How do children read words? A focus on reading processes

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But when he was reading, his eye glided over the pages, and his heart searched out the sense, but his voice and tongue were at rest. Ofttimes when we had come (for no man was forbidden to enter, nor was it his wont that any who came should be announced to him), we saw him thus reading to himself, and never otherwise

- Augustine -

Chapter 3
Underlying skills of oral and silent reading

Many studies have examined reading and reading development. The majority of these studies, however, focused on oral reading, rather than the more dominant silent reading mode. Similarly, it is common practice to assess oral rather than silent reading abilities in schools and in diagnosis of reading impairments. More importantly, insights gained through examinations of oral reading tend to be generalized to silent reading. In the current study we examined whether such generalizations are justified. We directly compared oral and silent reading fluency and studied whether these reading modes rely on the same underlying skills. One hundred thirty-two sixth graders read words, sentences and text orally, and one hundred twenty-three classmates read the same material silently. As underlying skills we considered phonological awareness, rapid naming, and visual attention span. Results indicated that silent reading speed was higher than oral reading speed. All skills correlated significantly with both reading modes. Phonological awareness contributed equally to oral and silent reading. Rapid naming, however, correlated more strongly with oral than with silent reading. Visual attention span correlated equally strongly with both reading modes, but showed a significant unique contribution only to silent reading. In short, we showed that oral and silent reading indeed are fairly similar reading modes, that to a large extent draw on the same underlying processes. However, we also found differences that warrant caution in generalizing findings across reading modes.

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INTRODUCTION

Learning to read is an important, but complex process. Therefore, it is not surprising that many studies examined reading and reading development. It is surprising, however, that the majority of these studies have focused on oral reading rather than silent reading, which is actually the primary reading mode for proficient readers. In schools, the focus shifts rapidly from initial instruction in oral decoding toward independent silent reading. That same shift, however, is not seen in the assessment of reading abilities. Not in research, where there has been a focus on oral reading at the expense of silent reading (see Share, 2008), in for example models of the reading process, studies of reading development, and studies of skills underlying reading. Nor in practice, for example, in diagnosing dyslexia, a basic deficit in learning to decode print (e.g., Vellutino, Fletcher, Snowling, & Scanlon, 2004). Although definitions of dyslexia do not specify which reading mode the difficulties with accurate and/or fluent word recognition occur in (e.g., American Psychiatric Association, 1994; Blomert, 2006; British Dyslexia Association, 1998; Lyon, Shaywitz, & Shaywitz, 2003), it is common practice to asses oral rather than silent reading. More importantly, insights gained through research on or assessment of oral reading are tacitly generalized to silent reading. It is unclear, however, whether the production of overt, oral responses in reading aloud is fully comparable to silent reading. In the current study we compared oral and silent reading fluency and examined whether these reading modes draw on similar underlying skills.

The focus on oral over silent reading is understandable from a practical point of view. The easiest way to assess both speed and accuracy of reading is asking participants to read aloud a list of words or a text. Silent reading fluency, in contrast, is more difficult to assess. Measuring pure reading rates, for example, might invoke inaccurate reports of performance (e.g., Hale et al., 2007). Therefore, measures of silent reading typically include semantic categorization, sentence verification, and lexical decision. However, effects of lexical variables such as length, frequency and neighborhood size on lexical decisions, for example, have been found to differ greatly from their effect on oral naming (e.g., Balota, Cortese, Sergent-Marshall, Spieler, & Yap, 2004), but also from their effects on other tasks requiring silent reading, such as categorization latencies and eye movements during silent reading (e.g., Balota & Chumbley, 1984;

Kuperman, Drieghe, Keuleers, & Brysbaert, 2013; Pollatsek, Perea, & Binder, 1999; Schilling, Rayner, & Chumbley, 1998). It is unclear whether these differences should be ascribed to oral versus silent reading, or to task specific demands, such as oral responses in naming, the decision component in lexical decision, and activation of meaning in silent reading of text. For a proper comparison of oral and silent reading fluency preferably the same measures should be used in both reading conditions.

Only a small number of studies have directly compared oral and silent reading. These studies have mainly focused on reading comprehension. Studies in the early 1900s showed that children read more text and also comprehended more of the material read during silent than during oral reading (Mead, 1915, 1917; Pintner, 1913). This advantage of silent over oral reading increased with age and was even more pronounced in adults (Pintner & Gilliland, 1916). More recently, mixed findings have been reported. Silent reading was found to be the more efficient reading mode, because it resulted in equal comprehension but shorter reading times (Juel & Holmes, 1981; McCallum, Sharp, Bell, & George, 2004). Or, silent reading resulted in better comprehension, when oral pronunciations required attentional resources, which in silent reading were all deployed for comprehension (Holmes, 1985). Oral reading, however, has also been found to be the superior mode for comprehension, especially in the early grades (de Jong & Share, 2007; Elgart, 1978; Prior et al., 2011; Swalm, 1972). A shift in favor of silent reading occurred as early as third grade (Swalm, 1972), up to seventh grade (Prior et al., 2011), or not at all (Hale et al., 2007).

Whether oral and silent reading depend on similar reading processes is a question that has received considerably less attention. Substantial correlations have been reported between oral and silent text reading speed (r = .71-.87; e.g., Barker, Torgesen, & Wagner, 1992; Kim, Wagner, & Foster, 2011; Landerl & Wimmer, 2008). However, the correlations clearly deviated from one, suggesting that oral and silent reading are not entirely identical reading modes. Findings of Juel and Holmes (1981) support this notion. Children were presented with sentences including words that differed in decodability, number of syllables, frequency, and semantic difficulty. All factors significantly affected reading speed in both reading modes. However, longer reading times were found for difficult words (i.e., low frequency, more syllables, irregular phonetic patterns) in oral than in silent reading, indicating that effects were stronger on oral reading. Schumm and Baldwin (1989) presented children with passages that included orthographically altered words (e.g., ‘celled’ instead of ‘called’), and showed that children noticed these incorrect words more often in oral reading than in silent reading. These findings suggest that word-level orthographic and phonological characteristics might affect oral reading more than silent reading.

In line with these findings, it has been suggested that differences between oral and silent reading should be ascribed to less extensive phonological processing in silent as compared to oral reading (e.g., Juel & Holmes, 1981; Share, 2008). Oral reading, by definition, requires activation of phonological codes. In silent reading the role of phonology is less clear, since the orthographic word form could directly activate meaning. This stands in sharp contrast to strong phonological theories of reading, which state that phonology is important in both oral and silent reading (e.g., Frost, 1998; Perfetti & Hart, 2002). Before reading instruction starts, children have acquired mappings between phonological codes and meanings though spoken language. Throughout reading development, orthographic representations are added to and integrated with the phonological and semantic information to form high-quality word representations. Upon encountering orthographic forms during reading, the entire representation is activated, and both phonological and semantic information are immediately available. Strong phonological theories are supported by findings of activation of phonology in silent word reading in adults (e.g., Newman & Connolly, 2004; Perfetti, Bell, & Delaney, 1988), and in children, as evidenced by, for example, orthographic learning during silent reading (Bowey & Muller, 2005; de Jong, Bitter, van Setten, & Marinus, 2009), and difficulty in rejecting homophone foils as words (Sprenger-Charolles, Siegel, & Béchennec, 1998). Taken together, these results suggest that phonological processing occurs in both oral and silent reading, but that there might be differences in the relative importance of phonology across reading modes. To further unravel this issue, however, studies are needed that directly compare the role of phonology in oral and silent reading.

In the current study we examined differences and similarities between oral and silent reading fluency through the relations with cognitive skills that are important in reading development. In other words, we examined whether both reading modes rely on similar cognitive processes. To our knowledge, this question has never been addressed before. Studies of oral reading have shown that several cognitive skills are important. Awareness of the phonological structure of the language, and the ability to rapidly name highly familiar symbols have been shown to be particularly strong concurrent and longitudinal predictors of oral reading skills in many languages (e.g., de Jong & van der Leij, 1999; Georgiou, Parrila, & Papadopoulos, 2008; Landerl & Wimmer, 2008; Lervåg, Bråten, & Hulme, 2009; Torgesen, Wagner, Rashotte, Burgess, & Hecht, 1997; Vaessen et al., 2010; Ziegler et al., 2010). More recently, it has been shown that the visual attention span, the number of orthographic units (e.g., letters or syllables) that can be processed in parallel, also contributes to reading performance, independent from phonological processing skills (e.g., Bosse & Valdois, 2009; Valdois, Bosse, & Tainturier, 2004; van den Boer, de Jong, & Haentjens-van Meeteren, 2013).

Only one study focused specifically on predictors of silent reading fluency. Bar-Kochva (2013) studied reading development in Hebrew from kindergarten to Grade 2. Phonological awareness was a significant predictor. Other important predictors were phonological working memory, rapid naming, and vocabulary. Visual processing skills and morphological awareness did not contribute to silent reading fluency. Bar-Kochva's results seem to indicate that the underlying skills of silent reading do not differ much from the underlying skills of oral reading, at least not in the early stages of reading acquisition. However, oral reading performance was not included in the study, so a direct comparison could not be made.

In the current study we examined whether oral and silent reading depend on the same underlying skills. We focused on phonological awareness, rapid naming, and visual attention span. In general, little is known about possible differences between oral and silent reading fluency. From a theoretical perspective (Frost, 1998; Perfetti & Hart, 2002), as well as from the results of a single study on silent reading fluency (Bar-Kochva, 2013), it can be expected that phonological awareness is important for both oral and silent reading, but possibly more so for oral reading (Juel & Holmes, 1981; Schumm & Baldwin, 1989; Share, 2008). There are, however, no theoretical accounts of the role of rapid naming or visual attention span in silent reading. Based on previous findings that oral and silent reading represent similar, but not identical reading modes, it seems likely that these skills could be predictors of both oral and silent reading, but that the relative strength of the relations might differ across reading modes.

METHOD

PARTICIPANTS

Participants were 255 fourth-grade children (133 boys, 122 girls) from 12 classes of 11 schools in the Netherlands. The children had a mean age of 9 years 11 months (*SD* = 5.41 months). All children attended mainstream primary education. Most children were native speakers of Dutch (85.1%) or spoke Dutch at home although as a second language (12.2%). Within in each classroom half of the children were randomly assigned to the oral condition and the other half to the silent reading condition.

MEASURES

Three reading tasks were administered, as well as measures of nonverbal intelligence, verbal short-term memory, phonological awareness, rapid naming, and visual attention span. Multiple measures were included for each skill, except for nonverbal intelligence.

Reading. Three reading tasks were administered to measure reading fluency of words, sentences, and text. Children performed the exact same tasks in either the oral or silent reading condition. Therefore, similar scores were obtained for oral and silent reading. Because decoding errors could not be assessed in silent reading, incidental decoding errors in oral reading were not taken into account.
Word reading. Reading of words was assessed with a paper-and-pencil lexical decision task (*Doorstreepleestoets;* van Bon, 2007). Children were presented with a list of 90 bisyllabic words (e.g., ‘speeltuin’, meaning *playground*) intermixed with 30 bisyllabic pseudowords (e.g., ‘flaaphek’). They were instructed to read the items either aloud or silently and cross out pseudowords. After 1 minute children were asked to stop. In the oral condition the experimenter marked the last word the children read. In the silent reading condition, children were asked to mark the last item read. The scores consisted of the number of items read minus the number of errors. Errors were

pseudowords that were not identified, as well as words that were incorrectly crossed out.

Sentence reading. Reading of sentences was assessed with a sentence verification task. Fifty sentences were constructed. The sentences were short (3 to 7 words) statements about simple facts that were expected to be well known by the children (e.g., '*The grass is green*'). Half of the sentences were true and the other half was false. Children were instructed to read the sentences either aloud or silently and judge the veracity by encircling either 'correct' or 'incorrect'. After 2 minutes children were asked to stop. The scores consisted of the number of sentences judged correctly.

Text reading. Reading of text was assessed with a maze task (*Leestempo;* Krom, 2011). Children were presented with a text from which about every tenth word was deleted and replaced by three possible choices (e.g., 'beginnen [to begin] / beginner [beginner] / begingen [committed]'). Children encountered a maximum of 100 deleted words. They were instructed to read the text either aloud or silently and choose from among the alternatives the words that fitted the text. After 4 minutes children were asked to stop. The scores consisted of the number of items judged correctly.

Nonverbal intelligence. A nonverbal subtest from the *Groninger School Onderzoek* (Kema & Kema-van Leggelo, 1987) was administered to obtain an estimate of the children's nonverbal intelligence. Children were presented with four pictures. Three pictures shared one or more characteristic(s), but the fourth picture did not. Children were instructed to identify the odd one out. They had 10 minutes to complete the task, which consisted of a total of 27 items. The score consisted of the number of items correct. Cronbach's alpha in our sample was .58.

Verbal short-term memory. Short-term memory was assessed with a letter span task (e.g., Johnston, Rugg, & Scott, 1987) and the forward digit span task from the Wechsler Intelligence Scale (WISC-III-NL; Kort et al., 2005).

Letter span. The experimenter read aloud letter sequences increasing in length from two to seven letters, three sequences of each length. Children were asked to repeat the letters in the correct order. The task was discontinued after two consecutive errors within the same sequence length. The score consisted of the number of sequences repeated correctly.

Digit span. The experimenter read aloud digit sequences increasing in length from two to nine digits, two sequences of each length. Children were asked to repeat the digits in the correct order. The task was discontinued when both sequences of the same length were incorrect. The score consisted of the number of sequences repeated correctly. Internal consistency reported in the WISC-manual for Grade 4 is .64 (Kort et al., 2005).

Phonological awareness. Phonological awareness was assessed with an elision and spoonerism task (de Jong & van der Leij, 2003). This task consisted of items requiring manipulation of either one or two phonemes. Separate scores were calculated for both item types.
One phoneme. The experimenter read aloud a nonword and children were asked to repeat the nonword completely. Next, the experimenter repeated the nonword and named a phoneme to be deleted (e.g., 'tral' without 'r'). Children were asked to repeat the nonword without this phoneme. A total of 18 items were administered, nine monosyllabic and nine bisyllabic items. The score consisted of the number of correct responses. Cronbach's alpha in our sample was .78.
Two phonemes. Following the same procedure, children were presented with nine bisyllabic items with the phoneme to be deleted included twice (e.g., 'gepgral' without 'g'). If more than three responses were correct, children were presented with six bisyllabic spoonerism items. For these items, children were asked to switch the position of two phonemes (e.g., 'larspos' switch 'l' and 'p'). The score consisted of the number of correct responses.

Rapid naming. Rapid naming was assessed with digit and letter naming.
Digits. Five digits (1, 3, 5 ,6, and 8) were presented ten times each in a random order on a sheet with five lines of ten digits each. Children were asked to name aloud all digits as quickly as possible. The experimenter recorded the time needed to name all digits. The score consisted of the number of digits named per second.
Letters. Naming of letters (A, D, O, P, and S) was administered in the same way.

Visual attention span. Visual attention span was assessed with the whole report task (see Valdois et al., 2003). Children were presented with 20 five-letter strings (e.g., R H S D M). They were asked to repeat, in the correct order, as many letters of the string as possible. The strings were created from ten consonants (B, D, F, H, L, M, P, R, S, and T), each repeated in ten strings, twice in each letter position. The task was programmed in E-prime Version 1.0 (Schneider, Eschman, & Zuccolotto, 2002). Letters were presented for 200 ms in bold 24-point Arial font. To focus attention, trials were preceded by a plus sign, presented for 1000 ms. The score consisted of the number of letters repeated correctly (from a total of 100), calculated for uneven and even items separately. Cronbach's alpha in our sample was .76 and .77 for uneven and even items respectively.

PROCEDURE

The tasks were administered in January/February during three sessions. The intelligence task was administered during a classroom session of about 15 minutes. The other tasks were administered in a fixed order to each child individually in two sessions of about 25 minutes each.

ANALYSES

The main question concerned similarities and differences in the relations between oral and silent reading and predictors of reading. To test these effects, multigroup structural equation modeling was conducted, using Mplus version 5.21 (Muthén & Muthén, 2009). The models were fitted with full information maximum likelihood estimation. Model fit was evaluated using the chi-square statistic of overall goodness of fit, the comparative fit index (CFI), and the root mean square error of approximation (RMSEA). A chi-square p-value larger than .05 indicates exact fit (Hayduk, 1996). A CFI larger than .95 indicates good fit (Hu & Bentler, 1999). Values of the RMSEA below .05 indicate close fit, below .08 satisfactory fit, and values over .10 indicate poor fit (Browne & Cudeck, 1993). To test the difference in model fit between two nested models, a chi-square test was used (Kline, 2011).

RESULTS

DESCRIPTIVE STATISTICS

Before running analyses, data were inspected for outliers. Scores more than three standard deviations above or below the group mean were coded as missing (0.5%).

Scores could also be missing due to children being absent, unwilling or unable to participate during one or more tasks (1.0%), as well as errors in task administration by the test assistants (2.3%). Descriptive statistics for both the oral and silent reading groups are presented in Table 1. Table 2 contains the correlations between the variables in both groups.

First, the word, sentence and text reading scores of the oral and silent reading groups were compared using t-tests (see Table 1). Silent reading fluency was higher than oral reading fluency for words and text. For sentence reading, the difference approached significance. The correlations between the three reading tasks were high (r = .70-.80) in both reading groups (see Table 2).

As predictors we tested nonverbal intelligence, verbal short-term memory, phonological awareness, rapid naming, and visual attention span. Two measures were used for each skill, except nonverbal intelligence. The scores of the oral and silent reading groups on the predictor skills did not differ significantly (see Table 1). This was expected as children were randomly assigned to the oral and silent reading groups.

MEASUREMENT INVARIANCE

Next, a multigroup structural equation model was fitted to the data to describe the relations among the variables in the two groups. Nonverbal intelligence did not correlate significantly with any of the oral or silent reading tasks (see Table 2) and was therefore not included in this model, nor in any of the following models. For the other measures a factor model was specified in which the three reading tasks loaded on one reading factor in both the oral and silent reading groups. Latent variables were also specified for verbal short-term memory, phonological awareness, rapid naming and visual attention span, with two indicators each.

Measurement invariance across groups was tested. Measurement invariance concerns equality of factor loadings, and also residual variances, factor variances, and factor intercorrelations. Factor covariances, however, are a function of both factor variances and factor intercorrelations (Marsh & Hocevar, 1985). To differentiate between possible group differences in factor variances and factor correlations, we used

Table 1
Descriptive Statistics for the Oral and Silent Reading Conditions

	Oral Reading (*N* = 132)			Silent Reading (*N* = 123)				
	N	*M(SD)*	Range	*N*	*M(SD)*	Range	*t*	*p*
Reading								
Word	131	47.24 (14.34)	21–83	123	55.15 (16.11)	11–95	4.139	.000
Sentence	132	28.55 (7.01)	16–46	123	30.29 (7.55)	10–49	1.917	.056
Text	131	28.47 (6.63)	14–48	123	31.14 (8.33)	9–55	2.838	.005
Intelligence								
Nonverbal IQ	130	20.52 (2.91)	12–26	123	20.48 (2.87)	12–27	0.098	.922
Short-term memory								
Letter span	131	10.41 (2.41)	6–17	122	10.48 (2.06)	7–17	0.223	.823
Digit span	120	8.45 (1.92)	5–14	113	8.69 (1.98)	5–14	0.940	.348
Phonological awareness								
One phoneme	119	14.74 (2.85)	5–18	121	15.21 (2.89)	5–18	1.262	.208
Two phonemes	118	5.21 (4.17)	0–15	110	6.28 (4.40)	0–15	1.884	.061
Rapid Naming								
Digits	132	2.19 (.42)	1.25–3.21	123	2.15 (.40)	1.35–3.36	0.768	.443
Letters	132	2.10 (.40)	1.07–3.17	122	2.10 (.35)	1.22–3.16	0.003	.997
Visual attention span								
Uneven items	119	37.45 (7.17)	17–50	114	38.76 (6.30)	20–50	1.487	.138
Even items	119	35.05 (6.91)	19–49	114	35.69 (6.62)	16–50	0.724	.470

Table 2

Correlations for the Oral and Silent Reading Groups

	1	2	3	4	5	6	7	8	9	10	11	12
1. Word reading	-	.71*	.73*	.06	.19*	.04	.23*	.33*	.25*	.38*	.41*	.44*
2. Sentence reading	.78*	-	.77*	-.01	.13	-.09	.17	.22*	.29*	.35*	.34*	.33*
3. Text reading	.70*	.70*	-	.14	.17	.01	.29*	.37*	.26*	.36*	.35*	.42*
4. Nonverbal intelligence	-.05	-.08	-.12	-	.13	.04	.30*	.26*	-.10	-.01	.14	.11
5. VSTM letter span	.39*	.36*	.36*	-.03	-	.61*	.26*	.20*	.05	.05	.28*	.27*
6. VSTM digit span	.20*	.28*	.31*	-.03	.57*	-	.16	.19	.03	.01	.23*	.22*
7. PA one phoneme	.34*	.28*	.36*	.05	.36*	.35*	-	.66*	.14	.15	.11	.12
8. PA two phonemes	.47*	.44*	.48*	.05	.46*	.30*	.64*	-	.24*	.22*	.34*	.37*
9. RAN digits	.62*	.51*	.43*	-.10	.35*	.21*	.26*	.36*	-	.71*	.26*	.33*
10. RAN letters	.58*	.46*	.39*	-.09	.26*	.19*	.31*	.38*	.76*	-	.27*	.33*
11. VAS uneven	.49*	.43*	.39*	.02	.36*	.19*	.45*	.49*	.42*	.39*	-	.82*
12. VAS even	.41*	.35*	.36*	.00	.29*	.14	.27*	.39*	.40*	.38*	.78*	-

Note. VSTM = verbal short-term memory, PA = phonological awareness, RAN = rapid naming, VAS = visual attention span. Silent reading group above diagonal, oral reading group below diagonal.

* $p < .05$.

phantom factors, or second order latent variables (see also de Jong, 1999; Macho & Ledermann, 2011). Because the parameters of these factors are completely constrained, including phantom factors does not affect model fit. The model is shown in Figure 1. In this model, second-order factors were specified for each construct, with the first-order factors as single indictors. The variances of these second-order factors were fixed to 1, and the residual variances of the first-order factors were fixed to 0. As a result, the factor loadings of the second-order factors represent the standard deviations of the first-order constructs. By constraining the second-order factor loadings to be equal across groups, equality of factor variances can be tested. Because the second-order factors all have equal variances (specified to be 1), factor covariances become factor correlations and the interrelations among the factors are no longer influenced by possible differences in factor variances. Accordingly, differences in factor correlations across groups could be tested reliably. The second-order multigroup model with one reading factor and four predictor factors in both the oral and silent reading group (see Figure 1) provided a good fit to the data , $\chi^2(68)$ = 74.732, p = .269, RMSEA = .028 [.000-.061], CFI = .995.

First, measurement invariance was tested for the predictors. Because children were randomly assigned to the oral and silent reading groups, no differences were expected in the factor structures and correlations of the predictors. Therefore, measurement invariance was tested by simultaneously constraining factor loadings, residual variances, factor variances, and factor correlations to be equal across groups. This model provided a good fit to the data, $\chi^2(90)$ = 105.780, p = .123, RMSEA = .037 [.000-.063], CFI = .988, that did not differ significantly from the fit of the previous model, $\Delta\chi^2(22)$ = 31.048, p = .095.

Second, measurement invariance was tested for the oral and silent reading factors by sequentially constraining factor loadings, residual variances, and factor variances to be equal across groups. A model with all factor loadings constrained to be equal across groups showed a significant deterioration in model fit, $\Delta\chi^2(2)$ = 7.201, p = .027. Modification indices showed the strongest non-invariance for the factor loadings of text reading. Therefore, a model was specified in which the factor loadings of word and sentence reading were equal across groups, but the factor loadings of text reading were not. This model provided a good fit to the data, $\chi^2(91)$ =

105.981, p = .135, RMSEA = .036 [.000-.062], CFI = .989, that did not differ significantly from the fit of the previous model, $\Delta\chi^2(1)$ = .201, p = .654. Next, invariance of residual variances was tested. A model with all residual variances constrained to be equal across groups showed a significant deterioration in model fit, $\Delta\chi^2(3)$ = 10.338, p = .016. Modification indices showed the strongest non-invariance for the residuals of word reading. Therefore, a model was specified in which the residuals of sentence and text reading were equal across groups, but the residuals of word reading were not. This model provided a good fit to the data, $\chi^2(93)$ = 106.715, p = .157, RMSEA = .034 [.000-.061], CFI = .990, that did not differ significantly from the fit of the previous model, $\Delta\chi^2(1)$ = .734, p = .392. Finally, equality of factor variances was tested. A model with the factor variances of oral and silent reading constrained to be equal provided a good fit to the data, $\chi^2(94)$ = 108.103, p = .152, RMSEA = .034 [.000-.061], CFI = .990, that did not differ significantly from the fit of the previous model, $\Delta\chi^2(1)$ = 1.388, p = .239.

RELATIONS OF ORAL AND SILENT READING WITH COGNITIVE SKILLS

The main research question was whether oral and silent reading show the same relations with underlying cognitive skills. First, we looked at the correlations of each of the predictor skills with oral and silent reading. We used the final measurement model and looked at the correlations between the latent variables (presented in Table 3). All correlations were significant (p-values < .01). The correlations of oral and silent reading with short-term memory ($\Delta\chi^2(1)$ = 1.347, p = .246), phonological awareness ($\Delta\chi^2(1)$ = .955, p = .328), and visual attention span ($\Delta\chi^2(1)$ = .037, p = .847) did not differ significantly. The correlations of oral and silent reading with rapid naming, however, were significantly different ($\Delta\chi^2(1)$ = 5.050, p = .025). Rapid naming correlated more strongly with oral than with silent reading.

Next, we examined the unique contributions of the skills in predicting oral and silent reading. We specified a regression model, with direct effects of all predictors on oral and silent reading. In this simultaneous regression model, the effect of each predictor reflects the unique contribution of that predictor, controlled for the other predictors in the model. To allow for such a model, however, minor model adaptations had to be made. The variances of oral and silent reading should not be fixed to 1, but need to be freely estimated. Therefore, the factor loadings of the first order reading factors on the second order factors were fixed. To allow for a reliable comparison of the effects on oral and silent reading, the factor loadings were fixed to their respective standard deviations. Accordingly, the residual variance of both oral and silent reading could be freely estimated, under the condition that the total variance in each reading factor equals 1. This model included one additional parameter (Model fit: $\chi^2(93) = 106.715$, $p = .157$, RMSEA = .034 [.000-.061], CFI = .990). The model and the standardized parameter estimates are shown in Figure 2. The second order structure was maintained, but left out of the picture. As a result of small differences in the variances of oral and silent reading, the standardized estimates of the factor loadings and residual variances of the reading variables differ slightly across groups.

Phonological awareness (.231, $p = .030$), and rapid naming (.478, $p < .001$) were significant unique predictors of oral reading. For silent reading, phonological awareness (.188, $p = .050$), rapid naming (.220, $p = .039$), and visual attention span (.366, $p = .001$) were significant predictors. Together, short-term memory, phonological awareness, rapid naming, and visual attention span explained 55% of the variance in oral reading, and 39% of the variance in silent reading.

Table 3
Correlations of Predictors with Oral and Silent Reading

	Oral reading	Silent reading
Verbal short-term memory	.373	.243
Phonological awareness	.526	.425
Rapid naming	.669	.453
Visual attention span	.524	.543

Note. All *p*-values < .01.

DISCUSSION

In the current study we examined similarities and differences between oral and silent reading fluency through the relations of both reading modes with cognitive skills that have been shown to be important in reading development. Reading was assessed at the word, sentence, and text level. As predictors we considered phonological awareness, rapid naming, and visual attention span.

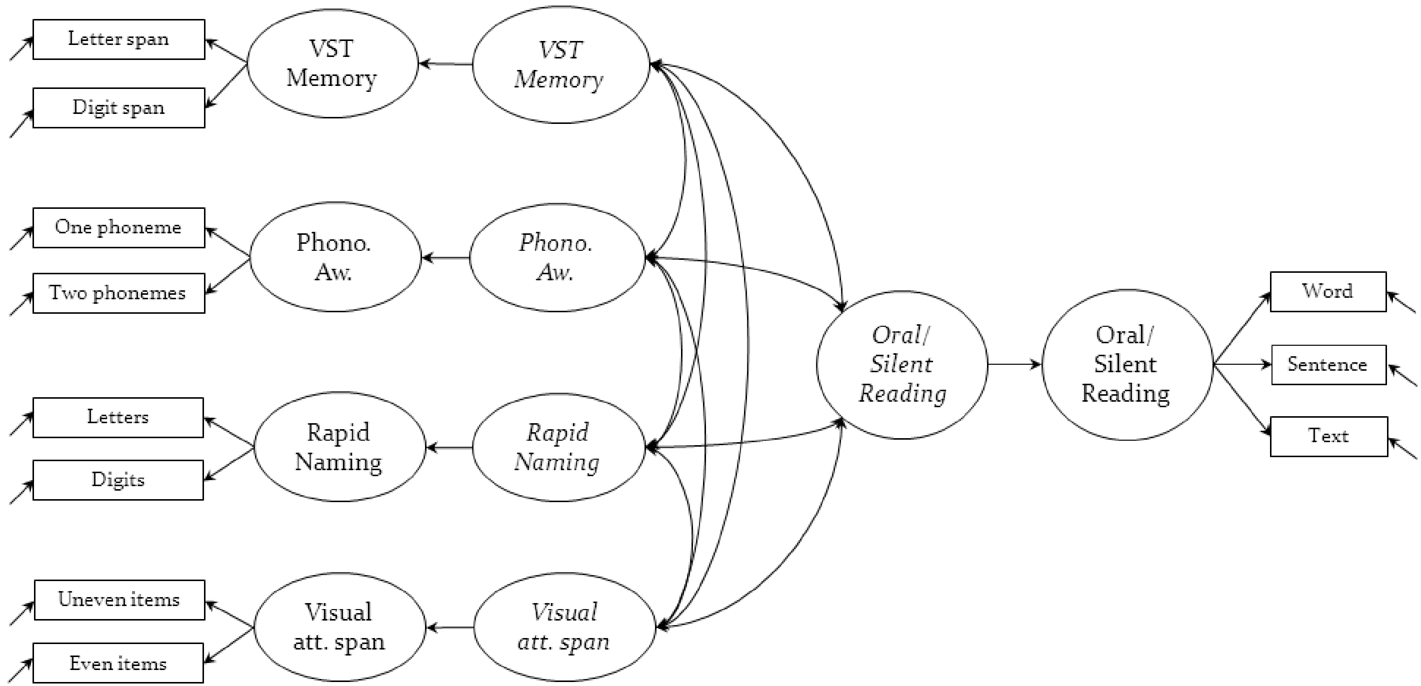

Figure 1. Multigroup second-order factor model used to test measurement invariance. VST Memory = Verbal short-term memory. Phono. Aw. = Phonological awareness. Visual att. span = Visual attention span.

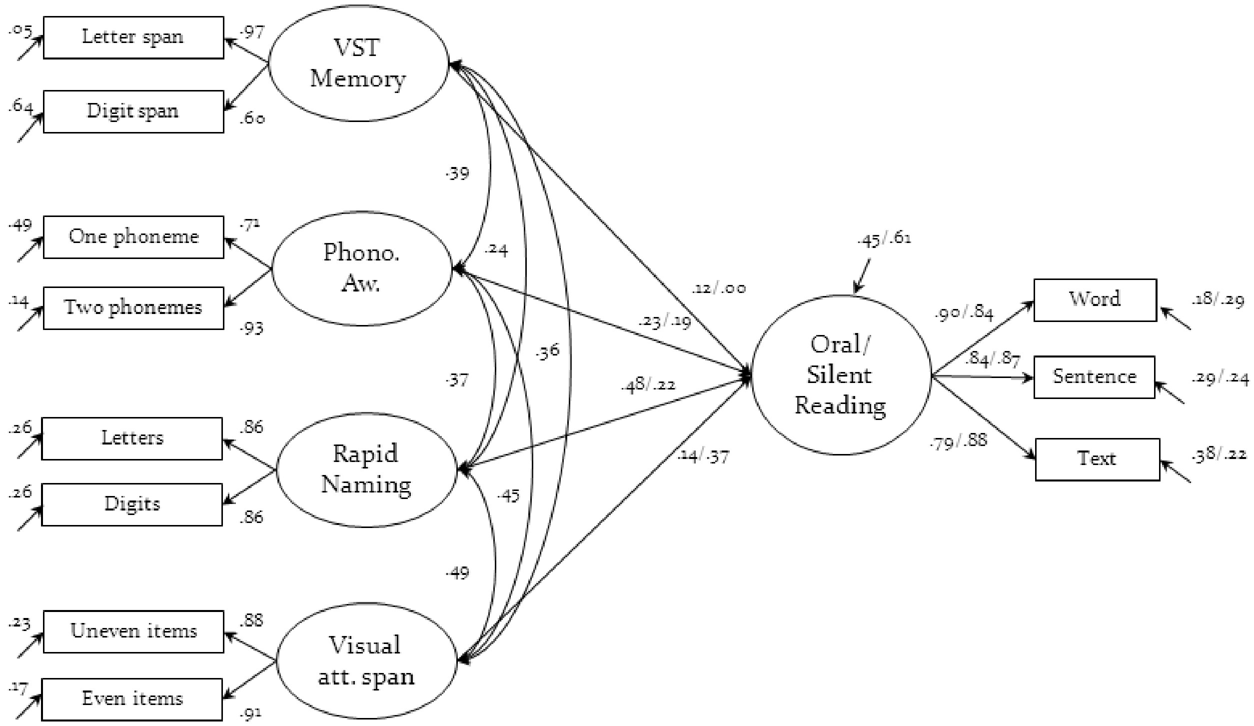

Figure 2. Multigroup regression model. Relations that were not (constrained to be) equal across groups are presented as oral/silent. VST Memory = Verbal short-term memory. Phono. Aw. = Phonological awareness. Visual att. span = Visual attention span.

In line with previous findings of studies focusing on reading comprehension (e.g., de Jong & Share, 2007; Juel & Holmes, 1981; McCallum et al., 2004), we found small but significant differences in reading speed. When the same materials were presented in both reading modes, reading speed was higher during silent than oral reading. The main question, however, was whether oral and silent reading depend on the same underlying skills. We found similarities as well as differences. Phonological awareness was a significant correlate of both oral and silent reading, even after controlling for rapid naming and visual attention span. Visual attention span correlated equally strongly with oral and silent reading, but showed a significant unique contribution only to silent reading. Rapid naming correlated with both oral and silent reading, also after controlling for phonological awareness and visual attention span, but its relation with oral reading was significantly stronger than with silent reading.

In general, these results are in line with the study of Bar-Kochva (2013), who showed that both phonological awareness and rapid naming were predictors of silent reading fluency. However, our results indicated that when oral and silent reading are directly compared, the relation of rapid naming with silent reading is not as strong as with oral reading. Also, unlike Bar-Kochva, who showed that visual processing skills did not relate to silent reading, we found a significant relation with visual attention span. Although more research is needed on this topic, one possibility is that the different findings should be ascribed to differences in task requirements. Possibly, the number of elements that can be processed at one glance, as measured in the visual attention span task, but not in the visual search tasks used by Bar-Kochva, is what is especially important for reading.

Our finding that phonological awareness was of equal importance to oral and silent reading, is in line with previous findings of activation of phonology during silent reading in children (Bowey & Muller, 2008; de Jong et al., 2009; Sprenger-Charolles et al., 1998). These findings can be explained within the context of strong phonological theories of reading (Frost, 1998; Perfetti & Hart, 2002). According to these theories, lexical representations of words include knowledge about phonology, orthography and meaning. More importantly, these types of knowledge are so well integrated, that upon encountering either a word's orthography or phonology, both other aspects are immediately and automatically activated. Our findings would indicate that word representations of these advanced, but young readers, are already integrated enough for phonology to be quickly activated upon encountering orthographic representations, even during silent reading, when the task does not demand it.

The most important difference between oral and silent reading was found in the relations with rapid naming. Rapid naming has been shown to relate to a range of reading tasks, but the nature of this relation is still not completely understood (see for a review Kirby, Georgiou, Martinussen, & Parrila, 2010). The current study adds to this ongoing debate that rapid naming taps an aspect of reading that is more important in oral than in silent reading. This aspect is most likely not related to phonological knowledge, since phonological awareness related equally strongly to both reading modes. However, our measure of phonological awareness is a measure of accuracy, whereas rapid naming reflects speed. Therefore, it could be that rapid naming relates specifically to the speed of retrieving orthographic and phonological codes during reading.

A more apparent explanation could be that both rapid naming and oral reading require articulation, or production of verbal output. It has been shown previously that rapid naming related more strongly to oral word and nonword reading than to a silent wordchains task (Georgiou, Parrila, Cui, & Papadopoulos, 2013). The authors interpreted this difference as evidence for the importance of oral production in the relation of rapid naming with reading. In the current study we found support for this interpretation, while presenting the same reading materials in both reading modes. Also in models of speech production (e.g., Levelt, 1992), a distinction is made between a stage of lexical selection or lexical access, and a second stage of phonological encoding, or the creation of an executable phonetic code. Whereas phonological representations might be activated in both silent and oral reading, computation of a phonetic code is specific to oral reading.

More recently, visual attention span has been shown to be an additional independent predictor of reading. Previous studies have shown that visual attention span relates to oral reading speed of words (Bosse & Valdois, 2009; van den Boer et al., 2013), and text (Lobier, Dubois, & Valdois, 2013). The current study extends these findings by showing that visual attention span relates to a broader construct of reading, including reading of words, sentences, and text. In addition, we showed that visual attention span also correlated strongly with silent reading. Surprisingly, the unique contribution of visual attention span, after controlling for phonological awareness and rapid naming, was significant for silent, but not oral reading.

These findings could indicate that visual attention span taps various aspects that are important in reading. On the one hand, it reflects skills that are important in oral reading. These aspects are, however, to a large extent shared with rapid naming, and could include access to phonological codes and generation of verbal output. On the other hand, visual attention span is an important independent predictor of silent reading, indicating that parallel processing of multiple orthographic units might be more important in silent reading, when reading speed is higher as compared to oral reading.

Nevertheless, a unique contribution of visual attention span to oral reading has been reported previously (Bosse & Valdois, 2009; Valdois et al., 2003; Valdois et al., 2004; van den Boer et al., 2013). Our divergent results could be due to the strong relation of rapid naming with oral reading. Visual attention span correlated significantly with rapid naming, indicating that the variables share a certain amount of explained variance in reading. Rapid naming, however, was the dominant predictor for oral reading, whereas visual attention span was the stronger correlate of silent reading. In addition, the results might be due to differences in the reading tasks administered. Whereas previous studies mainly included word lists, the reading tasks in the current study, in addition to reflecting reading speed, also included decision components. Further research is needed to address these issues.

The current findings indicate that visual attention span could be an interesting variable in diagnosing reading problems. It is common practice to assess mainly oral reading, phonological awareness and rapid naming when diagnosing reading difficulties. However, silent rather than oral reading is the primary reading mode. As long as it is unclear to what extent oral and silent reading are the same or different, a safe choice would be to assess skills that relate equally strongly to both reading modes, such as phonological awareness and visual attention span, rather than rapid naming, which relates more strongly to oral reading, than to the more prominent silent reading mode.

A few comments should be made about our materials. First, three reading tasks were presented in both the oral and silent reading conditions. Correlations between the word, sentence, and text reading tasks were around .70, and the three tasks loaded on one reading factor in both conditions. Although reliability estimates of the reading tasks were not available, these findings indicate that the tasks are reliable estimates of reading performance. Second, presenting the same tasks in both oral and silent reading conditions was important to allow for a direct comparison of the reading modes. Differences cannot be ascribed to task specific requirements, as could be the case when different tasks were used to measure oral and silent reading. However, presenting the exact same tasks prevented us from using a within-subjects design, and therefore from investigating the relations between oral and silent reading within individuals.

There is a general tendency to generalize research findings across reading modes, especially from oral to silent reading. In the current study we have shown that oral and silent reading indeed are fairly similar reading modes, that to a large extent draw on the same underlying processes. However, we also found differences, most importantly in the relation with rapid naming, that warrant caution in generalizing findings across reading modes. This study highlights the importance of including both reading modes in the same study to directly test similarities and differences. It is an important first attempt at understanding oral and silent reading. However, our findings in a relatively shallow orthography call for replication in deep orthographies. Previous studies have hinted at less extensive phonological processing in silent as compared to oral reading in English (Juel & Holmes, 1981; Schumm & Baldwin, 1989; Share, 2008). Findings on the role of phonology in silent reading could be different in less transparent languages, with more complex phonological patterns than in the more transparent Dutch language. Also, the current study included young, advanced readers. Similar studies with both younger and older readers could help gain insight into possible developmental changes in oral and silent reading per se, but also in the relations of both reading modes with underlying cognitive skills.