

RESEARCH ARTICLE

WILEY

How phonological awareness mediates the relation between working memory and word reading efficiency in children with dyslexia

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This study examined the relation between working memory, phonological awareness, and word reading efficiency in fourth-grade children with dyslexia. To test whether the relation between phonological awareness and word reading efficiency differed for children with dyslexia versus typically developing children, we assessed phonological awareness and word reading efficiency in 50 children with dyslexia (aged 9;10, 35 boys) and 613 typically developing children (aged 9;5, 279 boys). Phonological awareness was found to be associated with word reading efficiency, similar for children with dyslexia and typically developing children. To find out whether the relation between working memory and word reading efficiency in the group with dyslexia could be explained by phonological awareness, the children with dyslexia were also tested on working memory. Results of a mediation analysis showed a significant indirect effect of working memory on word reading efficiency via phonological awareness. Working memory predicted reading efficiency, via its relation with phonological awareness in children with dyslexia. This indicates that working memory is necessary for word reading efficiency via its impact on phonological awareness and that phonological awareness continues to be important for word reading efficiency in older children with dyslexia.

KEYWORDS

dyslexia, phonological awareness, reading, working memory

1 | INTRODUCTION

Phonological awareness is crucial in learning to read (Anthony & Francis, 2005; Melby-Lervag, Lyster, & Hulme, 2012). Children with dyslexia often have poor phonological awareness, which is seen as an important predictor of their poor

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Practitioner points

- Phonological awareness remains a good predictor for reading efficiency in older children with dyslexia
- Two complementary phonological tests suitable for a paper and pencil group assessment were developed.

reading abilities (Boets et al., 2010). Interestingly, the phonological awareness impairments of children with dyslexia seen at the start of formal education are often not found anymore at the end of primary school, except when task demands increase (de Jong & van der Leij, 2003). This apparent difference in phonological awareness impairments may partly be due to the increased demand on working memory in more complex phonological awareness tasks (Berninger, 2008). Children with dyslexia show deficits in their working memory, phonological awareness, and word reading efficiency (Berninger, Raskind, Richards, Abbott, & Stock, 2008; Brosnan et al., 2002; Swanson, Zheng, & Jerman, 2009). Working memory predicts both phonological awareness and word reading efficiency (de Abreu, Gathercole, & Martin, 2011; Berninger, Abbott, Vermeulen, & Fulton, 2006; Christopher et al., 2012; Locascio, Mahone, Eason, & Cutting, 2010; Ramscar & Gitcho, 2007). Because phonological awareness predicts word reading efficiency (Anthony & Francis, 2005; Melby-Lervag et al., 2012), and phonological working memory is associated to word reading (Gathercole & Baddeley, 2014), working memory may be important to word reading efficiency via its impact on phonological awareness in children with dyslexia; a mediation model can be expected but has not yet been tested. Therefore, in the present study, we examined (a) whether the relation between phonological awareness and word reading efficiency differed for children with dyslexia and typically developing children and (b) to what extent working memory impacts word reading efficiency in the group of children with dyslexia via its effect on phonological awareness.

1.1 | Phonological awareness and word reading efficiency

Phonological awareness, defined as the ability to reflect upon and manipulate the sound structure of spoken words, plays a very important role in reading development in the lower grades of primary education (Anthony & Francis, 2005). In several longitudinal studies, phonological awareness was found to be a powerful predictor of success in learning to read (Bowey, 2005; Ehri et al., 2001; Hulme, Bowyer-Crane, Carroll, Duff, & Snowling, 2012). During the primary grades, the relation between phonological awareness and word reading efficiency in typically developing children appears stable and strong over time (e.g., Blachman, 2000; Hogan, Catts, & Little, 2005; Roman, Kirby, Parrila, Wade-Woolley, & Deacon, 2009). Although phonological awareness has been shown to be predictive for reading abilities, the reverse has also been evidenced (Hogan et al., 2005); the relationship between the two can be interpreted as reciprocal causality. In addition, linguistic differences may play a role in the relation between phonological awareness and word reading. This relation is stronger in opaque languages such as English than in more transparent orthographies (Georgiou, Parrila, & Papadopoulos, 2008; Landerl & Wimmer, 2000). Deficits in phonological awareness are often found in children with dyslexia (Blomert, 2006). Consequently, children with lower phonological skills are more likely to be diagnosed with dyslexia (Boets et al., 2010). Phonological awareness deficits in children with dyslexia have been shown to last into late adolescence (Bekebrede, van der Leij, Plakas, Share, & Morfidi, 2010; Melby-Lervag et al., 2012; Moura, Moreno, Pereira, & Simões, 2015). However, it has also been found that such deficits in phonological awareness in children with dyslexia may change over time. In a longitudinal study, de Jong and van der Leij (2003) demonstrated that children with dyslexia showed phonological awareness deficits in kindergarten and in the first grades of primary school but less so at the end of primary school unless more difficult tasks were administered. These more difficult tasks include, for example, phoneme deletion and spoonerism. These aspects tap onto the phonological complexity of the stimuli, which can according to Cunningham, Witton, Talcott, Burgess, and Shapiro (2015) be considered one of the key components to drive the relationship between phonological tasks and reading. In a similar vein as de Jong and van der Leij (2003), Dandache, Wouters, and Ghesquière (2014)

examined the growth of phonological awareness in typically developing children and children with dyslexia across the primary grades. They found children with dyslexia to be impaired on phonological awareness across grade levels. Interestingly, they also found that children with dyslexia still showed growth on the more difficult phonological awareness tasks whereas the typically developing children were already at ceiling level in Grade 3.

1.2 | Role of working memory in reading efficiency

The fact that children with dyslexia in the upper grades show problems on the more difficult phonological tasks could be caused by the higher demand these tasks put on working memory. In contrast to short-term memory, which is the ability to keep a small amount of information in mind for a short period of time, working memory requires monitoring and coding of incoming information and updating the information held in the working memory (Miyake et al., 2000). A commonly used measure of working memory is the digit span backwards (Lezak, 2004). Working memory underlies both phonological awareness and word reading efficiency, and as such, one could expect that working memory impacts reading via its effect on phonological awareness. In typically developing children, working memory has indeed been found to predict phonological awareness (de Abreu et al., 2011; Oakhill & Kyle, 2000) and word reading efficiency (Berninger, Abbott, Vermeulen, et al., 2006; Christopher et al., 2012; Locascio et al., 2010). Children with dyslexia generally show deficits in working memory and having phonological awareness and word reading efficiency problems (Berninger, Raskind, et al., 2008; Brosnan et al., 2002; Swanson et al., 2009).

The studies described above point in the direction of a mediation model: Poor working memory may cause poor performance on more difficult phonological awareness tasks which in turn leads to lower reading efficiency (see de Jong & van der Leij, 2003). Indeed, the more difficult phonological awareness tasks also appeal to children's working memory by demanding more updating capacities. This is in line with the suggestion by Ramus and Szenkovits (2008) who argued that the phonological representations of people with dyslexia may be intact, but not their access to these representations. They thus suggest that the phonological deficit can be seen as a function of task requirements. Ramus and Szenkovits, however, focused on adults with dyslexia and "cannot rule out the possibility that people with dyslexia may have deficient phonological representations as children, but these representations have recovered when we test them in adulthood" (p. 137). It is thus unclear to what extent the phonological deficit indeed can be seen as a function of task requirements in children with dyslexia. Also Berninger, Abbott, Thomson, et al. (2006), also in Berninger, 2008) showed that working memory is an important factor in reading in dyslexia. They found that phonological awareness and working memory were highly correlated in adults with dyslexia and suggested that at least part of the phonological awareness deficits in dyslexia could be attributed to deficits in working memory. However, they did not examine the effect of working memory on phonological awareness in their study, because they included tasks that combined working memory and phonological awareness requiring temporary storage of written or spoken words or multimodal coding (e.g., elision, non-word repetition, receptive coding, and morphological decomposition). A unique phonological word factor was not used. In research on numerical cognition, a comparable mediation model of phonological awareness on working memory has already been proposed by Lopes-Silva, Moura, Júlio-Costa, Geraldi Haase, and Wood (2014) stating that phonemic awareness mediated the influence of verbal working memory on number transcoding.

To follow-up on the suggestions of Berninger and colleagues, it is important that the influence of phonological awareness is disentangled from working memory. It should be noticed that cognitive profiles of people with dyslexia differ from typical developing peers in general on reading, writing, and phonological processing (see meta-analysis of Swanson & Hsieh, 2009; Callens, Tops, & Brysbaert, 2012). A recent meta-analysis of Kudo, Lussier, and Swanson (2015) also states that cognitive deficits in children with reading disabilities are persistent. Regarding general intelligence, there appear to be no cognitive differences between the two groups (Swanson & Hsieh, 2009), as the diagnosis of dyslexia hinges upon normal intelligence. The DSM-V states that the learning difficulties in children with dyslexia are not better accounted for by intellectual disabilities (APA, 2013). Their phonological deficits are thus not the result of a lower intelligence but may be due to lower working memory.

1.3 | The present study

From the above overview of the literature, two issues remain. First, children with dyslexia show both phonological awareness and word reading efficacy deficits (e.g., Moura et al., 2015). They still improve in phonological awareness when they grow older, whereas typically developing children are already at ceiling level in the lower grades of primary school (de Jong & van der Leij, 2003; Dandache et al., 2014). The relation between phonological awareness and word reading efficacy in children with dyslexia at the end of primary school may thus be different than the relation in typical developing children.

Second, although a mediation model for phonological awareness on the relation between working memory and word reading efficiency in children with dyslexia has often been suggested, it has not yet been examined (Berninger, 2008; Berninger, Abbott, Thomson, et al., 2006; Berninger, Abbott, Vermeulen, et al., 2006). This could be due to the fact that phonological awareness tasks for older children by definition have a higher working memory component. If the working memory component were lower, the tasks would be too easy and would not show possible phonological awareness deficits (see de Jong & van der Leij, 2003). This makes it more difficult to disentangle both influences on word reading efficacy. In the present study, we thus had two research questions:

1. Is the relation between phonological awareness and word reading efficiency different between children with and without dyslexia in the upper grades of primary school?
2. To what extent can the relation between working memory and word reading efficiency be explained by phonological awareness in children with dyslexia in upper grades of primary school?

Regarding the first question, 663 children (5th year), including children with dyslexia, were classroom-tested on phonological awareness and word reading efficiency. It was expected that the relation between phonological awareness and word reading efficiency would be weaker in children with dyslexia compared with typical developing children. The relation between phonological awareness and word reading ability is strong in typically developing children (e.g., Hulme et al., 2012). Although these children are already at ceiling level half way primary school, children with dyslexia are still improving their phonological awareness (de Jong & van der Leij, 2003; Dandache et al., 2014). At the end of primary school, the reading efficiency of children with dyslexia remains low, but the level of phonological awareness has become higher (de Jong & van der Leij, 2003). Due to restriction of range, we expected the relation between phonological awareness and reading in this group to be weaker than in typical developing children.

With respect to the second question, a subsample of 50 children with dyslexia were, in addition to phonological awareness and word reading efficiency, also tested on working memory. We expected that children with dyslexia would show phonological deficits because of the task load of more difficult phonological tasks (de Jong & van der Leij, 2003). More complex tasks demand a higher working memory load. As such, it was expected that the relation between working memory and word reading efficiency would be mediated via phonological awareness in children with dyslexia.

2 | METHOD

2.1 | Participants

In the central region of the Netherlands, 450 regular primary schools were approached via a letter. After this open invitation, 52 classes from 39 schools signed up to participate. In total, 1,041 children (506 boys) from Grade 5 took part in the study. The parents of the children were informed via a letter and could indicate if they did not want their child to participate. None did. We used reading efficiency measures from the national standardized technical reading assessment (Verhoeven, 1995). Not all the schools had administered these tests, and could thus not provide word reading scores, and were thus excluded from analysis. Children were included in the analyses when they were monolingual and when word reading efficiency scores were available. In total, 613 typically developing children (279 boys) aged 9;6 years ($SD = 7.68$ months) and 50 children with dyslexia (35 boys) aged 9;10 years

($SD = 7.41$ months) participated in this research (663 in total). Children with dyslexia were on average 5 months older than typical developing children, $t(661) = 3.93, p < .001, d = .59$.

All children with dyslexia in this research had a clinical diagnosis of dyslexia. When Dutch children in primary school continuously score very low on reading and/or spelling (test scores lowest 10% on reading, or test scores lowest 16% on reading and lowest 10% of spelling), the child normally will be recommended for clinical assessment according to the Protocol Dyslexia Diagnosis and Treatment (Blomert, 2006). The Protocol Dyslexia Diagnosis and Treatment is a guide to the diagnosing, indicating, and treating clients with dyslexia with the aim of describing optimal care for clients with dyslexia based on current scientific, professional, and social insights. During the clinical assessment, the child is tested on dyslexia by a certified child psychologist. Several dyslexia-typical cognitive indicators are investigated: phonological processing (accuracy and speed), grapheme-phoneme association (accuracy and speed), and rapid naming speed (numbers and letters). A child is diagnosed with dyslexia when the child scores in the lowest 10% in at least two of these six indicators. All children with dyslexia in this research had a clinical diagnosis of dyslexia and were in possession of an official dyslexia statement provided by a certified child psychologist. As an extra check, we compared children with and without dyslexia on general non-verbal intelligence, word reading efficiency, and phonological awareness (phoneme deletion and spoonerism, see Section 2.2). Paired-samples t tests were conducted to compare the children with and without dyslexia. As expected, children with dyslexia scored in the normal range on general non-verbal intelligence, although the children with dyslexia scored slightly lower compared with the typically developing children, $t(661) = 2.51, p = .012, d = .37$. In line with their diagnosis, the children with dyslexia scored significantly lower on word reading efficiency, $t(661) = 11.37, p < .001, d = 1.59$, phoneme deletion, $t(661) = 5.37, p < .001, d = .79$, and spoonerism, $t(661) = 5.08, p < .001, d = .95$ (see Table 1).

2.2 | Measures

2.2.1 | General non-verbal intelligence

The Raven's Progressive Matrices General was used to measure non-verbal intelligence (Raven, 2006) and administered according to its group assessment instructions. Forty-eight visual patterns of increasing difficulty were presented (B–E). In each pattern, children had to choose the missing piece of information from six or eight alternatives. Percentile scores (number of correct answers controlled for age) were used for the analysis. In the present study, Cronbach's α was .88, indicating a good reliability.

2.2.2 | Working memory

The subtest Digits-backwards of the WISC-III-NL (Wechsler, 2005) was used to measure working memory. Children had to recall a sequence of spoken digits (between two and nine). Children were asked to recall the sequence backwards, for example, when the sequence 5-4-7 was provided, children had to recall 7-4-5. The number of digits in a list increased by one, until two sequences of the same length were incorrectly recalled. There were no time limits. The score given was the number of correct recalled lists. These sum scores were used in the analysis. Higher scores reflected better performance.

TABLE 1 Children's general non-verbal intelligence (NVIQ), word reading efficiency, phoneme deletion, and spoonerism per group

	Dyslexia				Control				Cohen's d
	N	M (SD)	Min.	Max.	N	M (SD)	Min.	Max.	
NVIQ percentile	50	59.90 (25.41)	5	100	613	69.09 (24.85)	5	100	.37*
Word reading efficiency	50	52.66 (17.30)	5	97	613	78.69 (15.43)	30	182	1.59*
Phoneme deletion	50	12.36 (2.97)	4	18	613	14.69 (2.95)	0	18	.79*
Spoonerism	50	9.58 (4.08)	0	20	613	12.39 (3.73)	0	22	.95*
Working memory	50	4.04 (1.26)	2	7					

* $p < .05$. Although we used factor scores for the analyses for phonological awareness, we report the sum scores here because the factor scores by default have $M = 0$ and $SD = 1$.

2.2.3 | Phonological awareness

Two complementary phonological tests that could be conducted in a classroom setting (multiple children at the same time) were developed for the present study: Phoneme Deletion and Spoonerism. These newly developed phonological awareness tasks are intended for testing in classrooms, as well as to test phonological awareness in older primary school children without showing ceiling effects.

Phoneme Deletion was assessed with a task based on the digital subtest *Foneemdeletie* (Phoneme deletion) of the *Dutch Screeningsinstrument Beginnende Geletterdheid* (Screening Instrument for Emerging Literacy; Vloedgraven, Keuning, & Verhoeven, 2009). During the task, children saw three pictures (e.g., “ball,” “mall,” and “wall”), heard a word (“small”), heard the character they had to delete from the word (“s”), and had to cross the new word (“mall”). Children only heard the words once. Before testing, two example items were provided. During the test, children had 4 s per item to cross the correct answer. They were instructed to skip an item if they did not know the answer. The test contained 18 items. The score was determined by the number of correct answers (one point per correct answer, with a maximum of 18 points). The internal consistency of the test was sufficient ($\alpha = .75$). See Appendix A for test items.

Spoonerism

This spoonerism task used partly the same pictures as in the test Phoneme Deletion, including new pictures to complete 12 items with five pictures each. During the test, children heard two words, had to switch the first characters, and had to tick the corresponding pictures of the two new words out of five possible options (one point each, with a maximum of 24 points in total). For example, the words “mouse” and “heat” became the words “house” and “meat.” The remaining three pictures (distracters) were chosen in such a way that two distracters were rhymes of the new words (“louse,” “seat”) whereas the third distracter had a vowel change in the middle of one of the two new words (“moat”). Before testing, two example items were provided. During the test, children had 5 s to finish an item, after which, a new pair of words was offered. Children were instructed to skip an item if they did not know the answer. The score was determined by the number of correct answers. The internal consistency of the test was sufficient ($\alpha = .70$). See Appendix B for test items.

Phonological awareness analysis

A principal component analysis with no rotation was performed for phonological awareness. One component was found to be above Eigenvalue 1 (Eigenvalue = 1.39). Phoneme Deletion and Spoonerism both highly loaded on this component (both .83). The regression weights of this component were saved as a measure of phonological awareness. This factor score was used for further analyses.

2.2.4 | Word reading efficiency

The national standardized technical reading assessment, CITO the Drie-Minuten-Test (Three-Minute-Test), was used to measure children's word reading efficiency (Verhoeven, 1995). The Drie-Minuten-Test consists of three reading cards with different words in increasing difficulty level. Children had to read out loud as many words correct in 1 min per card as possible. Although the Three-Minute-Test is not mandatory for Dutch primary schools, it is used by 85% (over 5,500 schools) of the Dutch primary schools (Inspectorate of Education, 2010) to track children's technical reading ability. Because many schools use these tests, norms are set accordingly (Inspectorate of Education, 2010). The raw scores of the word reading task were converted into scale scores based on these national standardized normed ability score. It thus provides a reference to the ability level of the children in relation to his/her peer group. Scale scores were used for analysis.

2.3 | Procedure

Word reading efficiency scores were provided by the schools. Typically developing children and children with dyslexia were all classroom-tested (1 hr) with the two phonological awareness tests and the general non-verbal intelligence

test. Next, children with dyslexia were tested individually on working memory in a quiet room inside the school by the first author, who is a certified child psychologist.

2.4 | Data-analyses

A moderation analysis was performed to examine whether the influence of phonological awareness on word reading efficiency was moderated by group (dyslexia and control) using the bootstrapping PROCESS procedure (Preacher & Hayes, 2004). Second, a mediation analysis was performed to examine whether phonological awareness mediated the relation of working memory and word reading efficiency in children with dyslexia, also using PROCESS and bootstrapping. In this analysis, word reading efficiency was included in the model as dependent variable, working memory as independent variable, and phonological as mediator (Model 4; Hayes, 2013). In the analysis, a resampling strategy of 5,000 bootstraps, as advised by Preacher and Hayes (2008, p. 889) was used. Statistical significance ($p = .05$) is indicated if the range from the upper to lower bounds of the bias-corrected 95% confidence intervals does not cross zero. Also with a marginal or even a nonsignificant relation between working memory and phonological awareness (Path A) or between phonological awareness and word reading efficiency (Path B), a significant indirect effect from working memory via phonological awareness to word reading efficiency (Path AB) can be found (see Hayes, 2013).

3 | RESULTS

3.1 | Moderation effect on phonological awareness and word reading efficiency

Overall, phonological awareness and word reading efficiency were significantly correlated, $r(663) = .42, p < .001$; dyslexia: $r(50) = .365, p < .005$, typically developing: $r(613) = .366, p < .001$. A moderation analysis was performed to examine whether the influence of phonological awareness on word reading efficiency was moderated by group (dyslexia and control) using the bootstrapping process procedure (Preacher & Hayes, 2004). This model explained 28% of the variance in word reading efficiency ($R^2 = .28, p < .001$). Phonological awareness significantly predicted word reading efficiency, $\beta = 5.80, SE(\beta) = .60, p < .001$; children with good phonological awareness scored better on word reading efficiency. No moderation effect of group was found, $\beta = .83, SE(\beta) = 2.26, p = .714$. The relation between phonological awareness and word reading efficiency was the same for children with and without dyslexia.

3.2 | Mediation effect of phonological awareness on working memory and word reading efficiency

We next examined to what extent the relation between working memory and word reading efficiency can be explained by phonological awareness in children with dyslexia in upper grades of primary school, a mediation analysis was performed also using the bootstrapping process procedure (Preacher & Hayes, 2004). Following our second research question, this mediation model was run only for the students with dyslexia.

Table 1 shows test scores of children with dyslexia on word reading efficiency, phonological awareness, and working memory. In children with dyslexia, word reading efficiency was significantly correlated with working memory, $r(50) = .30, p < .001$, and the correlation between phonological awareness and working memory was not significant, $r(50) = .26, p = .064$. The results of the mediation analysis are presented in Figure 1. As shown in this figure, the total effect of working memory on word reading efficiency was significant but became nonsignificant after the mediator, phonological awareness, was added to the model. There was a significant indirect effect of working memory on word reading efficiency via phonological awareness, $\beta = 1.12$, confidence interval = [.058–3.52]. This model explained 18% of the variance in word reading efficiency, $R^2 = .18, F(2, 47) = 5.04, p = .010$.

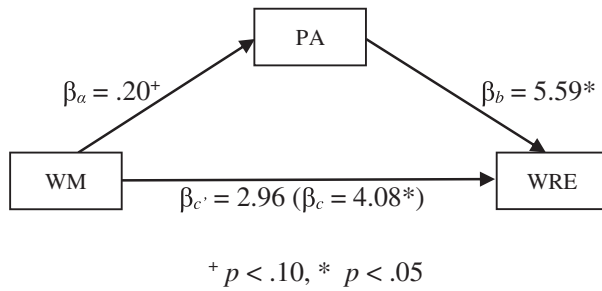


FIGURE 1 Mediation effect of phonological awareness (PA) on the relation between working memory (WM) and word reading efficiency (WRE)

4 | DISCUSSION

In this study, the relation between phonological awareness and word reading efficiency in older children with dyslexia and their typical developing peers was examined. In addition, in children with dyslexia, phonological awareness and working memory were examined as predictors of word reading efficacy, to find out whether phonological awareness remains a predictor for reading in the upper grades of primary school, even after controlling for working memory. In line with the clinical population, a larger percentage of children with dyslexia in this study were boys (Rutter et al., 2004). The relation between phonological awareness and word reading efficiency was found to be similar for children with dyslexia and typically developing children. Further, in children with dyslexia, phonological awareness mediated the relation between working memory and word reading efficiency: Working memory affected word reading efficiency through phonological awareness.

Contrary to our first hypothesis, phonological awareness was similarly associated with word reading efficiency in both children with and without dyslexia. In a previous study, Wilson and Lesaux (2001) showed that adolescents with dyslexia can attain age-appropriate performances on reading measures, while still showing phonological awareness deficits. This would imply a lower correlation between phonological awareness and reading in this group. However, participants in their study were well-performing university students, who could be defined as a special group, high-functioning students with dyslexia, who read more than average and have thus more reading experience. Primary school children form a much more heterogeneous group than university students; the range of student's abilities in Wilson and Lesaux (2001) is thus more narrow than in the children in our study. Also, their reading development is still in a state of flux. In studies that did focus on primary school children, ceiling effects of phonological awareness in typically developing children (Dandache et al., 2014) or children with dyslexia (de Jong & van der Leij, 2003) were found, whereas children with dyslexia were outperformed on reading measures. In the present study, we used newly developed phonological awareness tasks, which were more difficult because there was a time constraint, and it were multiple-choice tasks with distractors. However, it may also be the case that the task included relatively complex phonological stimuli according to the criteria given by Cunningham et al. (2015), because the distractors were chosen in such a way that they resembled the correct item, only by one phonological difference (e.g., by one vowel). Indeed, we did not find ceiling effects, neither in the control group nor in the group with dyslexia. This offered more opportunity to specifically examine the relation between phonological awareness and word reading efficiency. Our results are in line with de Jong and van der Leij (2003): When phonological awareness tasks are more demanding, significant differences in task performances between children with dyslexia and typical developing children can still be observed and can be interpreted as phonological awareness deficits in children with dyslexia. In addition, we showed that the strong relation between phonological awareness—measured with age appropriated tasks—and word reading efficiency remains not only in typically developing children but also in children with dyslexia. As in young children (Dufva, Niemi, & Voeten, 2001), also in older children, phonological awareness is a strong predictor of reading. Cunningham et al. (2015) showed two core components in phonological tasks that predict word reading: the linguistic

nature of a stimulus and the phonological complexity. In addition, they found a third component: the production of a verbal response. These three components were found to be important factors in the relation between phonological awareness and word reading efficiency. In the present research, we focused on the phonological complexity of the words, by using phonologically difficult distractors, while keeping the other two components constant. Our results support Cunningham et al.'s (2015) argumentation for phonological complex stimuli predicting reading and add that this can be extended to older children at the end of primary school.

In line with the second hypothesis, working memory was an important factor for reading of children with dyslexia, and it affected word reading efficiency through phonological awareness. De Jong and van der Leij (2003) suggested that measuring phonological awareness deficits in older children with dyslexia is difficult, unless one increases the task load and thus the working memory component of the phonological task. In the present study, we did use a more difficult task and confirmed the importance of working memory in the word reading process of children with dyslexia. By adding working memory to our model, we were able to control for the working memory component in the phonological awareness task. Our results provided evidence for the argumentation of Berninger et al. (2008) that the level of word reading efficiency in children with dyslexia is associated with both phonological awareness problems and working memory. The variation in working memory thus accounts for part of the relation between phonological awareness and word reading efficiency. The self-teaching hypothesis theory (Share, 1999) proposes that phonological awareness is essential for word reading efficiency. Children with dyslexia do not read as fluently as typically developing children do, because they often experience difficulties reading via the grapho-phonological route (Castles & Coltheart, 1993). Instead of retrieving the phonological representation of the appropriate word from the mental lexicon, advanced readers with dyslexia tend to continue decoding words via sublexical units. This may explain why working memory influences phonological awareness and in turn, reading in children with dyslexia: Children who read by decoding must keep single letters (or small parts of words) in mind while reading and must update this information with every new piece of information they decode. Phonological awareness alone is not sufficient when children have difficulties updating the current read words with the newly decoded material. Both working memory and phonological awareness thus continues to be important factors in word reading efficiency in older children with dyslexia.

A limitation of the present study is that working memory was not assessed in typically developing children. Even though the relation between phonological awareness and word reading efficiency was found to be the same in children with and without dyslexia, it would have been interesting to compare whether the influence of working memory in the reading process would be different or the same in typically developing children. This is a suggestion for future research. We only included children with dyslexia (also given time constraints) and started from a specific hypothesis for the group of children with dyslexia. Based on our theoretic framework on children with dyslexia, we expected the mediation model specifically in children with dyslexia because previous research showed that in typical developing children, working memory and phonological awareness was not strongly associated (Oakhill & Kyle, 2000; Snowling, Hulme, Smith, & Thomas, 1994). A second limitation is that, although we included the two-core elements phoneme deletion and spoonerism to represent phonological awareness, we only had one measure of verbal working memory. In future research, visual working memory may also be included, because it links to different elements in the reading process than verbal working memory (van den Boer, van Bergen, & de Jong, 2015). Measuring different aspects of working memory will help to understand which aspect of working memory is restricted to phonological awareness and word reading efficiency.

For future research, it is important to notice that the current study was performed in Dutch, a relatively transparent orthography. For example, Landerl, Wimmer, and Frith (1997) showed large differences between English, a more opaque orthography, and German, a similar transparent orthography as Dutch, in both children with and without dyslexia on phonological awareness. In such transparent orthographies, phonological awareness has less influence on word reading, but more on orthographic spelling (Wimmer, Mayringer, & Landerl, 2000). In English, it can thus be expected that the influence of phonological awareness on reading ability is stronger than in a transparent orthography like Dutch (e.g., Furnes & Samuelsson, 2010; Hogan et al., 2005; Share, 2008). Therefore, in an opaque

orthography, working memory may have a more direct effect on word reading efficiency. Given the fact that the relation between orthographic and phonological representations in an opaque orthography are less transparent, a higher demand on working memory capacity is warranted. In our model, the direction is from working memory, to phonological awareness measure. In a longitudinal study, it would be interesting to find out whether cross-lagged paths can be discriminated between working memory and phonological awareness, and whether this changes over time. This way, it could be examined to what extent working memory and phonological awareness interact over time. Our current model explained 18% of the variance in word reading efficiency. This leaves room to reflect on further explanations regarding word reading efficiency. For example, other cognitive variables could influence or explain the relation between working memory, phonological awareness, and word reading efficacy, such as intelligence, attention, or rapid automatized naming (RAN). Although intelligence is considered to be related to reading (Ferrer, Shaywitz, Holahan, Marchione, & Shaywitz, 2010), adding intelligence to the model in the present study hardly improved the explained variance (21% vs. 18%). Attention was previously found to account for variance in children reading scores (Berninger, Abbott, Cook, & Nagy, 2017). Because both working memory and attention can be defined as part of executive functions, taking into account a broader range of executive functions in further research is recommendable. A larger amount of variance could be expected to be explained by RAN (Norton & Wolf, 2012): Word reading efficiency is an efficiency measure, whereas our working memory and phonological awareness tasks were accuracy measures. It can thus be expected that the model would explain a much larger percentage of variance if RAN were to be included. Also, environmental factors can explain part of the variance, like the amount of specialist treatment with regard to reading. The amount of specialist treatment may differ within the group with dyslexia and perhaps explain part of the variance in word reading efficacy.

A practical implication of the present study is that the results support phonological awareness as a diagnostic measure even in older children, because the relation between phonological awareness and word reading efficiency has proved to be strong when measured with more difficult tasks. This research showed that phonological awareness adds substantially to word reading efficiency even in older children. This implies that practitioners can use more cognitively demanding phonological awareness tasks for diagnostic purposes. To conclude, working memory is necessary to word reading efficiency via its impact on phonological awareness, and phonological awareness continues to be important for word reading efficiency in older children with dyslexia.

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How to cite this article: Knoop-van Campen CAN, Segers E, Verhoeven L. How phonological awareness mediates the relation between working memory and word reading efficiency in children with dyslexia. *Dyslexia*. 2018;1–14. <https://doi.org/10.1002/dys.1583>

APPENDIX A

PHONEME DELETION TASK

Item	Spoken word	Letter to be deleted	Correct word	Distractor 1	Distractor 2
1	speer	s	peer	veer	beer
2	sterk	k	ster	step	kerk
3	blok	l	bok	lok	hok
4	post	s	pot	pop	bot
5	blad	l	bad	bak	lat
6	zweep	w	zeep	zeef	reep
7	stand	s	tand	tak	stad
8	brok	b	rok	bok	hok
9	klam	k	lam	kam	lat
10	pret	r	pet	bed	pen
11	kalm	l	kam	kat	lam
12	stand	n	stad	tand	stam
13	zwak	w	zak	wak	tak
14	kamp	p	kam	kat	kar
15	zwak	z	wak	bak	zak
16	brok	r	bok	rok	sok
17	klus	k	lus	kus	bus
18	balk	l	bak	bal	zak

Note. Per item, the words were randomly shuffled.

APPENDIX B

SPOONERISM TASK

Item	Correct picture 1	Correct picture 1	Distractor 1	Distractor 2	Distractor 3	Spoken word 1	Spoken word 2
1	gier	kaas	vier	vaas	haar	kier	gaas
2	bad	mus	lat	kus	bed	mat	bus
3	mat	land	kat	hand	lont	lat	mand
4	teen	land	been	mand	tuin	leen	tand
5	kus	bad	lus	kat	bed	bus	kat
6	net	boot	pet	poot	bad	bed	noot
7	boos	dak	roos	zak	doek	doos	bak
8	lam	rok	kam	hok	lijm	ram	lok
9	beer	kus	veer	lus	bier	keer	bus
10	zak	wijn	tak	lijn	ziek	wak	zijn
11	pet	veer	net	heer	poot	vet	peer
12	mes	bier	zes	gier	boor	bes	mier

Note. Per item, the words were randomly shuffled.