−.21*	−.24*	.16	.09	–	.28**
7. Visual attention span	.42**	−.01	.05	.35**	.20*	.16	–

Note. Grade 2 above the diagonal, Grade 5 below the diagonal.
* $p < .05$.
** $p < .01$.

4.2. Measures

4.2.1. Word reading fluency

Word reading fluency was assessed with the One Minute Test as described for Study 1.

4.2.2. Nonword reading fluency

Nonword reading fluency was assessed with the Klepel (van den Bos, lutje Spelberg, Scheepstra, & de Vries, 1994). This standardized reading test is regularly used as a measure of reading achievement in Dutch schools. The test consists of 116 nonwords of increasing length and difficulty. Children were asked to read the nonwords aloud as quickly and accurately as possible for 2 min. The score consisted of the number of items read correctly.

4.2.3. Orthographic knowledge

Orthographic knowledge was assessed with an orthographic choice task. Children were presented with four alternative spellings of words. They were instructed to choose the correct spelling (e.g., haut hout houd haud; for the word 'hout', meaning *wood*). All distractor items were pseudohomophones of the target word, but not all distractor items were orthographically legal. The task consisted of 70 items. The score consisted of the number of correct items.

4.2.4. Spelling

Spelling was assessed with a spelling to dictation task (*PI-dictee*; Geelhoed & Reitsma, 1999). This standardized spelling test is regularly used in Dutch schools to evaluate spelling achievement. The task includes blocks of items that correspond to rules, categories, and exception words in Dutch spelling that are taught in each grade and therefore increase in difficulty. We administered three blocks of 15 words each. The experimenter dictated the 45 words. Each word was read aloud, as well as a sentence including the word. Then, children were instructed to write down the target word. The score consisted of the number of items spelled correctly.

4.2.5. Nonverbal intelligence

Nonverbal intelligence was assessed with a subtest from the *Groninger School Onderzoek* developed to measure cognitive development (Kema & Kema-van Leggelo, 1987). Children were presented with four pictures. Three pictures shared one or more characteristic(s), but the fourth picture did not. They were instructed to identify the odd one out. Children had 10 min to complete the task, which consisted of a total of 27 items. The score consisted of the number of correct items.

4.2.6. Verbal short-term memory

Verbal short-term memory was assessed with the letter span task as described for Study 1.

4.2.7. Phonological awareness

Phonological awareness was assessed with the elision and spoonerism task as described for Study 1.

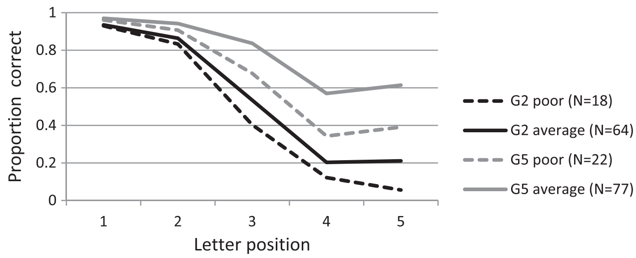

Fig. 1. Proportion of correctly identified letters on each position in the visual attention span task for poor and average readers.

4.2.8. Rapid naming

Rapid naming of digits was assessed as described for Study 1. In addition, rapid naming of letters (A, D, O, P, S) was assessed in the same way.

4.2.9. Visual attention span

The whole report visual attention span task was administered as described for Study 1.

4.3. Procedure

All children were tested in January/February. The nonverbal intelligence, orthographic choice and spelling tasks were administered during a classroom session of about 45 min. The other tasks were administered in a fixed order to each child individually in two sessions of about 25 min each. The data was part of a larger dataset, also including assessment of oral or silent reading skills which are reported elsewhere (see van den Boer, van Bergen, & de Jong, 2014).

5. Study 2 — results

5.1. Descriptive statistics

Descriptive statistics are presented in Table 4 and correlations between the variables are shown in Table 5. A strong correlation was found between word and nonword reading ($r = .86$). Orthographic choice and spelling correlated moderately ($r = .68$). Moderate correlations were also found between the reading and spelling tasks (*r*s between .46 and .65). Verbal short-term memory, phonological awareness, rapid naming and visual attention span correlated significantly with the reading and spelling tasks, and with each other. Nonverbal intelligence correlated significantly with orthographic knowledge and phonological awareness.

5.2. Predictors of reading and spelling

As in Study 1, hierarchical regression analysis was used to determine whether nonverbal intelligence, verbal short-term memory, phonological awareness, rapid naming, and visual attention span uniquely contributed to word reading fluency, nonword reading fluency, orthographic knowledge and spelling performance. We assessed rapid naming of letters and digits, but these measures were found to be very similar, both in average naming speed, and in the correlations with the other variables. Rapid naming of letters was included in the regression analyses, mainly because of its similarity to the other predictors (i.e., all tasks included letters as stimuli). However, unless otherwise specified, the results were the same when rapid naming of digits rather than letters was used.

Again, missing values were imputed to avoid losing participants for the analyses. Three children were excluded from further analyses because their scores were missing on three or more tasks. For 40 children one or two scores were missing on the predictor variables, because the children were unable or unwilling to complete a task, or due to errors in task administration by the test assistants. These scores were imputed based on the relations among the predictor variables, using the EM algorithm. Little's MCAR test indicated that the scores were missing completely at random, $\chi^2(29) = 37.293$, $p = .139$. The children with missing scores on the predictors did not differ from the children without missing scores on the predictors and the dependent variables before and after imputation. For 23 children one or two scores were missing on the dependent variables, because the children were absent during classroom administration of the spelling tests, or obtained a score that was more than three standard deviations above or below the group mean. Little's MCAR test indicated that these scores were not missing completely at random, $\chi^2(11) = 46.460$, $p < .001$. Consequently, these scores were not imputed. Therefore, the sample size fluctuates across analyses (see Table 6). Results were very similar when listwise deletion was used to handle missing data.

In the first step we entered nonverbal intelligence and verbal short-term memory. Phonological awareness and rapid naming were added in the second step. Visual attention span was again entered in the third and final step. The results are presented in Table 6. Nonverbal intelligence and verbal short-term memory accounted for variance in word and nonword reading (16% and 10% respectively). Phonological awareness and rapid naming accounted for additional explained variance in both word and nonword reading fluency (28% and 44% respectively). Visual attention span, entered in the third step, also explained additional variance (3% for both word and nonword reading). Together the variables explained a substantial amount of variance in word and nonword reading fluency (47% and 57% respectively). Standardized beta coefficients indicated that rapid naming appears to be the strongest predictor of reading fluency, as in Study 1. Phonological awareness seems to be related more strongly to nonword than to word reading fluency, but was a significant predictor of both. Visual attention span was a

Table 3
Hierarchical regression results of phonological awareness, rapid naming, and visual attention span as predictors of word reading fluency in Grade 2 and Grade 5.

		Grade 2		Grade 5	
		ΔR^2	β^a	ΔR^2	β^a
1.	Nonverbal IQ	.06	.08	.17**	.07
	Vocabulary		.05		−.02
	Verbal short-term memory		.01		.12
2.	Phonological awareness	.32**	.23**	.23**	.19*
	Rapid naming		.41**		.45**
3.	Visual attention span	.02*	.17*	.06**	.27**
Total R^2		.40		.46	

[a] Standardized beta coefficients from the final model.
* $p < .05$.
** $p < .01$.

Table 4
Descriptive statistics for Grade 4.

	Grade 4		
	N	*M* (*SD*)	Range
Word reading	254	64.81 (13.57)	27–102
Nonword reading	255	56.89 (18.74)	18–101
Orthographic knowledge	234	57.96 (6.42)	39–70
Spelling	249	31.63 (7.32)	10–44
Nonverbal intelligence	253	20.50 (2.88)	12–27
Verbal short-term memory	253	10.44 (2.25)	6–17
Phonological awareness	228	20.86 (6.43)	5–33
Rapid naming digits	255	2.18 (.41)	1.25–3.36
Rapid naming letters	254	2.10 (.38)	1.07–3.17
Visual attention span	233	73.45 (12.83)	36–98

Table 5
Correlations among all variables for Grade 4.

	1	2	3	4	5	6	7	8	9	10
1. Word reading	–									
2. Nonword reading	.86**	–								
3. Orthographic knowledge	.54**	.46**	–							
4. Spelling	.65**	.59**	.68**	–						
5. Nonverbal intelligence	.00	−.01	.16*	.11	–					
6. Verbal short-term memory	.38**	.31**	.27**	.40**	.04	–				
7. Phonological awareness	.44**	.55**	.39**	.53**	.18**	.35**	–			
8. Rapid naming digits	.58**	.64**	.18**	.31**	−.10	.22**	.28**	–		
9. Rapid naming letters	.56**	.63**	.24**	.34**	−.06	.17**	.29**	.74**	–	
10. Visual attention span	.48**	.52**	.36**	.50**	.07	.32**	.42**	.38**	.37**	–

* $p < .05$.
** $p < .01$.

significant and equally strong predictor of word and nonword reading fluency.

Nonverbal intelligence and verbal short-term memory also accounted for variance in orthographic knowledge and spelling (10% and 17% respectively). Phonological awareness and rapid naming accounted for additional explained variance in both orthographic knowledge and spelling (10% and 19% respectively), although this effect was mainly due to the effect of phonological awareness. Standardized beta coefficients indicated that rapid naming did not contribute significantly to orthographic knowledge. The contribution of rapid naming to spelling was small, but significant. However, when rapid naming of digits, rather than letters, was included in the model, rapid naming did not contribute significantly to either orthographic knowledge, or spelling. Visual attention span, entered in the third step, explained additional variance in both orthographic knowledge and spelling (3% and 6% respectively). All predictors appeared to have stronger effects on spelling performance than on orthographic knowledge. Together the variables explained a substantial amount of variance in orthographic knowledge and spelling (23% and 41% respectively).

In addition, we examined whether the relation between visual attention span and spelling performance was mediated by reading performance and orthographic knowledge. In the hierarchical regression analysis with spelling as the dependent variable, word reading fluency and orthographic knowledge were added in the first step, followed by nonverbal intelligence and verbal short-term memory, phonological awareness and rapid naming, and in the fourth and final step visual attention span. Word reading and orthographic knowledge accounted for a substantial amount of variance in spelling performance ($R^2 = .58$, $p < .001$). Nonverbal intelligence and verbal short-term memory ($R^2 = .02$, $p = .013$), as well as phonological awareness and rapid naming ($R^2 = .03$, $p < .001$), accounted for additional explained variance. Importantly, in the fourth and final step visual attention span still contributed a small, but significant proportion of explained variance ($R^2 = .01$, $p = .004$).

6. Discussion

In the current paper we examined the relation of visual attention span with literacy skills in a more transparent orthography. In two studies we examined whether visual attention span contributed to reading fluency, and whether this relation was independent of rapid naming. In the second study we also examined the relation of visual attention span with orthographic knowledge and spelling performance.

In the first study we found clear differences in the performance on the visual attention span task between the second and fifth graders and between poorer and average readers. For all readers, accuracy on the first and second letters of the string was almost at ceiling. Subsequently, a drop was seen in the recall of the letters in positions 3, 4, and 5. As expected, performance on these letter positions was worse for younger than for older children and for poorer readers as compared to average readers. Overall, these patterns were similar to those reported by Valdois et al. (2003), although performance on the final positions was on average somewhat lower. These differences, however, are to be expected given that in the current study the children were younger, the scoring method was more strict, and the performance of the above-average readers was not included in the analysis. The findings that younger and poorer readers were less able to process the five-letter strings in parallel, is in line with the multiple-trace memory model (Ans et al., 1998; Valdois et al., 2004). Within this model, visual attention span as a measure of the visual attentional window is essential in determining the efficiency of letter string processing. A larger visual attention span allows reading through the faster global procedure, whereas a smaller visual attention span is associated with slower reading due to analytic processing of the letter strings.

Table 6
Hierarchical regression results of phonological awareness, rapid naming, and visual attention span as predictors of word and pseudoword reading fluency, orthographic knowledge and spelling in Grade 4.

		Word reading		Nonword reading		Orthographic knowledge		Spelling	
		($N = 251$)		($N = 252$)		($N = 234$)		($N = 246$)	
		ΔR^2	β[a]	ΔR^2	β[a]	ΔR^2	β[a]	ΔR^2	β[a]
1.	Nonverbal IQ	.16**	−.04	.10**	−.06	.10**	.11	.17**	.02
	Short-term memory		.19**		.06		.10		.17**
2.	Phonological awareness	.28**	.18**	.44**	.31**	.10**	.22**	.19**	.30**
	Rapid naming		.38**		.44**		.10		.11*
3.	Visual attention span	.03**	.21**	.03**	.21**	.03**	.20**	.06**	.28**
Total R^2		.47		.57		.23		.41	

[a] Standardized beta coefficients from the final model.
* $p < .05$.
** $p < .01$.

In addition, visual attention span was a significant unique predictor of word reading fluency for both beginning (Grade 2) and more advanced (Grades 4 and 5) readers. Previous studies have already shown that the contribution of visual attention span to reading performance is independent of phonological awareness (Bosse & Valdois, 2009; Bosse et al., 2007; Valdois et al., 2003, 2004). The results of the current studies indicate that the relation remains substantial when controlling for rapid naming. Verbal short-term memory of letter strings was also controlled for. Our results therefore support the claim of Valdois and colleagues (Bosse & Valdois, 2009; Valdois et al., 2004), that although the visual attention span task involves reporting verbal material, it should not be considered a rapid naming task, nor a verbal short-term memory task.

In Study 2 we also examined the relation of visual attention span with nonword reading. In line with previous studies (Bosse & Valdois, 2009; van den Boer et al., 2013) visual attention span related to both word and nonword reading. The relation with nonword reading indicates that visual attention span not only determines whether words can be processed through the global route (Ans et al., 1998; Valdois et al., 2004), but also relates to the size of the orthographic units that can be processed through the analytic procedure if an orthographic representation of the letter string is not available. In other words, visual attention span seems to affect processing speed of all letter strings at all stages of reading development.

Bosse and Valdois (2009) showed that the contribution of visual attention span to word reading accuracy decreased for regular words, and remained stable across grades only for irregular words. They ascribed this result to the effect of visual attention span on the long-term acquisition and establishment of orthographic knowledge, which is of specific importance in reading irregular words, more than in reading regular words or nonwords. Our results in Dutch, a relatively transparent orthography, did not show a decrease in the contribution of visual attention span to word reading fluency. Visual attention span was a significant predictor of word reading fluency in all grades tested. Therefore, our results might indicate that, perhaps especially in languages with relatively few exception words, the crucial aspect in the relation of visual attention span with reading fluency might not be the acquisition of orthographic knowledge. Rather, it could be the amount of orthographic information that can be processed within one glance, irrespective of whether this information is mapped onto whole-word phonology through the global route or to sublexical units in the analytic procedure.

To our knowledge, this is the first study that also examined the relation of visual attention span with spelling abilities. Visual attention span was a unique predictor of both orthographic knowledge and spelling performance. This result was expected as visual attention span has been shown to relate to the extraction and storage of orthographic information during reading (e.g., Bosse et al., 2013), which in turn determines the quality of the orthographic representations that can be called upon in spelling tasks. However, the effect of visual attention span on spelling performance remained significant after controlling for reading fluency and orthographic knowledge. These findings could still be explained in terms of the effect of visual attention span on the acquisition and establishment of orthographic knowledge if we assume that performance on the spelling-to-dictation task is merely a better reflection of the orthographic knowledge that a child has acquired than our reading or orthographic choice tasks. In fact, to perform well on the reading and orthographic choice tasks children could rely on partial or imprecise processing of the orthographic form, whereas detailed orthographic representations need to be retrieved in order to spell a word correctly. In other words, the relation between visual attention span and spelling could be explained as an indirect effect. Visual attention span, through its effect on whole word processing, affects how much orthographic knowledge is acquired during reading, which in turn determines how well children perform on a spelling test.

An alternative explanation of the effect of visual attention span on spelling skills, however, could be that visual attention span also captures skills that are of specific importance in spelling performance. It has been suggested that visual attention span taps grapheme–phoneme connections, or verbal coding abilities, rather than visual processing (Hawelka & Wimmer, 2008; Ziegler, Pech-Georgel, et al., 2010). Since reading and spelling rely heavily on grapheme–phoneme connections, such an interpretation of visual attention span could possibly explain the relations with both types of literacy skills. The contributions of visual attention span to reading and spelling performance were significant after controlling for verbal short-term memory, phonological awareness, and rapid naming. These tasks were rather similar to the visual attention span task, since all tasks included letters (or words) as stimuli, and all tasks required verbal output. Moreover, rapid naming also involves verbal coding as the names of the symbols (i.e., letters or digits) have to be provided. However, an important difference between visual attention span and the phonological tasks included in the study is the focus on fast parallel multi-element processing. Thus, verbal coding is probably involved in visual attention span, but performance on the task probably does not reflect the ability to generate verbal codes per se, but rather the ability to activate verbal codes in parallel.

An interpretation of visual attention span in terms of parallel processing of orthographic units, and simultaneously, parallel activation of the corresponding phonological codes, incorporates both the multi-element, and the verbal coding interpretations of the task. Parallel activation of phonology from print obviously fosters reading speed, but might not specifically benefit spelling performance. The specific relation of visual attention span with spelling seems easier to understand, however, if we interpret visual attention span in terms of the quality of orthography–phonology connections. This is a slightly different, though related interpretation, since only strong connections would enable processing multiple elements within one glance. The connection between written and spoken word forms is important for both reading and spelling performance (Perfetti & Hart, 2002). Different from the rapid naming task, where orthographic information remains available, and from the phonological awareness tasks, where there is no constraint on processing time, the visual attention span task demands strong orthography–phonology connections, because letters are presented only briefly, and need to be reported verbally. Only if the letters automatically activate the associated phonological codes within one glance, can the letters be reported correctly.

In addition to visual attention span we included phonological awareness and rapid naming as predictors of reading and spelling. Phonological awareness was related to word reading across grades, and was an especially strong predictor of nonword reading (Study 2). The relation between phonological awareness and reading is generally found to be stronger in less transparent orthographies (e.g., Ziegler, Bertrand, et al., 2010). However, the current results are in line with a number of studies indicating that strong relations are also found in transparent languages, when sufficiently difficult measures are used to assess phonological awareness skills (Caravolas, Volín, & Hulme, 2005; de Jong & van der Leij, 2003; Patel, Snowling, & de Jong, 2004; Vaessen & Blomert, 2010). In line with previous studies, phonological awareness was also a strong predictor of spelling performance (Landerl & Wimmer, 2008; Moll et al., 2009; Nikolopoulos, Goulandris, Hulme, & Snowling, 2006; Verhagen, Aarnoutse, & van Leeuwe, 2008, 2010).

As is often found in transparent orthographies, rapid naming appeared to be the strongest predictor of reading fluency (de Jong & van der Leij, 2002; Landerl & Wimmer, 2008; Moll et al., 2009; Vaessen & Blomert, 2010), with equal relations with both word and nonword reading (Georgiou, Papadopoulos, Fella, & Parrila, 2012; Moll et al., 2009; van den Boer et al., 2013). In contrast, rapid naming was the least important predictor of spelling. Rapid naming of digits did not contribute significantly to spelling performance, and rapid naming of letters had a very small independent effect. The relation between rapid naming and spelling is still debated. Some studies have shown a unique contribution to spelling (Savage, Pillay, & Melidona, 2008; Sunseth & Bowers, 2002; Verhagen et al., 2010), whereas others have indicated that rapid naming did not contribute to spelling performance over and above phonological awareness (Cornwall, 1992; Landerl & Wimmer, 2008). Our findings would be in line with the latter. The results are also in line with the findings of Wimmer and Mayringer (2002). In children who spoke German, a transparent orthography similar to Dutch, they found that a rapid naming deficit was associated with a specific problem with fluent reading. Spelling difficulties, in contrast, were associated with deficits in phonological awareness. The dissociation led the authors to propose the phonological speed dyslexia account, which states that some children do build orthographic representations, but lack efficiency accessing and using these representations to foster fluent reading. They do, however, succeed in spelling tasks, since orthographic representations are intact and can be accessed when performance is less time constrained. There is still quite some debate about the exact nature of the relation between rapid naming and reading (see Kirby, Georgiou, Martinussen, & Parrila, 2010, for a review). If rapid naming indeed contributes to reading, but not to spelling performance, the likely explanations would include the ability to access and retrieve phonological representations (e.g., Wagner & Torgesen, 1987), rather than the learning of orthographic codes (e.g., Bowers, 1995).

In sum, the current studies showed that visual attention span is a predictor of both beginning and advanced reading skills, and of spelling performance in an orthographically transparent language. Importantly, visual attention span contributed to literacy skills independent of established phonological predictors, that is phonological awareness and rapid naming. The relation of visual attention span with fluent reading and most importantly spelling can be explained through the acquisition and use of orthographic knowledge. Alternatively, we argued that visual attention span performance might reflect the quality of the connections between orthographic and phonological units, and thereby the ability to activate phonology in parallel upon encountering orthography and vice versa.

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