Parrila, R., Georgiou, G. K., & Papadopoulos, T. C. (2020). Dyslexia in a consistent orthography: Evidence from reading-level match design. *Dyslexia*, *26*(4), 343-358.

which has been published in final form at:
https://doi.org/10.1002/dys.1650

Dyslexia in a Consistent Orthography: Evidence from Reading-Level Match Design

Rauno Parrila

Macquarie University

George K. Georgiou

University of Alberta

Timothy C. Papadopoulos

University of Cyprus

IN PRESS

DYSLEXIA

Rauno Parrila, Department of Educational Studies and Macquarie Centre for Reading, Macquarie University, Sydney, Australia (rauno.parrila@mq.edu.au); George K. Georgiou, Department of Educational Psychology, University of Alberta, Edmonton, Canada (georgiou@ualberta.ca); Timothy C. Papadopoulos, Department of Psychology, University of Cyprus, Nikosia, Cyprus. Correspondence regarding this paper should be sent to Rauno Parrila at rauno.parrila@mq.edu.au

Abstract

Studies in consistent orthographies using reading-level (RL) match design have produced conflicting results, possibly because of problems with general ability and reading-level matching in many studies. We matched the participants on both verbal and nonverbal ability and on reading tasks with no ceiling effects and compared the performance of Grade 4 and 6 Greek-speaking children with dyslexia to those of chronological age (CA) and RL matched control groups across a variety of tasks associated with dyslexia (phonological awareness, rapid naming, phonological memory, and orthographic processing). The results showed that while both Grade 4 and Grade 6 dyslexics performed poorer than the CA groups in most tasks, they did not perform poorer than the RL group in any of the tasks included. We conclude with a discussion of the theoretical ramifications of the results and the appropriateness of the RL match design in studying dyslexia in consistent orthographies.

Keywords: dyslexia, consistent orthography, reading-level match design, phonological awareness, rapid naming, orthographic processing, Greek

Dyslexia in a Consistent Orthography: Evidence from Reading-Level Match Design

Developmental dyslexia, defined here *as a persistent and unexpected difficulty in developing age- and experience-appropriate word reading skills* (e.g., Parrila & Protopapas, 2017; Peterson & Pennington, 2012), is the most common learning disability in children, with prevalence estimates varying between 3% and 20% of all school-age children (see e.g., Shaywitz, 1996; Snowling, 2013). It affects children across languages, writing systems, and educational approaches to reading instruction. Developmental dyslexia is also the most widely studied behaviourally defined developmental disorder, with a rapidly expanding evidence base on associated genetics, neural functioning, cognitive skills, and environmental influences.

Despite intensive research efforts across languages, there is substantial debate regarding the causes of dyslexia. Several core deficits, including phonological awareness, rapid naming, phonological memory, and orthographic processing, have been proposed (see e.g., Elliot & Grigorenko, 2014, and Parrila & Protopapas, 2017, for recent reviews) but the evidence for each has been inconsistent, particularly in highly consistent orthographies, such as Finnish, German, and Greek. The purpose of this paper was to utilize reading-level (RL) match design to examine whether Grade 4 and Grade 6 Greek-speaking children with severe word reading difficulties show reliable deficits in phonological awareness, rapid naming, phonological memory, and orthographic processing, all of which have been argued to be causally linked to dyslexia (see e.g., Elliot & Grigorenko, 2014; Protopapas, 2014; and Snowling, 2000, for reviews).

Bryant and Goswami (1986) suggested that for a processing skill to be considered a cause of reading difficulties, it is not sufficient to show that individuals with dyslexia perform poorer than their general ability (GA; typically assessed by an IQ test) and chronological age (CA) matched controls because the deficit may simply reflect differences in reading ability and print exposure. A group of younger readers matched to the dyslexics on both general ability and reading ability should also be included in studies examining dyslexia. If children with dyslexia perform poorer than GA+RL matched younger readers on the examined (theoretically relevant) processing skills, then these skills could be considered as potential causes of their reading difficulties, or as secondary deficits related to a primary deficit that also causes dyslexia. RL match design rests on the assumption of bidirectional relationships between cognitive processes and reading skills or exposure. Such bidirectional relationships are established in various alphabetic orthographies for phonological awareness (see e.g., Landerl et al., 2018; Perfetti, Beck, Bell, & Hughes, 1987), and at least some studies have suggested they exist also for orthographic processing (see e.g., Manis, Custodia, & Szeszulski, 1993; Table 6), rapid naming (e.g., Compton, 2003; Peterson, Arnett, Pennington, Byrne, Samuelsson, & Olson, 2018), and phonological memory (e.g., Tang, 2016, but see Nation & Hulme, 2011, for unidirectional effects from reading to memory). Thus, the RL match design seems suited for examining the particular suggested causes of dyslexia included in this study.

The RL match design has been used with considerable success with English-speaking participants (see e.g., Greaney & Tunmer, 1996; Manis & Bailey, 2008; Richardson, Thomson, Scott, & Goswami, 2004; see Melby-Lervåg, Lyster, & Hulme, 2012, for a meta-analysis). However, the studies in consistent orthographies using an RL match design have reported conflicting findings (e.g., Constantinidou & Stainthorp, 2009; Diamanti, Goulandris, Campbell, & Protopapas, 2018; Georgiou, Protopapas, Papadopoulos, Skaloumbakas & Parrila, 2010; Jiménez, 1997; Papadopoulos, Georgiou, & Parrila, 2012; Serrano & Defior, 2008; Soriano & Miranda, 2010; Tobia & Marzocchi, 2014). For example, Georgiou et al. (2010) compared 12-year-old Greek children with dyslexia to CA and RL matched control groups on phonological awareness and rapid naming tasks. Their results indicated that children with dyslexia showed deficits in phonological awareness and naming speed tasks when compared to their CA controls, but not when compared to their RL controls. In contrast, working with slightly younger Grade 4 (age range 9.6 to 9.11 years old) Greek-speaking children with dyslexia, Constantinidou and Stainthorp (2008) found that the children with dyslexia performed significantly poorer than their CA and RL controls on both phonological awareness and rapid naming speed tasks. In terms of phonological memory, a few studies (Georgiou et al., 2010; Soriano & Miranda, 2010; Talli, Sprenger-Charolles, & Stavrakaki, 2016) have reported relatively large effect sizes favouring the RL group, whereas others have reported the opposite (e.g., Diamanti, Goulandris, Stuart, Campbell, & Protopapas, 2018; Tobia & Mazocchi, 2014). However, in most studies the differences have not been significant. Finally, the few studies that have included orthographic processing tasks have reported null results (e.g., Diamanti, Goulandris, Stuart et al., 2018; Serrano & Defior, 2008). At the minimum, the contradictory findings for most constructs examined suggest a need to explore the appropriateness of the RL match design in consistent orthographies further.

A critical issue for RL matching is that the use of different reading and general ability measures as criteria for matching can lead both to identifying very different kinds of children as poor readers (see e.g., Share & Leikin, 2004) and to differently composed RL matched control groups. For example, Deacon, Parrila, and Kirby (2006) presented data on adults with dyslexia whose mean performance levels in word decoding, word identification, and reading comprehension were comparable to those of Grade 7, Grade 11, and second-year university students, respectively. As a result, RL matching on the basis of any one reading measure would have resulted in groups that would have differed not only on other reading measures, but possibly also on many additional relevant characteristics, such as general language skills, background knowledge, and reading experience, which is the key variable RL matching supposedly controls. If this is the case, then it is possible that the older children with dyslexia reach the same word or text reading score relying on different mechanisms, such as better vocabulary or word-specific knowledge, than the younger readers who are likely to rely on decoding. Van den Broeck and Geudens (2012) noted that this scenario would indicate that the frequently observed nonword reading difficulties could be an RL design artefact rather than a defining feature of dyslexia. In this scenario, we would also expect that the RL matched group would show better phonological awareness skills given the close relationship between decoding and phonological awareness.

A related problem in consistent orthographies is the use of accuracy measures for matching. As accuracy measures tend to show limited variability due to ceiling effects, matching on the basis of them can result in RL control groups varying in other measures of word and nonword reading (e.g., Jiménez et al., 2005). In general, studies in which matching was based on accuracy (e.g., Constantinidou & Stainthorp, 2009; Jimenez, 1997; Jiménez, Rodríguez, & Ramírez, 2009; Soriano & Miranda, 2010) seem to show more differences favouring the RL match group than studies that matched the groups on the basis of efficiency measures (e.g., Cuetos, Martinez-Garcia, & Suarez-Coalla, 2018; Georgiou et al., 2010), although this is not always the case (e.g., Serrano & Defior, 2008; Talli et al., 2016). Given that the selection criteria for the reading disabled group is remarkably consistent across the studies, these results suggest that the cognitive profiles of the RL matched groups could differ substantially based on the matching tasks.

Similarly, the choice of verbal or nonverbal ability as an indicator of general ability can have a considerable impact on what comorbidities are at least partially controlled and to whom their performance is compared. Verbal ability (usually measured with a vocabulary test) correlates highly with language deficits, such as specific language impairment (SLI), that result in syntactic and semantic problems and frequently in poor reading (Bishop & Snowling, 2004; Catts, Hu, Larrivee, & Swank, 1994; Spanoudis, Papadopoulos, & Spyrou, 2019), whereas nonverbal ability (typically assessed with Raven's Matrices or with one or more nonverbal subtests from an intelligence test) is less correlated with language deficits. As a result, using nonverbal ability as the sole criterion is more likely to result in a poor reading or dyslexic group that includes children who have both reading and other language-based problems that can impact, for example, phonological processing and rapid naming (e.g., Vandewalle, Boets, Ghesquière, & Zink, 2010). However, poor reading progress has been associated with a decline in verbal ability over time (e.g., Ritchie, Bates, & Plomin, 2015; Share, McGee, & Silva, 1989), making verbal ability a problematic criterion of general ability after the first few years of school.

In this study, we addressed the potential methodological problems with earlier RL match studies in consistent orthographies and posed two research questions: (1) do children with dyslexia in a highly consistent orthography experience phonological awareness, phonological memory, rapid naming, and orthographic processing deficits? and (2) are there differences in the manifestation of core deficits in dyslexia at two different time points of elementary education? To answer these questions, we administered a wide range of tasks to two groups of children with dyslexia and their chronological age and reading-level matched control groups. We examined both the performance accuracy and the speed of performance as children with reading difficulties in consistent orthographies are often accurate in phonological awareness tasks (e.g., Diamanti, Goulandris, Stuart et al., 2018; Landerl & Wimmer, 2000); however, very few studies have examined whether speed differences remain (see Georgiou, Papadopoulos, Zarouna & Parrila, 2012; Lundberg & Høien, 1990; and Serrano & Defior, 2008, for exceptions). Further, we matched as closely as possible the dyslexic and RL groups on both word reading fluency and phonological decoding fluency to increase the chances that the groups were indeed comparable in skills critical for the diagnosis of dyslexia. In the existing studies, groups matched on the basis of one word reading measure frequently differ in others (e.g., Jimenez & Ramirez, 2002; Soriano & Miranda, 2010; see Lundberg & Høien, 1990, for a discussion). As in other consistent orthographies, accuracy measures in Greek reach ceiling early (see Papadopoulos, Georgiou, & Kendeou, 2009; Protopapas & Skaloumbakas, 2007) and provide little diagnostic information in Grades 4 and 6 targeted in this study. Finally, we matched the groups on standard scores on both nonverbal and verbal ability measures. In doing so, we hoped, at least partly, to control for additional language difficulties and to create RL matched groups whose raw scores on vocabulary are poorer than those of the dyslexic groups. As a consequence, we predicted that if the dyslexic groups experienced only word reading problems, their stronger language skills compared to the RL groups should result in better reading comprehension performance (e.g., Ellis, McDougall, & Monk, 1996; Gough & Tunmer, 1986). This, we believe, is critical for establishing the specificity of the reading problems.

Method

Participants and Matching

Two groups of children with dyslexia, two chronological-age matched groups, and two reading-level matched groups participated in the study. All children were native speakers of Greek and came from six inner-city public elementary schools in Cyprus that serve families of middle SES background (see e.g., Georgiou et al., 2012; Georgiou, Parrila, & Papadopoulos, 2008). To identify the children with dyslexia, we first asked teachers to nominate children from their classes who were experiencing reading difficulties but had no documented sensory, intellectual or attentional problems. We then tested these children on measures of reading fluency (Word Reading Efficiency, Phonemic Decoding Efficiency, and Text Reading Speed), passage comprehension, and general ability (Block Design and Vocabulary; from WISC-III Greek adaptation: Georgas, Paraskevopoulos, Bezevegis, & Giannitsas, 1997). Twenty-two Grade 4 (12 boys), and 22 Grade 6 students (12 boys) who scored at least one standard deviation below their respective age group mean on two out of three reading fluency tasks and within average range (scaled score > 7) on both Block Design and Vocabulary were included in the dyslexic groups. Twelve children were excluded either because they were low only in one reading task or scored below 7 on either of the cognitive ability tasks. Eight children had a formal diagnosis of dyslexia (rare in Cyprus), and 28 were receiving some special education services. To obtain the CA matched controls, 28 Grade 4 (16 boys), and 26 Grade 6 children (11 boys) were matched on a group level to the dyslexic groups on age, Block Design and Vocabulary scores.

Finally, to obtain two RL matched control groups, Grade 1 and 3 teachers were asked to identify typically reading children in their classroom who were then, after receiving parental consent, administered word and pseudoword reading fluency tasks (see below). Five (Grade 3) and eight (Grade 1) children were excluded due to their very high performance on the two reading tasks, and 24 Grade 3 children (13 boys) and 24 Grade 1 children (8 boys) were matched on a group level to the dyslexic groups on word and pseudoword reading fluency and the Block Design and Vocabulary scaled scores.

The characteristics of the participants are summarized in Tables 1 and 2. We acknowledge that in Grade 6, matching on word reading lead to imperfect matching on pseudoword reading and vice versa. The tables also include Cohen's *d* for comparisons of means between children with dyslexia and their CA and RL matched controls, and *t*-values and *p*-values for the same pairwise comparisons. The groups were also compared within each measure with an ANOVA followed by post hoc pairwise comparisons with Bonferroni correction and alpha = .05). The bolded *p*-values in Tables 1 and 2 were significant after Bonferroni correction. The ANOVAs were significant (*p*s < .001) for all measures except Block Design and Vocabulary scaled scores. As expected, the older children with dyslexia exhibited better vocabulary raw scores and reading comprehension than the two RL matched groups. It is possible that the higher vocabulary raw scores of children with dyslexia explain why they were faster in text reading as well.

Measures

Reading. Four measures of reading were administered. Word Reading Efficiency (WRE) and Phonemic Decoding Efficiency (PDE) were adapted in Greek from Test of Word Reading Efficiency (TOWRE; Torgesen, Wagner, & Rashotte, 1999). In WRE, children were asked to read as fast as possible a list of 104 words placed in four columns. The words were selected from textbooks used in schools and ordered in terms of assumed difficulty based on length, syllable complexity, and frequency. Before the actual task children completed an 8-item practice task. In PDE, children were first shown an 8-item practice list and then asked to read as fast as possible 63 nonwords placed in three columns. In both tasks, the score was the number of words/nonwords read correctly in 45 seconds. Test-retest reliability for WRE and PDE has been reported to range from .86 to .93 (Georgiou et al., 2012).

Text Reading Fluency (TRF) consisted of two short passages that the children were asked to read as quickly and as accurately as possible. The texts were selected so that one would be well within the reading ability of nearly all children in a given grade level and one would be a bit more challenging. TRF has been used in several previous studies in Greek showing good psychometric properties (e.g., Georgiou et al., 2008, 2012; Manolitsis, Georgiou, Stephenson, & Parrila, 2009). For the older groups (Grade 6 DYS, CA, Grade 3 RL), the first story was at Grade 4 and the second at Grade 6 level. For the younger cohort (Grade 4 DYS, CA, Grade 1 RL), the first story was at Grade 2 and the second at Grade 4 level. The length of the stories varied from 19 to 125 words. The score was the total time in seconds to read both passages. Because the reading errors were few (mean < 2 in each group), they were not considered further. Georgiou et al. (2012) reported test-retest reliability for TRF to range from .81 to .89.

Finally, Passage Comprehension was adapted in Greek from the Woodcock-Johnson Reading Mastery-Revised (see Georgiou, Manolitsis, Nurmi, & Parrila, 2010, for more information) and required children to provide a missing word that was important to the meaning of the sentence or passage. The task was discontinued after 6 consecutive errors and a participant’s score was the total number correct (max = 68). The Cronbach’s alpha reliability coefficient in our sample was .90.

General Cognitive Ability. All children were administered Block Design and Vocabulary subtests from WISC-III (Wechsler, 1992; Greek adaptation: Georgas et al., 1997). This particular dyad of subtests has been used in several previous studies (e.g., Mouzaki & Sideridis, 2007; Windfuhr & Snowling, 2001). Georgas et al. (1997) reported Cronbach’s alpha reliability coefficients for Block Design to be .80 and .83 for Grades 3 and 6, respectively. The corresponding reliability coefficient for Vocabulary was .81 in both grades.

Phonological awareness. Two measures of phonological awareness were administered: phoneme elision and phoneme matching. In the phoneme elision task, the participants were asked to say a word without saying one of the sounds in the word. A participant's score was the number of correct items (max = 29). The Cronbach's alpha reliability coefficient in our sample was .92. In phoneme matching, a coloured picture of an object was presented on the top half of a laptop screen along with three coloured pictures of different objects presented on the bottom half of the laptop screen. The children were asked to choose the one of the three pictures on the bottom in whose name began (eight items) or ended (eight items) with the same sound as the picture on the top. Initial phoneme matching was completed before final phoneme matching. Prior to each set of items, children completed two practice items. Both the accuracy and the response time were recorded; as accuracy was at ceiling, only response times results are reported. Georgiou et al. (2012) reported test-retest reliability for Phoneme Matching response time to be .84.

Rapid naming speed. RAN Colours, RAN Digits, and RAN Objects were adapted in Greek from the RAN/RAS test battery (Wolf & Denckla, 2005). Children were asked to name as fast as possible five colours, digits, or objects that were repeated 10 times each and arranged in five rows of ten. Prior to timed testing, children named the five colours, digits, and objects in a practice trial. Because naming errors were few (mean number of errors was less than 1 in each group), they were not considered further. A participant's score in each task was the total time to name all the items. Georgiou et al. (2012) reported test-retest reliability coefficients ranging from .80 to .88.

Phonological memory. Forward Digit Span from WISC-III Greek adaptation (Georgas et al., 1997) and Word Series from Cognitive Assessment System (CAS; Naglieri & Das, 1997;

Greek adaptation: Papadopoulos, Georgiou, Kendeou, & Spanoudis, 2009) were used to assess phonological memory. In Digit Span Forward, children were asked to repeat a string of digits in the same order they heard them. The strings started with only two digits, and one digit was added for each new digit string. The task was terminated when the child failed both trials of a given length. The performance score was the number of digit strings that the child could accurately provide. The Cronbach's alpha reliability coefficient in our sample was .80. In Word Series, children were required to repeat a series of words in the same order they heard them. The series increased in length from two to nine words (e.g., μαμά-γάτα-δώρο /mama/-/γata/-/'ðoro/; "mother"-"cat"-"gift"). A participant's score was the number of word series recalled correctly (max = 27). The Cronbach's alpha reliability coefficient in our sample was .84. Note that while both WISC-III and CAS provide scaled scores, the comparisons reported below were performed with raw scores.

Orthographic processing. Two measures of orthographic processing were administered. Orthographic Choice was adapted from Olson and colleagues (e.g., Olson, Forsberg, Wise, & Rack, 1994). The students viewed 30 pairs of phonologically similar letter strings (e.g., σχολείο – σχολίο) and were asked to choose the one that spelled a word by pressing the left or the right Ctrl button. The score was the number of correctly chosen real words and the time to select the correct response. The Cronbach's alpha reliability coefficient for Orthographic Choice accuracy in our sample was .78. Georgiou et al. (2012) reported test-retest reliability for Orthographic Choice response time to be .73. Quick Spelling Test (QST) was adapted in Greek from Rueffer (2000) and it assesses the ability of a child to report the letters in 4-letter words (e.g., *πίσω*), pseudowords (e.g., *σώδε*), and nonwords with high frequency bigram combinations (e.g., *χρπλ*) and low frequency bigram combinations (e.g., *μβφλ*) that were presented in random order on a computer screen for 250 ms. There were 10 letter strings in each condition and the number of strings correctly written was scored. A participant's score was the total number correct (max = 10) in each category. As children in the Grade 1 RL group were not able to reliably complete the task, the results are reported only for the older groups. The Cronbach's alpha reliability coefficient in our sample was .82.

Procedure

Children were assessed in April/May of the school year in a quiet room in their schools during school hours by the second author and a graduate student. Testing was divided into two sessions lasting roughly 45 minutes each. The first session consisted of the paper and pencil tasks (Block Design, Vocabulary, WRE, PDE, TRF, Digit Span, Word Series, and Passage Comprehension). The second session consisted of the computerized tasks (Colour Naming, Digit Naming, Phoneme Elision, Object Naming, Phoneme Matching, Quick Spelling Test, and Orthographic Choice). Half of the participants did first session A and the other half session B. The order of the task administration was fixed within each session.

For the computerized session, we used a TOSHIBA laptop with a 15.4' screen and the Direct RT experiment presentation software (Jarvis, 2005). The viewing distance was about 50 cm and the stimuli in Orthographic Choice and QST were presented in back Arial font (font size 28) on a white background.

Response Time Data

Response time data were collected for Phoneme Matching, Phoneme Elision, and Orthographic Choice. For Orthographic Choice, the response time represents the time interval from the appearance of the stimulus on the computer screen to the child's response of pressing the right or left Ctrl button. In Phoneme Matching and Phoneme Elision, the experimenter pressed a button on a keypad at the onset of the child's response. To calculate the mean response times, we first removed incorrect responses. Next, we removed any responses below 200 ms (anticipation responses) or above 20000 ms (likely technical errors) in Phoneme Matching and Orthographic Choice. Finally, we removed response times that were 2 SD below or above the individual's mean (after steps 1 and 2 were completed).

Results

Table 3 summarizes the results for Grade 4 and Grade 1 participants. MANOVA with the four phonological awareness measures as the dependent variables and group as the independent variable showed a significant effect of group, Wilk's $\Lambda = .577$, $F(8, 136) = 5.89$, $p < .001$. Subsequent ANOVAs showed significant between group differences in Elision Accuracy, $F(2, 71) = 7.70$, $p = .001$, and Final Phoneme Matching response times, $F(2, 71) = 15.99$, $p < .001$, but not in Elision response time or Initial Phoneme Matching response time (*F*s < 1.03). Table 3 shows Cohen's *d* values and results from independent samples *t*-tests for all pairwise comparisons. The *p*-values that were significant after Bonferroni correction at .05 (two-sided) significance level are bolded in Table 3 and indicate that Grade 4 children with dyslexia performed as well or better than their Grade 1 RL matched control group in all tasks. MANOVA with the three RAN tasks as the dependent variables also showed a significant effect of group, Wilk's $\Lambda = .501$, $F(6, 138) = 9.49$, $p < .001$, and the subsequent ANOVAs were all significant (all *F*s > .11.50). In all tasks, Grade 4 children with dyslexia were significantly faster than the Grade 1 RL matched control group. MANOVA with the two phonological memory tasks was not significant, $F < 1.0$, and the three groups did not differ significantly from each other. Finally, MANOVA with Orthographic Choice accuracy and response times as the two dependent variables showed a significant effect of group, Wilk's $\Lambda = .536$, $F(4, 140) = 12.80$, $p < .001$.

Both ANOVAs were significant ($F(2, 71) = 8.82$ for accuracy and 24.56 for response time), and pairwise comparisons indicated that Grade 4 children with dyslexia were equal to Grade 1 RL match group on the accuracy measure and faster on the response time measure, while both performed poorer than the CA control group on these measures.

Table 4 summarizes the results for the Grade 6 participants and the Grade 3 RL matched control group. MANOVA with the four phonological awareness measures as the dependent variables showed a significant effect of group, Wilk's $\Lambda = .586$, $F(8, 132) = 5.06$, $p < .001$. Subsequent ANOVAs showed significant between group differences in all four measures (all Fs > 4.80). Pairwise comparisons indicated that Grade 6 children with dyslexia performed as well or better than their Grade 3 RL matched controls in all tasks. MANOVA with the three RAN tasks also indicated a significant effect of group, Wilk's $\Lambda = .397$, $F(6, 134) = 13.10$, $p < .001$. Subsequent ANOVAs showed significant group effects with all Fs > 23.00, and pairwise comparisons again indicated that the dyslexia group performed poorer than the CA comparison group but as well or better than the RL matched group. MANOVA with the two phonological memory measures showed a significant main effect of group, Wilk's $\Lambda = .859$, $F(4, 136) = 2.68$, $p = .035$. ANOVAs localized the effect on Digit Span, $F(2, 69) = 4.72$, $p = .012$, and pairwise comparisons indicated that only the difference between CA and RL groups was significant with the dyslexia group falling in between. Finally, MANOVA with the six orthographic processing measures as dependent variables showed a significant main effect of group, Wilk's $\Lambda = .451$, $F(12, 120) = 4.88$, $p < .001$. Subsequent ANOVAs indicated that the effect of group was significant (all Fs > 6.25) for all other tasks but Quick Spelling Task with real words ($F(2, 65) = 1.51$). As summarized in Table 4, pairwise comparisons again indicated that Grade 6 students with dyslexia performed poorer than their CA matched control group in most tasks, but equal to their RL matched Grade 3 control group.

In sum, when differences were observed between Grade 3 or 6 children with dyslexia and their RL matched control groups, these were in timed tasks and favoured the children with dyslexia. When differences were observed between children with dyslexia and their CA matched peers, these always favoured the CA group.

Discussion

We examined whether children with dyslexia learning to read a highly consistent orthography (Greek) experience phonological awareness, phonological memory, rapid naming, and orthographic processing deficits compared to reading-level matched younger peers, and whether the possible deficits are the same or different at two different time points of elementary education. The results of the study are clear: when comorbidity associated with reading deficits is controlled in sample selection and the groups are matched on both verbal and nonverbal general ability and on more than one task relevant for the diagnosis of dyslexia, the older dyslexic children perform as well or better than the younger RL matched control children in all administered tasks. Similar results in terms of RL comparisons were recently reported by Diamanti, Goulandris, Stuart et al. (2018) in a longitudinal study covering roughly the same age range as we did. Further, children with dyslexia performed as well as their chronological age and general ability matched peers on many of the tasks, in particular when accuracy was measured, suggesting that at least some of the accuracy tasks may not have been sensitive enough to capture possible differences between the groups. Alternatively, it can also be argued that when comorbidity and general ability are controlled, children with dyslexia show only very specific phonological awareness, rapid naming and orthographic processing deficits rather than a generally depressed performance level on all tasks. However, given that Diamanti, Goulandris, Stuart et al. (2018) reported significant differences between the CA and dyslexia groups in all of their tasks, many assessing the same constructs as we did here, this alternative needs to be considered with caution at this point. Future studies could establish the extent to which phonological awareness, rapid naming and orthographic processing results vary as a function of specific task characteristics.

Our results also showed that when general ability and word reading level are matched more rigorously, reading comprehension of children with dyslexia is comparable to what we would expect on the basis of their age (see Protopapas & Skaloumbakas, 2007, for comparable results) and indeed better than the comprehension of younger RL controls, as would be theoretically expected (Gough & Tunmer, 1986). We are not aware of other RL match studies in consistent orthographies where this would have been the case. Thus, we believe that our sample mostly consisted of "true dyslexics" (Stanovich, 1988) and that the differences in our results and those of the previous studies (e.g., Constantinidou & Stainthorp, 2009; Jiménez et al., 2005; Soriano & Miranda, 2010) are due to these studies not matching either the reading ability or the cognitive ability of their groups in a manner that would have resulted in groups matched beyond a selected task that may have shown questionable psychometric properties. For example, in Jiménez et al. (2005), the groups were matched on one word reading accuracy measure (that likely showed a ceiling effect; see Table 1 in Jiménez et al., 2005), but differed on another. In Constantinidou and Stainthorp (2009), the dyslexic group consisted of extremely slow readers, whose reading comprehension was also poorer than that of the RL matched group (see also Loizidou-Ieridou, 2012). When this is the case, we suspect that the dyslexic groups consisted of, or at the minimum included several, “garden-variety poor readers” (Stanovich, 1988) whose deficits are less modular, more severe, and likely impact a wider variety of cognitive tasks.

One possible conclusion from these results is that phonological awareness, rapid naming, phonological memory, or orthographic processing skills are not causally related to dyslexia in a consistent orthography, at least during the elementary school years. Note that we really could not study younger children using the RL match design as the control group for Grade 4 children with dyslexia was already from Grade 1 when reading instruction starts in Cyprus. We believe this conclusion is likely warranted for phonological memory in which the children with dyslexia showed no deficits, and that when studies report phonological memory deficits (e.g., Georgiou et al., 2010; Gustafson, 2001), these are likely related to uncontrolled comorbidity in the examined samples.

A second possible conclusion is that RL match design is methodologically flawed as a tool for establishing causality in consistent orthographies. RL match design has been criticized by van den Broeck and Geudens (2012) for making untenable assumptions about the homogeneity of skill development across the examined age groups. Their specific argument was that when groups are matched based on word reading, there will likely be a non-word reading difference as the older children’s word reading score will reflect greater familiarity with words, whereas the younger RL groups’ performance will reflect better decoding skills. While our results provide tentative support for this – Grade 6 children with dyslexia showed somewhat poorer decoding efficiency when matched on word reading efficiency – we also observed equal or better reaction times for the children with dyslexia in phonological processing tasks. Given this result, we would like to suggest a slightly different interpretation of the RL match design’s shortcomings. The RL match design was originally intended to control the bidirectional effects of reading practice/print exposure on cognitive skills in studies of children learning to read English, arguably the most inconsistent alphabetic orthography. It thus rests on the assumption that the practice effects are more important than the maturation effects. In English, both word reading accuracy and fluency likely are highly correlated with practice – many words are difficult, if not impossible, to decode correctly without prior exposure to their pronunciations. However, it is not clear that print exposure in general and item-specific exposure in particular are similarly important for accurate or even fluent decoding in consistent orthographies where the correct response can always be reached by applying accurately a limited set of grapheme-to-phoneme correspondences – to what extent fluency is dependent on the speed of these processes or on the familiarity with the target words is not clear (e.g., Aro, 2006; de Jong, 2011; however, see Heikkilä, Aro, Närhi, Westerholm, & Ahonen, 2013, for an argument for familiarity with syllables). If the reading fluency depends more on raw cognitive speed than on practice, then we would expect maturation effects to work against finding significant differences in the RL match design studies in consistent orthographies. Our results are consistent with this proposition in that when differences were observed between the reading-level matched groups, they were evident only in speeded tasks and consistently favoured the older children with dyslexia. To control for the maturation effects, future studies may want to employ other matching techniques, such as state trace analysis (see Van den Broeck & Geudens, 2010, for an example). It is also possible that CA matched control groups are more appropriate for dyslexia studies in consistent orthographies than they are for similar studies in less consistent orthographies. Nevertheless, future studies should compare results from different matching methods to establish what the proper control group is for what questions.

Finally, several authors have recently questioned the theoretical assumption that behaviourally defined developmental disorders, such as dyslexia, can have a single (or double) core cause (e.g., Parrila & Protopapas, 2017; Pennington, 2006; van Bergen, van der Leij, & de Jong, 2014). In his seminal analysis of research of comorbid developmental disorders, Pennington (2006) concluded that probabilistic multiple deficit models (PMDM) are needed to provide a more realistic account of developmental disorders, their comorbidity, and the nondeterministic relationships between disorders and their suggested causes. In terms of cognitive level predictors examined in this study, such models would suggest that a significant deficit in any one of them could be associated with a reading deficit, but none are necessary or sufficient on their own and a reading deficit could also result from an interaction of multiple subclinical deficits that jointly contribute to a clinically identifiable reading deficit. Dyslexia theories derived from probabilistic multiple deficit models can accommodate a wider range of results than single or double deficit theories, including diverging empirical results in cognitive, neurological (see e.g., Protopapas & Parrila, 2018, for a discussion), and genetic (e.g., Carrion-Castillo, Franke, & Fisher, 2013) levels. However, such theories will not be compatible with the assumptions underlying the RL match design.

References

Aro, M. (2006). Learning to read: The effect of orthography. In R. M. Joshi & P. G. Aaron (Eds.), *Handbook of Orthography and Literacy* (pp. 531-550). Mahwah, NJ: Erlbaum.

Bryant, P., & Goswami, U. (1986). Strengths and weaknesses of the reading level design: A comment on Backman, Mamen, and Ferguson. *Psychological Bulletin, 100,* 101-103.

Bishop, D. V. M., & Snowling, M. J. (2004). Developmental dyslexia and specific language impairment: Same or different? *Psychological Bulletin, 130,* 858-886.

Carrion-Castillo, A., Franke, B., & Fisher, S. E. (2013). Molecular genetics of dyslexia: An overview. *Dyslexia, 19*, 214–240. doi: 10.1002/dys.1464

Catts, H.W., Hu, C.-F., Larrivee, L., & Swank, L. (1994). Early identification of reading disabilities in children with speech-language impairments. In R. V. Watkins & M. L. Rice (Eds.), *Specific language impairments in children* (pp. 145-160). Baltimore, MD: Paul H. Brookes Publishing.

Compton, D. L. (2003). Modeling the relationship between growth in rapid naming speed and decoding skill in first-grade children*. Journal of Educational Psychology*, *95*, 225-239.

Constantinidou, M., & Stainthorp, R. (2009). Phonological awareness and reading speed deficits in reading-disabled Greek-speaking children. *Educational Psychology, 29*, 171-186.

Cuetos, F., Martinez-Garcia, C., & Suarez-Coalla, P. (2018). Prosodic perception problems in Spanish dyslexia. *Scientific Studies of Reading, 21*, 41-54. doi: 10.1080/10888438.2017.1359273

Diamanti, V., Goulandris, N., Campbell, R., & Protopapas, A. (2018). Dyslexia profiles across orthographies differing in transparency: An evaluation of theoretical predictions contrasting English and Greek. *Scientific Studies of Reading, 22*, 55–69. doi: 10.1080/10888438.2017.1338291

Diamanti, V., Goulandris, N., Stuart, M., Campbell, R., & Protopapas, A. (2018) Tracking the effects of dyslexia in reading and spelling development: A longitudinal study of Greek readers. *Dyslexia, 24*, 170-189. doi: 10.1002/dys.1578

de Jong, P. F. (2011). What discrete and serial rapid naming automatized naming can reveal about reading. *Scientific Studies of Reading, 15*, 314-337.

Deacon, S.H., Parrila, R., & Kirby, J. (2006). The status of morphological processing in compensated dyslexics. *Annals of Dyslexia, 56*, 103-128.

Elliott, J. G., & Grigorenko, E. L. (2014). *The dyslexia debate.* Cambridge University Press.

Ellis, A.W., McDougall, S. J. P., & Monk, A. F. (1996). Are dyslexics different? A comparison between dyslexics, reading age controls, poor readers and precocious readers. *Dyslexia, 2*, 31-58.

Georgas, D. D., Paraskevopoulos, I. N., Bezevegis, I. G., & Giannitsas, N. D. (1997). *Ελληνικό WISC-III: Wechsler κλίμακες νοημοσύνης για παιδιά* [Greek WISC-III: Wechsler intelligence scale for children]. Athens: Ellinika Grammata.

Georgiou, G., Manolitsis, G., Nurmi, J. E., & Parrila, R. (2010). Does task-focused versus task-avoidance behavior matter for literacy development in an orthographically consistent language. *Contemporary Educational Psychology, 35*, 1-10. doi:10.1016/j.cedpsych.2009.07.001

Georgiou, G., Papadopoulos, T., Zarouna, E., & Parrila, R. (2012). Are auditory and visual processing deficits related to developmental dyslexia? *Dyslexia, 18*, 110-129.

Georgiou, G. K., Parrila, R., & Papadopoulos, T. C. (2008). Predictors of word decoding and reading fluency across languages varying in orthographic consistency. *Journal of Educational Psychology, 100,* 566-580. DOI: 10.1037/0022-0663.100.3.566

Georgiou, G. K., Protopapas, A., Papadopoulos, T. C., Skaloumbakas, C., & Parrila, R. (2010). Auditory temporal processing and dyslexia in an orthographically consistent language. *Cortex, 46*, 1330-1344.

Gough, P. B., & Tunmer, W. E. (1986). Decoding, reading and reading disability. *Remedial and Special Education, 7*, 6-10.

Greaney, K. T., & Tunmer, W. E. (1996). Onset/rime sensitivity and orthographic analogies in normal and poor readers. *Applied Psycholinguistics, 17*, 15-40.

Gustafson, S. (2001). Cognitive abilities and print exposure in surface and phonological types of reading disability. *Scientific Studies of Reading, 5*, 351-375.

Heikkilä, R., Aro, M., Närhi, V., Westerholm, J., & Ahonen, T. (2013). Does training in syllable recognition improve reading speed? A computer-based trial with poor readers from second and third grade. *Scientific Studies of Reading, 17*, 398-414.

Jarvis, B. G. (2005). DirectRT [computer software]. New York: Empirisoft Corporation.

Jiménez, J. E. (1997). A reading-level matched study of phonemic processes underlying reading disabilities in a transparent orthography. *Reading and Writing: An Interdisciplinary Journal, 9*, 23-40.

Jiménez, J. E., Garcia, E., Ortiz, R., Hernández-Valle, R., Guzmán, R., Rodrigo, M., et al. (2005). Is the deficit in phonological awareness better explained in terms of task differences or effects of syllable structure? *Applied Psycholinguistics, 26,* 267-283.

Jiménez, J. E., & Ramírez, G. (2002). Identifying subtypes of reading disability in the Spanish language. *The Spanish Journal of Psychology, 5*, 3-19. doi: 10.1017/S1138741600005783

Jiménez, J. E., Rodríguez, C., & Ramírez, G (2009). Spanish developmental dyslexia: Prevalence, cognitive profile, and home literacy experiences. *Journal of Experimental Child Psychology, 103*, 167-185. doi: 10.1016/j.jecp.2009.02.004

Landerl, K., Heene, M., Freudenthaler, H., Desrochers, A., Parrila, R., de Jong, P., Manolitis, G., & Georgiou, G. (2018). Phonological awareness and rapid automatized naming as longitudinal predictors of reading in five alphabetic orthographies with varying degrees of consistency. *Scientific Studies of Reading, 23,*220-234. doi: 10.1080/10888438.2018.1510936

Landerl, K., & Wimmer, H. (2000). Deficits in phoneme segmentation are not the core problem of dyslexia: Evidence from German and English children. *Applied Psycholinguistics, 21*, 243-262.

Loizidou-Ieridou, N. (2012). Reading, spelling and phonological ability in 9 to 10 year old Greek-speaking dyslexic children. In A. Chatzipanagiotidou & S. Tsolakidis (Eds.) *Proceedings of the conference on Schools of Education: Their role in the challenges of the modern society* (pp. 357- 374). Nicosia, Cyprus: Frederick University Press.

Lundberg, I., & Høien, T. (1990). Patterns of information processing skills and word recognition strategies in developmental dyslexia. *Scandinavian Journal of Educational Research, 34*, 231-240.

Manis, F. R., & Bailey, C. E. (2008). Exploring heterogeneity in developmental dyslexia: A longitudinal investigation. In G. Reid, A. Fawcett, F. Manis, & L. Siegel (eds.), *The SAGE Handbook of Dyslexia* (pp. 149-173). London: Sage Publications.

Manis, F. R., Custodio, R., & Szeszulski, P. A. (1993). Development of phonological and orthographic skill: A 2-year longitudinal study of dyslexic children. *Journal of Experimental Child Psychology, 56*, 64-86.

Manolitsis, G., Georgiou, G., Stephenson, K., & Parrila, R. (2009). Beginning to read across languages varying in orthographic consistency: Comparing the effects of non-cognitive and cognitive predictors. *Learning and Instruction, 19*, 466-480. doi:10.1016/j.learninstruc.2008.07.003

Melby-Lervåg, M., Lyster, S.-A., & Hulme, C. (2012). Phonological skills and their role in learning to read: A meta-analytic review. *Psychological Bulletin, 138*, 322-352. doi: 10.1037/a0026744

Mouzaki, A., & Sideridis, G. D. (2007). Poor readers' profiles among Greek students of elementary school. *Hellenic Journal of Psychology, 4* (2), 205-232.

Naglieri, J. A., & Das, J. P. (1997). *Das-Naglieri Cognitive Assessment System*. Itasca, IL: Riverside Publishing.

Nation, K., & Hulme, C. (2011). Learning to read changes children’s phonological skills: Evidence from a latent variable longitudinal study of reading and nonword repetition. *Developmental Science, 14*, 649-659.

Olson, R. K., Forsberg, H., Wise, B., & Rack, J. (1994). Measurement of word recognition, orthographic, and phonological skills. In G. R. Lyon (Ed.), *Frames of reference for the assessment of learning disabilities* (pp. 243-277). Baltimore, MD: Brookes.

Papadopoulos, T. C., Georgiou, G. K., & Kendeou, P. (2009). Investigating the double-deficit hypothesis in Greek: Findings from a longitudinal study. *Journal of Learning Disabilities, 42*, 528-547.

Papadopoulos, T. C., Georgiou, G. K., Kendeou, P., & Spanoudis, G. (2008). *Standardization in Greek of the Das-Naglieri Cognitive Assessment System*. Department of Psychology, University of Cyprus.

Papadopoulos, T. C., Georgiou, G. K., & Parrila, R. K. (2012). Low-level deficits in beat perception: Neither necessary nor sufficient for explaining developmental dyslexia in a consistent orthography. *Research in Developmental Disabilities, 33*, 1841-1856.

Parrila, R., & Protopapas, A. (2017). Dyslexia and word reading problems. In K. Cain, D. Compton, & R. Parrila (eds.), *Theories of reading development* (pp. 333-358). Amsterdam: Benjamins. doi: 10.1075/swll.15.19par

Pennington, B. F. (2006). From single to multiple deficit models of developmental disorders. *Cognition, 101*, 385-413. doi: 10.1016/j.cognition.2006.04.008

Perfetti, C. A., Beck, I., Bell, L. C., & Hughes. C. (1987). Phonemic knowledge and learning to read are reciprocal: A longitudinal study of first grade children. *Merrill-Palmer Quarterly, 33*, 283–319.

Peterson, R. L., Arnett, A. B., Pennington, B. F., Byrne, B., Samuelsson, S., & Olson, R. K. (2018). Literacy acquisition influences children´s rapid automatized naming. *Developmental Science, 21*, e12589. doi:10.1111/desc.12589

Peterson, R. L. & Pennington, B. F. (2012). Developmental dyslexia. *The Lancet, 379* (9830), 1997-2007. doi: 10.1016/S0140-6736(12)60198-6.

Protopapas, A. (2014). From temporal processing to developmental language disorders: mind the gap. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *369* (1634), 1-11.

Protopapas, A., & Parrila, R. (2018). Is dyslexia a brain disorder? *Brain Sciences, 8*, 61. doi: 10.3390/brainsci8040061

Protopapas, A., & Skaloumbakas, C. (2007). Traditional and computer-based screening and diagnosis of reading disabilities in Greek. *Journal of Learning Disabilities, 40*, 15-36.

Richardson, U., Thomson, J. M., Scott, S. K., & Goswami, U. (2004). Auditory processing skills and phonological representation in dyslexic children. *Dyslexia*, *10*, 215-233.

Ritchie, S. J., Bates, T. C., & Plomin, R. (2015). Does learning to read improve intelligence? A longitudinal multivariate analysis of identical twins from age 7 to 16. *Child Development, 86,* 23-36.

Rueffer, K. A. (2000). *An examination of the factors underlying the development of skilled reading*. Unpublished master's thesis, University of Waterloo, Waterloo, Ontario, Canada.

Serrano, F., & Defior, S. (2008). Dyslexia speed problems in a transparent orthography. *Annals of Dyslexia*, *58*, 81-95.

Share, D. L., & Leikin, M. (2004). Language impairment at school entry and later reading disability: Connections at lexical versus supralexical levels of reading. *Scientific Studies of Reading, 8*, 87-110.

Share, D. L., McGee, R., & Silva, P. A. (1989). IQ and reading progress: A test of the capacity notion of IQ. *Journal of the American Academy of Child & Adolescent Psychiatry, 28,* 97-100.

Shaywitz, S. E. (1996). Dyslexia. *Scientific American, 275*, 98-104. doi: 10.1038/scientificamerican1196-98

Soriano, M., & Miranda, A. (2010). Developmental dyslexia in a transparent orthography: A study of Spanish dyslexic children. In T. E. Scruggs & M. A. Mastropieri (Eds.), *Literacy and Learning. Advances in Learning and Behavioral Disabilities* (vol. 23, pp. 95-114). Bingley, UK: Emerald Books.

Snowling, M. (2000). *Dyslexia*. Oxford: Blackwell.

Snowling, M. (2013). Early identification and interventions for dyslexia: A contemporary view. *Journal of Research in Special Educational Needs, 13*, 7–14. doi: 10.1111/j.1471-3802.2012.01262.x

Spanoudis, G. C., Papadopoulos, T. C., & Spyrou, S. (2019). Specific language impairment and reading disability: Categorical distinction or continuum? *Journal of Learning Disabilities, 52,* 3-14. doi:10.1177/0022219418775111

Stanovich, K. E. (1988). Explaining the differences between the dyslexic and the garden-variety poor reader: The phonological-core variable-difference model. *Journal of Learning Disabilities, 21*, 590-604.

Talli, J., Sprenger-Charolles, L., & Stavrakaki, S. (2016). Specific language impairment and developmental dyslexia: What are the boundaries? Data from Greek children. *Research in Developmental Disabilities, 49-50*, 339-353. doi: 10.1016/j.ridd.2015.12.014

Tang, S. (2016). *Examining the role of phonological memory in math and reading development*. Unpublished dissertation, University of Rhode Island, USA.

Tobia, V., & Marzocchi, G. M. (2014). Cognitive profiles of Italian children with developmental dyslexia. *Reading Research Quarterly, 49,* 437-452.

Torgesen, J. K., Wagner, R. K., & Rashotte, C. A. (1999). *Test of Word Reading Efficiency*. Austin, TX: PRO-ED.

van Bergen, E., van der Leij, A., & de Jong, P. F. (2014). The intergenerational multiple deficit model and the case of dyslexia. *Frontiers in Human Neuroscience, 8*, 346. doi: 10.3389/fnhum.2014.00346

Van den Broeck, W. & Geudens, A. (2012). Old and new ways to study characteristics of reading disability: The case of the nonword-reading deficit. *Cognition, 65*, 414-456. doi: 10.1016/j.cogpsych.2012.06.003

Vandewalle, E., Boets, B., Ghesquière, P., & Zink, I. (2010). Who is at risk for dyslexia? Phonological processing in five- to seven-year-old Dutch-speaking children with SLI. *Scientific Studies of Reading, 14*, 58-84.

Windfuhr, K. L., & Snowling, M. (2001). The relationship between paired associate learning and phonological skills in normally developing readers. *Journal of Experimental Child Psychology, 80*, 160–173.

Wolf, M., & Denckla, M. B. (2005). *Rapid automatized naming and rapid alternating stimulus tests (RAN/RAS)*. Austin, TX: PRO-ED.

Table 1.

Background and Reading Measures for Grade 4 and Grade 1 Participants

	Grade 4 DYS (n=22)		Grade 4 CA (n=28)		Grade 1 RL (n=24)		DYS vs CA			DYS vs RA		
	M	*SD*	*M*	*SD*	*M*	*SD*	*d*	*t*	*p*	*d*	*t*	*p*
Age	116.18	3.38	116.50	3.52	82.83	3.24	-.09	-.32	.747	10.08	34.33	**<.001**
Block Design raw score	27.82	8.87	29.89	7.67	18.75	8.47	-.25	-.89	.380	1.05	3.55	**.001**
Block Design scaled score	10.18	2.04	10.57	1.89	10.67	2.56	-.20	-.69	.488	-.21	-.70	.484
Vocabulary raw score	17.91	4.14	19.36	3.83	13.88	2.86	-.36	-1.28	.207	1.14	3.87	**<.001**
Vocabulary scaled score	8.00	1.90	8.39	1.58	8.50	1.72	-.22	-.80	.428	-.28	-.94	.354
WRE	38.23	7.30	55.50	5.95	35.83	7.48	-2.63	-9.22	**<.001**	.32	1.10	.279
PDE	24.45	4.10	34.32	4.82	25.75	4.43	-2.18	-7.66	**<.001**	-.35	-1.03	.310
TRF	24.10	5.51	14.70	2.45	39.38	16.77	2.30	6.44	**<.001**	-1.20	-3.95	**<.001**
WRMT/C	32.68	5.05	35.82	7.94	23.50	5.42	-.46	-1.62	.113	1.75	5.93	**<.001**

Note. DYS = Children with dyslexia; CA = Chronological-age controls; RL = Reading-level matched controls; WRE = Word Reading Efficiency; PDE = Phonemic Decoding Efficiency; TRF = Text-Reading Fluency; WRMT/C = Woodcock Reading Mastery Test – Comprehension. *t*-and *p*-values from independent samples *t*-tests. Bolded *p*-values were significant after Bonferroni correction. Scaled scores have an expected mean of 10 and SD of 3.

Table 2

Background and Reading Measures for Grade 6 and Grade 3 Participants

	Grade 6 DYS (n=22)		Grade 6 CA (n=26)		Grade 3 RL (n=24)		DYS vs CA			DYS vs RA		
	M	*SD*	*M*	*SD*	*M*	*SD*	*d*	*t*	*p*	*d*	*t*	*p*
Age	142.59	4.25	143.00	3.10	107.29	3.72	-.11	-.35	.729	8.86	30.02	**<.001**
Block Design raw score	37.68	5.43	40.58	6.87	24.08	8.82	-.47	-1.60	.117	1.84	6.23	**<.001**
Block Design scaled score	10.00	1.77	10.69	1.74	9.79	2.45	-.39	-1.36	.180	.10	.33	.745
Vocabulary raw score	24.50	5.33	27.31	4.24	17.17	3.28	-.59	-2.03	.048	1.67	5.67	**<.001**
Vocabulary scaled score	8.14	1.62	8.38	1.63	8.46	1.28	-.15	-.53	.599	-.22	-.75	.456
WRE	49.27	5.20	74.19	8.28	49.33	5.82	-3.57	-12.22	**<.001**	-.01	-.04	.971
PDE	29.91	4.33	47.12	5.64	32.42	3.87	-3.40	-11.68	**<.001**	-.61	-2.08	.044
TRF	16.02	2.86	11.42	3.25	19.17	3.18	1.50	5.16	**<.001**	-1.04	-3.52	**.001**
WRMT/C	37.59	5.27	40.62	6.89	23.11	7.69	.49	-1.62	.112	2.18	7.04	**<.001**

Note. DYS = Children with dyslexia; CA = Chronological-age controls; RL = Reading-level matched controls; WRE = Word Reading Efficiency; PDE = Phonemic Decoding Efficiency; TRF = Text-Reading Fluency; WRMT/C = Woodcock Reading Mastery Test – Comprehension. *t*-and *p*-values from independent samples *t*-tests. Bolded *p*-values were significant after Bonferroni correction. Scaled scores have an expected mean of 10 and SD of 3.

Table 3

Descriptive Statistics for Grade 4 and Grade 1 Participants

	Grade 4 DYS (n=22)		Grade 4 CA (n=28)		Grade 1 RL (n=24)		DYS vs CA			DYS vs RA		
Measures	*M*	*SD*	*M*	*SD*	*M*	*SD*	*d*	*t*	*p*	*d*	*t*	*p*
Phonological Awareness												
Elision AC	20.59	6.22	25.25	2.69	21.00	5.05	-1.02	-3.57	**.001**	-.07	-.25	.807
Elision RT	.30	.13	.27	.07	.27	.06	.30	1.17	.247	.30	1.07	.290
Initial Phoneme Matching RT	5.23	1.59	5.42	2.42	5.90	1.77	-.09	-.31	.756	-.40	-1.35	.184
Final Phoneme Matching RT	7.73	1.93	6.42	1.67	9.62	2.47	.73	2.56	.014	-.85	-2.87	**.006**
Rapid Naming												
RAN Colours	51.21	9.12	44.91	6.13	68.36	29.50	.83	2.91	.005	-.77	-2.61	**.012**
RAN Objects	55.76	10.32	47.58	8.29	67.68	16.03	.88	3.11	.003	-.88	-2.97	**.005**
RAN Digits	33.91	5.51	26.08	3.92	39.62	8.78	1.67	5.87	**<.001**	-.77	-2.61	**.012**
Phonological Memory												
Word Series	8.91	2.62	9.96	2.86	8.92	3.01	-.38	-1.34	.185	-.04	-.01	.993
Digit Span	6.86	1.32	7.29	1.41	6.92	1.14	-.31	-1.08	.285	-.05	-.15	.884
Orthographic Processing												
Orthographic Choice AC	17.45	3.96	21.39	4.16	17.83	2.88	-.97	-3.39	**.001**	-.11	-.37	.711
Orthographic Choice RT	5.01	1.31	3.03	.73	6.56	2.84	1.93	6.79	**<.001**	-.69	-2.34	**.024**

Note. DYS = Children with dyslexia; CA = Chronological-age controls; RL = Reading-level matched controls; AC = Accuracy; RT = Response time;. *t*-and *p*-values from independent samples *t*-tests. Bolded *p*-values were significant after Bonferroni correction. *t*-and *p*-values from independent samples *t*-tests. Bolded *p*-values were significant after Bonferroni correction.

Table 4

Descriptive Statistics for Grade 6 and Grade 3 Participants

	Grade 6 DYS (n=22)		Grade 6 CA (n=26)		Grade 3 RL (n=24)		DYS vs CA			DYS vs RA		
Measures	*M*	*SD*	*M*	*SD*	*M*	*SD*	*d*	*t*	*p*	*d*	*t*	*p*
Phonological Awareness												
Elision AC	23.45	4.37	*27.12*	1.73	21.13	5.26	-1.14	-3.23	**<.001**	.48	1.62	.111
Elision RT	.25	.03	.23	.02	.26	.03	.80	2.12	.039	-.33	-1.39	.171
Initial Phoneme Matching RT	4.27	1.53	3.50	.77	4.65	1.52	.65	2.24	.030	-.25	-.83	.412
Final Phoneme Matching RT	6.20	1.58	5.24	1.50	7.52	2.27	.62	2.17	.035	-.67	-2.26	.029
Rapid Naming												
RAN Colours	44.54	8.72	35.83	3.67	52.27	10.23	1.34	4.64	**<.001**	-.81	-2.74	**.009**
RAN Objects	48.88	8.16	38.86	4.65	54.81	10.99	1.54	5.33	**<.001**	-.61	-2.06	.045
RAN Digits	27.21	4.61	21.25	2.61	29.06	2.58	1.63	5.61	**<.001**	-.50	-1.71	.095
Phonological Memory												
Word Series	9.14	2.03	10.38	2.51	9.38	3.19	-.54	-1.87	.068	-.09	-.30	.766
Digit Span	7.23	.97	7.77	1.28	6.75	1.22	-.47	-1.63	.110	.43	1.46	.477
Orthographic Processing												
Orthographic Choice AC	20.95	5.14	26.77	3.99	19.71	3.78	-1.28	-4.41	**<.001**	.28	.94	.351
Orthographic Choice RT	4.29	2.22	2.50	.75	4.92	2.08	1.12	3.86	**<.001**	-.29	-.99	.326
Quick Spelling Real words	*9.41*	.85	*9.77*	.53	*9.46*	.83	-.52	-1.70	.097	-.06	-.20	.844
Quick Spelling pseudowords	8.18	2.11	*9.55*	.80	7.58	2.48	-.89	-2.84	.007	.26	.877	.385
Quick Spelling HF bigrams	3.82	2.79	5.09	2.11	2.21	1.84	-.52	-1.71	.095	.69	2.33	.024
Quick Spelling LF bigrams	1.95	2.08	3.45	2.30	1.42	1.61	-.68	-2.27	**.029**	.29	.984	.330

Note. DYS = Children with dyslexia; CA = Chronological-age controls; RL = Reading-level matched controls; AC = Accuracy; RT = Response time; HF = high-frequency; LF = low-frequency. Italics indicate substantial ceiling effect. *t*-and *p*-values from independent samples *t*-tests. Bolded *p*-values were significant after Bonferroni correction.