Tracking the effects of dyslexia in reading and spelling development: A longitudinal study of Greek readers

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Abstract

In this study we followed Greek children with and without dyslexia for eighteen months, assessing them twice on a battery of phonological, reading and spelling tasks, aiming to document the relative progress achieved and to uncover any specific effects of dyslexia in the development of reading and spelling beyond the longitudinal associations among variables that are observed in typical readers. A wide-ranging match was achieved between the dyslexic group and the younger reading-matched comparison group, enabling longitudinal comparisons on essentially identical initial performance profiles. Group differences were found in the development of tasks relying on phonological processing skill, such as phoneme deletion in pseudowords, pseudoword reading accuracy and time, as well as in graphemic spelling accuracy. The results confirm findings from cross-sectional studies of reading difficulty in the relatively transparent Greek orthography and are consistent with a phonological processing deficit underlying and reciprocally interacting with underdevelopment of reading and spelling skills in the impaired population.

Keywords: dyslexia; longitudinal; Greek; reading; spelling; phonological awareness

Tracking the effects of dyslexia in reading and spelling development: A longitudinal study of Greek readers

In this study we followed Greek children with and without dyslexia for eighteen months, assessing them twice on a battery of phonological, reading and spelling tasks, aiming to document the relative progress achieved and to uncover any specific effects of dyslexia in the development of reading and spelling beyond the longitudinal associations among variables observed in typical readers. Studies examining precursors of dyslexia have established concurrent and longitudinal predictors of reading and spelling difficulties across languages, notably including phonological awareness and rapid naming (e.g., Furnes & Samuelsson, 2009; Landerl et al., 2013). The same measures have consistently emerged as robust longitudinal predictors of literacy development, not limited to the identification of reading difficulties (e.g., Caravolas et al., 2012; Caravolas, Lervåg, Defior, Málková, & Hulme, 2013; Moll et al., 2014), consistent with the emerging consensus among reading researchers that the term dyslexia implies no qualitative distinction but simply refers to the low end of the reading ability spectrum (Elliot & Grigorenko, 2014).

Long-term longitudinal studies of children with dyslexia have established persistent slow rates of growth in reading skill and stable classification (from preschool risk through childhood dyslexia into adolescence and even adulthood) consistent with deficient phonological processing and rapid naming, across languages (e.g., Dandache, Wouters, & Ghesquière, 2014; Manis, Custodio, & Szeszulski, 1993; Meyer, Wood, Hart, & Felton, 1998; Peterson, Pennington, Olson, & Wadsworth, 2014; Shaywitz et al., 1999; Svensson & Jacobson, 2006; Tressoldi & Stella, 2001; Undheim, 2009; Wadsworth, DeFries, Olson, & Willcutt, 2007). However, it remains unclear whether the rate of progress in reading and related skills, which is already established to be slow for children with dyslexia, is different from what might be expected on the basis of earlier performance alone, that is, whether it is exceptionally slow even taking into account the earlier starting points. Moreover, it is unclear whether an impaired rate of progress is equally evident across the spectrum of reading and related skills, including precursor domains such as phonological awareness as well as arguably secondary domains such as spelling. These are the questions we aimed to address in the present study, which was conducted with native speakers of Greek, a relatively underexplored language which, nevertheless, is sufficiently well studied linguistically and orthographically so as to permit adequate matching and selection of stimuli.

Specifically, the Greek orthography is relatively transparent at the grapheme-phoneme level (estimated consistency 95% for reading and 80% for spelling; Protopapas & Vlahou, 2009). Alphabetic strategies for effective reading of words and pseudowords are observed as early as mid-first grade, with very high performance (98%) on simple single-syllable items (Seymour et al., 2003; cf. Porpodas, 1999). Greek is characterized by an extensive system of inflectional morphology affecting the suffixes of nouns, adjectives, and verbs, as well as systematic derivational processes, especially for nouns (based on verb stems) and adjectives (based on verb and noun stems), and highly productive compounding (Ralli, 2003, 2005). Morphology has extensive orthographic consequences insofar as derivational and grammatical suffixes are associated with specific spellings, which also serve to disambiguate homonyms. Knowledge of the inflectional type is often required for correct spelling of adjective, noun, and verb suffixes (Protopapas et al., 2013; see Papanastasiou, 2008, and Protopapas, in press, for examples and discussion).

Consistent with findings in other languages, studies of Greek children with dyslexia have documented deficits in phonological awareness, word and pseudoword reading accuracy and speed, spelling, rapid automatized naming, stress assignment, and verbal working memory, through primary and secondary education (Anastasiou & Protopapas, 2014; Constantinidou & Evripidou, 2012, Constantinidou & Stainthorp, 2009; Diamanti, Goulandris, Stuart, & Campbell, 2014; Hatzidaki, Gianneli, Petrakis, Makaronas, & Aslanides, 2011; Papadopoulos, Georgiou, & Kendeou, 2009; Protopapas, Fakou, Drakopoulou, Skaloumbakas, & Mouzaki, 2013; Protopapas & Skaloumbakas, 2007, 2008; Protopapas, Skaloumbakas, & Bali, 2008). As expected for a relatively consistent orthography, children with dyslexia are primarily distinguished from typically developing readers in timed measures of reading (i.e., speed or fluency; Protopapas & Skaloumbakas, 2008) and exhibit impaired spelling performance commensurate with their level of reading and phonological development (Diamanti et al, 2014; Protopapas et al., 2013). However, little is known about the relative rate of development of reading and spelling skills in Greek children with dyslexia.

Moreover, the great variety of Greek inflectional and—especially—derivational suffixes, and their orthographic diversity, cause additional difficulty in the spelling of children with dyslexia (Diamanti et al., 2014). Thus it is also of special interest to track the development of morphological orthographic processing and determine whether the increased difficulty resulting from the challenging orthographic demands of Greek inflectional and derivational word formation follows an otherwise typical (if delayed) progression. To address this question we have administered a number of orthographic tasks targeting specific morphemes (prefixes, stems, and suffixes).

The selection of participants for the study of dyslexia is a nontrivial issue. Participants in the group with dyslexia must meet stringent criteria to produce a well-characterized profile, as homogeneous as possible, while at the same time ensuring adequate opportunity for the participation of any children with word-level reading difficulties across the spectrum. The demands on the control conditions further complicate matters, due to the requirements for realistic yet theoretically informative matches among groups, especially for the younger group controlling for overall reading performance, in so-called “reading match” designs. However, matching on a single raw measure, such as word reading accuracy, can only expose relative differences in performance between the matching task and other tasks due to differences in their variance and relative rates of development (van den Broeck & Geudens, 2012). Similarly, matching on standardized measures of performance or on grade levels fails to account for potentially unequal variances and rates of development across measures. In the present study we have tried to minimize these problems by matching groups on multiple relevant measures to the extent possible.

In sum, in this study we followed a group of children with dyslexia and two control groups of typical readers—one matched in age and one matched in reading skill—for eighteen months, administering a battery of phonological, reading, and spelling assessment tasks, including measures of orthographic processing targeting specific morphemes. The age range of our participants was as young as possible within the usual range seen in dyslexia research, subject to recruitment limitations and, most importantly, the possibility to define a younger school-age reading level-control group with meaningful reading experience, which effectively restricted the lower end of the range to no less than 9 years of age. The study interval was the longest that could be practically implemented within the pragmatic constraints of the study, and we believe it is a strong point of the study that we have followed the children well beyond the more usual six- or twelve-month periods, thereby giving more time for meaningful differences to develop and become detectable even in a small sample.

The specific goals of the study were to compare the longitudinal trajectories of reading and spelling performance between children with dyslexia and typical readers and to determine whether the performance observed at the time of first assessment suffices to account for performance observed at the time of second assessment or, instead, the classification of participants as typical or dyslexic readers can significantly improve the longitudinal prediction of follow-up assessment. Moreover, we also examined the extent to which the well-known longitudinal predictors of reading skill, namely rapid naming and phonological awareness, account for performance improvements over the study period in the group with dyslexia to the same extent as in the control groups. Finally, with respect to spelling performance, we examined the extent to which improvement in spelling accuracy can be accounted for by earlier reading and phonological awareness, in comparison to earlier spelling skill.

Method

Participants

There were three groups of participants, including 24 children (16 boys) with dyslexia 9–12 years old (DYS), a chronological age (CA) control group of 22 same-age typically developing children (9 boys), and a reading age (RA) control group of 28 younger children (14 boys) matched for reading level to the children with dyslexia.[1] All had verbal and non-verbal IQ within the normal range (above 85; based on the subtests of Block Design and Similarities of the Wechsler Intelligence Scale-III for children; Georgas, Paraskevopoulos, Besevegis, & Giannitsas, 1997). Children with dyslexia had reading ability scores at least 1.5 SD below the normative mean on a sight word efficiency test (see Materials). Children with a history of sensory deficits, behavioral or

[1] These are the subset of children for which follow-up measurement proved feasible, out of an original sample of 25 children with dyslexia and 29 age-matched and 28 reading-matched typical readers assessed at Time 1. In the full set there was no significant difference in IQ between groups. Time 1 data are also presented in a cross-linguistic study reported elsewhere. Time 2 data have not been reported previously.

emotional difficulties, or irregular school attendance were excluded from the sample. Participants were recruited from three state primary schools in central Thessaloniki. All participants with dyslexia were identified by their teacher as having reading and spelling difficulties (but only one of them had received an official diagnosis). Table 1 shows descriptive statistics for group profile measures and associated comparisons between the group with dyslexia and each control group.

Materials

Sight word efficiency test. This test measured the child's ability to read words accurately and fluently. It consisted of a practice form with eight items and a test form containing a list of 104 words of increasing number of syllables, displayed vertically on an A4 page, modeled after the TOWRE (Torgesen, Wagner & Rashotte, 1999). The selection of words was based on criteria involving number of syllables, syllabic structure, phonemic and orthographic complexity, and frequency of occurrence in primary school textbooks. Very high frequency words occurred early in the list, followed by progressively less frequent words. Children were asked to read the words as fast as they could without making errors. The score was the number of words read correctly within 45 seconds. Normative data for this test were previously collected from 151 children from the general population attending Grades 2–6 in Thessaloniki.

Phoneme deletion, words. Children were asked to remove a phoneme from a set of 14 words. Target phonemes occurred in a variety of positions and syllabic structures. Five practice items preceded testing. The number of correct answers was noted (the maximum possible score was 14). Internal reliability (Cronbach's α) was .61.

Phoneme deletion, pseudowords. This test was identical to the preceding one except that items were formed from the words of the word test by replacing consonants and vowels while retaining the syllabic structure and target phoneme to the extent possible (max=14; α = .68).

Spoonerisms. Children had to transpose the initial sounds of twelve pairs of spoken words, following three practice trials. The number of correctly transposed items was noted (max=12; α = .91).

Digit Span. Children's memory span was tested with the Digit Span subtest of the WISC-III (forward and backward). Per standard administration, testing was discontinued when both sequences of a given length were missed.

Rapid Naming of Digits. Based on the Digit Naming subtest of the Comprehensive Test of Phonological Processing (Wagner, Torgesen & Rashotte, 1999). A practice form displayed six digits in a row; the two test forms included six digits (2, 3, 5, 6, 7, 8) displayed six times each in four rows (36 digits total), for the children to name as fast as possible. The score was the overall naming time of both forms.

Single Word Reading. A practice form of five regular words preceded a test form of 25 regular words 1–6 syllables long, nouns or adjectives (except one article), with gradually increasing number of syllables and phonological complexity and decreasing frequency of occurrence, printed vertically on an A4 page. Children were asked to read the words accurately as quickly as possible. Their reading time and number of words read correctly were noted (accuracy: max=25; α = .54).

Single Nonword Reading. Same as the word reading task, with pseudowords derived from those words by transposing or replacing letters, retaining graphophonemic structure and length (accuracy: max=25; α = .68).

Passage spelling. A 32-word passage was dictated at a pace determined by the child's writing, and the number of spelling errors was noted. This test was only administered at Time 1.

Graded spelling test. A set of 47 words of graded orthographic difficulty and decreasing frequency of occurrence was selected from school textbooks of progressively higher grades (items 1–20) and the Hellenic National Corpus (Hatzigeorgiou et al., 2000; items 21–47). Each word was spoken by the experimenter, first in isolation, then in a sentence, and again in isolation. Two scores were calculated for each word: The phonemic score was equal to the number of correct phonemes (e.g., for the word στοιχεία 'elements' /stiçia/ the maximum score, when correct, would be 6; if spelled στιχεία, which is an orthographic error οι→ι not affecting pronunciation, the score would still be 6, but if spelled στοχεία /stoçia/ the score would be 5). The graphemic score was equal to the number of correct graphemes (i.e., one point for each of the 6 graphemes in the same example: σ-τ-οι-χ-εί-α; if spelled either στιχεία or στοχεία the score would be 5 since one grapheme is incorrect in either case). In other words, the total number of graphemes in each word was reduced by the number of phonological and orthographic spelling errors, respectively (see Protopapas et al., 2013, for definitions of error types and examples). This test was only administered at Time 2.

Spelling of Suffixes. Children were required to spell the suffixes of pseudowords. Two practice sentences were presented on the classroom blackboard, followed by 18 test sentence pairs including one leading sentence and one containing the pseudoword with the incomplete suffix. Pseudowords were derived from real words by changing some of the letters of the stem. Target suffixes encoded noun number and possessive (genitive case), and verb person, tense, number, and voice.

Test sentences were printed in 14-pt Times New Roman font on three A4 pages, and were group-administered to whole classes. Children were instructed to fill in the spaces with the correct spelling. The number of correct spellings was noted (max=18; α = .85).

Stem Orthographic Choice. Children were asked to select the correct spelling out of four homophonous choices. The task was group administered. Two practice trials were presented on the blackboard, followed by twenty groups of one target word with three pseudohomophones printed in 14-pt Times New Roman font in twenty rows on an A4 page. Children were instructed to tick the correct word. The number of correct choices was noted (max=20; α = .75).

Word Prefix Orthographic Choice. This task was the same as Stem Orthographic Choice except that there were fifteen test trials (i.e., groups of one target word with three pseudohomophones) and the part of the words that was spelled differently was the prefix. Two monosyllabic and two bisyllabic prefixes were used (max=15; α = .82).

Pseudoword Prefix Orthographic Choice. This task was the same as Word Prefix Orthographic Choice except that the stimuli were pseudowords and there were twelve test trials. The same prefixes were used. The pseudowords were derived from real words by substituting letters in the stem (max=12; α= .72).

Procedure

At Time 1, children were assessed individually in a quiet room of their school in two 30–40 minute sessions, including selection and profile measures in the first session, and phonological and reading measures in the second one. The spelling and orthographic choice measures were group-administered to the entire class in a third session. At Time 2, approximately 18 months later, children were tested individually in one session, including phonological and reading measures, and in groups in a second session. Tests were administered orally by the experimenter. Task order was counterbalanced within sessions at both testing times.

Results

Of the 74 children, five missed Time 1 spelling and seven missed Time 2 spelling. Missing data were not replaced as spelling was analyzed separately. For all measures, accuracy was transformed to proportion by dividing by the number of items. Times (from digit naming and word and pseudoword reading) were logarithmically transformed to better approximate a normal distribution. All analyses were carried out in R version 3.3.1 (R Core Team, 2016). Figure 1 shows the means and distributions of performance for each group at each time point, and Table 2 presents the between-group comparisons at each time point. As expected, children with dyslexia (DYS) differed significantly from same-age typical readers (CA) on all experimental measures. There were no significant differences between DYS and reading-matched typical readers (RA) at Time 1; however, some differences were apparent at Time 2 (not surviving correction for multiple comparisons), perhaps suggesting slightly deviating developmental courses for measures involving pseudowords.

Within-Task Longitudinal Development

In the longitudinal analysis of the data we wished to examine whether the observed improvements in the performance of children with dyslexia on phonological, reading, and spelling measures were consistent with their performance at Time 1 as for the typical readers, or whether the diagnosis of dyslexia is associated with deviant patterns of development. Figure 2 displays the scatterplots of the data on the experimental measures. Each panel plots Time 2 vs. Time 1 performance for one measure, while the three groups are easily distinguishable by marker shape and color. It appears that the children with dyslexia lie on the same region of the two-dimensional space and, as expected, generally overlap with the RA group. Although the sample is too small to permit direct comparisons of longitudinal predictors between groups, we can address this question in other ways. For example, if the DYS group stood out by deviant patterns of development, then we would expect the correlation between measures from Time 1 and Time 2 to be higher when children with dyslexia are excluded, because their inclusion would increase the scatter. Table 3 lists the partial longitudinal correlation coefficients for each measure, for all participants (left) and for typical readers only (i.e., CA and RA groups; right), controlling for age at Time 1 to avoid inflation due to trivial age-related variance. Nonparametric coefficients were computed, using R package ppcor v.1.1 (Kim, 2015), to reduce distortions by nonlinear relations and ceiling effects, to the extent possible. It is clear that inclusion of the DYS group results in numerically increased, rather than decreased, coefficients, consistent with the developmental progression of this group being in line with the others.

To further address this question, we conducted linear regression analyses for each experimental measure, with Time 2 performance being the dependent variable and group and Time 1 performance being the independent variables, in addition to control predictor Time 1 variables (age and IQ). If group membership (i.e., DYS vs. CA/RA) affects the relationship between Time 1 and Time 2 measures, then a significant interaction of group by Time 1 performance should emerge. Table 4 displays the comparison of models differing in the inclusion of group effects. (The full models can be found in the Online Supplementary Materials.) There were significant differences for Spoonerisms and Pseudoword reading accuracy, due to significant interactions between group difference (RA vs. DYS) and Time 1 performance, consistent with a higher overall performance of RA at Time 2 and a shallower slope (i.e., weaker effect of Time 1 performance) for RA than for DYS. The marginally significant trends for word and pseudoword reading time were also consistent with the same pattern. Thus it seems that, for some measures, the RA group may have made more progress between Time 1 and Time 2 than the DYS group, which is not as strongly related to Time 1 performance as it was for DYS. This pattern withstood inclusion of age and IQ as control predictors.

It should be noted that, on the one hand, none of these differences survived control for multiple comparisons, so the evidence for group differences is very weak. On the other hand, only one in twenty comparisons is statistically expected to come out significant by chance alone, so the presence of two values $< .05$ and four more $< .10$ in a total of 12 comparisons, after controlling for age and IQ, suggests that real group differences are likely present and multiple-comparison control leads to an overly conservative conclusion due to low power.

Longitudinal Prediction by Rapid Naming and Phonological Awareness

We subsequently examined the longitudinal relationships between rapid naming and phonological awareness at Time 1 as predictors of reading accuracy and time at Time 2. To address this question we created composite scores for reading (separately for accuracy and time), by averaging performance on word and pseudoword reading, and for phonological awareness, by averaging performance on the three tasks (word and pseudoword phoneme deletion, and spoonerisms). The three composite scores and rapid naming time were then normalized to $M = 0$ and $SD = 1$. The longitudinal relationships are plotted in Figure 3, using the same visual distinction between groups as in Figure 2. It is evident that the DYS group largely overlaps with the control groups, especially with RA. It is also evident that longitudinal prediction of reading accuracy is less successful than prediction of reading time, most likely due to the ceiling effect observed for the typical readers, especially the CA group.

Applying the same analytical approaches as for the within-measure longitudinal relations, we first calculated partial nonparametric correlation coefficients including all participants and excluding participants with dyslexia. These are displayed in Table 5. Inclusion of participants from the DYS group did not diminish the estimated coefficients. It may seem surprising, especially for a relatively transparent orthography and the nonbeginner status of our participants, that reading time seems to be more strongly predictable on the basis of phonological awareness than of rapid naming.

Table 6 lists the comparison of models with and without effects of group. Although some significant differences are observed (surviving control for multiple comparisons), none of them are due to interactions; instead, they arise from overall higher performance of typical readers (as can be seen in the full models, which are listed in the Supplementary Materials). Significant differences involving the RA group included shorter Time 2 reading times than the DYS group, relative to Time 1 phonological awareness (see Figure 3, top right panel). The difference in reading times relative to earlier RAN did not quite reach significance and the difference in reading accuracy relative to earlier phonological awareness did not survive control for age and IQ (see Supplementary Materials, Part B). Given the small sample size, it seems that there is overall a slight underdevelopment in the reading performance of the DYS group at Time 2, compared to the RA group, given their levels of phonological awareness and rapid naming performance at Time 1.

Longitudinal Prediction of Spelling Performance

Finally, we turn to the examination of performance in spelling to dictation. We applied the same analytic procedure to examine the longitudinal prediction of spelling at Time 2 by Time 1 spelling, reading time, and phonological awareness. Time 2 (dependent) variables included the phonemic and graphemic accuracy scores derived from the graded spelling test, which was only administered at Time 2. Time 1 predictors included the passage spelling test, and the reading time and phonological awareness composites formed previously. Reading accuracy was not used as a predictor due to the observed ceiling effects. Figure 4 displays these longitudinal relations following the same visual conventions. It is evident that there is little variability in the phonemic accuracy score, due to performance close to ceiling, for the DYS and RA groups, and essentially error-free performance by the CA group. In contrast, there is ample variability in the graphemic accuracy score.

The partial nonparametric correlation coefficients between these pairs of variables, including all participants and excluding participants with dyslexia, are displayed in Table 7. Once more, inclusion of participants from the DYS group did not diminish the estimated coefficients. Notably, reading time and phonological awareness were only slightly behind Time 1 spelling in the longitudinal prediction of Time 2 graphemic spelling accuracy. Finally, Table 8 lists the comparison of models with and without effects of group. The multivariate outlier obvious in the bottom row panels of Figure 4 (one child in the RA group with robust Mahalanobis distance 6.17, $p < .00001$, calculated using package mvoutlier; Filzmoser & Gschwandtner, 2017) was excluded from these analyses (although including it did not change the findings). The only significant difference that survived control for IQ (but not correction for multiple comparisons) concerns the prediction of Time 2 graphemic spelling accuracy from Time 1 passage spelling, in which RA achieved higher performance than DYS—an overall group performance difference rather than an interaction. The other differences approaching significance also concerned graphemic and not phonemic accuracy.

Discussion

The data from Time 1 testing confirmed the previously documented profile of Greek children with dyslexia, showing deficits in all phonological, rapid naming, reading, and spelling tasks in comparison to an age-matched control group.

Nevertheless, as expected for a relatively transparent orthography, children with dyslexia were quite accurate readers, especially for words, and also achieved high performance in the phonological awareness tasks, in agreement with previous findings in Greek (Anastasiou & Protopapas, 2015; Nikolopoulos, Goulandris, & Snowling, 2003; Protopapas & Skaloumbakas, 2007; Protopapas, Skaloumbakas, & Bali, 2008) and German (e.g., Wimmer, 1993; Wimmer & Landerl, 2000; Ziegler, Perry, Ma-Wyatt, Ladner, & Schulte-Körne, 2003). However, they were substantially slower than age-matched peers in reading words and pseudowords, again in agreement with previous findings in Greek and with the expectation for a relatively consistent orthography that reading difficulties are most clearly evident in speed measures (e.g., Porpodas, 1999; Protopapas & Skaloumbakas 2008; Serrano, & Defior, 2008; Wimmer, 1993; Zoccolotti et al., 1999). Importantly, the younger group was indistinguishable from the group with dyslexia in all of these measures, establishing a wide-ranging match in reading and related skills and thereby permitting comparisons of rates of progress over the 18-month study period.

A significant difference of the DYS group from the CA group in the context of no difference from the RA group was also observed in the morphologically targeted orthographic tasks, including a suffix spelling task and three orthographic choice tasks targeting prefixes (in words and pseudowords) and word stems. This pattern held in both assessments and attests to a level of orthographic knowledge in the DYS group that is commensurate with overall reading skill and develops at typical rates, remaining in sync with reading and phonological development at least throughout the age range and duration of the study. This finding is in agreement with studies in English showing that orthographic skills of children and adults with dyslexia do not differ from those of younger typical readers (e.g., Nelson, 1980; Olson, 1985; Pennington et al., 1986).

However, the interpretation of this finding is complicated by the unavoidable confound with age, which is always an issue with reading-match designs: It cannot be precluded that younger readers have not yet amassed adequate reading and spelling experience to fully develop their orthographic skills, whereas older (however reading-impaired) readers may have been sufficiently exposed to a variety of orthographic patterns that can support adequate performance in orthographic tasks (cf. Miller-Shaul, 2005; Siegel, Share, & Geva, 1995).

Notably, the difference between DYS and RA groups in a few Time 2 measures approached or even exceeding statistical significance thresholds (before multiple-comparison correction), consistent with a particularly protracted rate of development concerning pseudoword processing. Regression of Time 2 measures onto their Time 1 counterparts, while controlling for age and IQ, also revealed a relative delay in pseudoword processing, manifesting itself as an interaction between group and Time 1 measure in the prediction of Time 2 measure. This suggests that children with dyslexia made somewhat less progress, over the 18-month period, in phoneme deletion in pseudowords and in pseudoword reading accuracy and time, compared to younger children with initially indistinguishable levels of performance. At the same time, there was no evidence for relative delay in other phonological awareness tasks, which involved words, in word reading, or in any of the orthographic choice or spelling tasks. Moreover, there was no significant difference involving pseudowords between the DYS and RA groups at Time 1. Thus, even though our findings are consistent with those in other languages—with transparent or opaque orthographies—in supporting a more pronounced difficulty with tasks involving pseudowords, interpretable as indicative of core phonological processing deficits (e.g., Jiménez Gonzalez, 1997; Jiménez Gonzalez & Valle, 2000; Rack, Snowling, & Olson, 1992; van IJzendoorn & Bus, 1994; Ziegler et al., 2003; but see Van den Broeck & Geudens, 2012, regarding the interpretation of such findings), they also suggest a more nuanced picture rather than a pervasive deficit involving pseudoword processing across the board.

Specifically, taking into account that at Time 1 the DYS group, which was procedurally matched to the RA group in word reading efficiency, ended up indistinguishable from RA in all phonological awareness and pseudoword reading tasks as well, the overall pattern of results seems difficult to interpret as evidence for a deficit that is specifically and persistently affecting either phonological processing or pseudowords. Rather, and in agreement with long-established results (e.g., Snowling, 1981; Snowling, Goulandris, & Defty , 1996), our findings indicate that the decoding skills of children with dyslexia do not develop quite as quickly as expected from their initial reading efficiency. However, rather than positing a specific deficit in phonological processing of pseudowords that unidirectionally holds back efficient literacy acquisition throughout the duration of the study period, one might suggest that progress in certain tasks involving pseudowords may depend reciprocally upon progress in phonological processing skills contingent on reading experience (cf. Castles & Coltheart, 2004), which accumulates more slowly for children with dyslexia compared to younger typical readers, perhaps due in part to the effort involved and associated motivational factors.

Why this difference shows up in pseudowords rather than in words (at least within the 18-month study period), and why it was not evident already at Time 1 but emerged in the longitudinal rate of development, may be the result of a design artifact: Specifically, younger reading-matched children may not have yet matured sufficiently in their phonological processing skills, thus matching the performance of the children with dyslexia primarily for age-related reasons (cf. Van den Broeck & Geudens, 2012). This interpretation is corroborated by the analysis of the differential longitudinal predictors of reading, in which we found somewhat lower Time 2 reading performance for DYS than for RA children, relative to their Time 1 phonological awareness and rapid naming, in effect amounting to a slower rate of reading development despite initial attainment of adequate phonological awareness skill. Additionally, it may also have to do with compensatory lexical strategies discovered and developed by the children with dyslexia, which can support adequate visual and phonological word processing but fail in the case of pseudoword processing. This speculative hypothesis may be related to earlier suggestions of compensatory orthographic processing skills and associated strategies in children with dyslexia (e.g., Martin, Pratt, & Fraser, 2000; Siegel, Share, & Geva, 1995).

Our study upholds the crucial role of phonological awareness for reading development even though it is carried out in a relatively transparent orthography and concerns readers past the very beginner stage. This finding is in agreement with previous studies in Greek, in which phonological awareness has consistently emerged as an important predictor of reading difficulty, from middle elementary through late secondary grades (Anastasiou & Protopapas, 2015; Protopapas & Skaloumbakas, 2007; Protopapas et al., 2008). In fact in the present study the phonological awareness composite was a (numerically) stronger longitudinal predictor of reading accuracy and time, compared to RAN (Table 5). This may seem surprising at first glance, but it should be considered in the context of the full bivariate distributions as shown in Figure 3. Note that there does not seem to be any relationship between phonological awareness and reading accuracy or speed for the CA group (right panels), as this group performs at ceiling in both phonological awareness and reading accuracy. Rather, the longitudinal relationship between phonological awareness and reading time (top right) is driven by the DYS and RA groups, both of which are arguably near-beginners in terms of actual performance. Evidently, it is highly diagnostic for future reading skill (after 18 months) that a child has yet to reach ceiling performance in phonological awareness, as shown in the top right panel. This seems to be an issue of general development, rather than qualitative impairment, because the bivariate distributions for DYS and RA are fully overlapping. In contrast, for the CA group, future reading time is clearly more closely related to Time 1 RAN, due to higher variance, as seen in the top left panel of Figure 3.

Interestingly, the observed differences at Time 2 between the DYS and RA groups in phonological and reading tasks involving pseudowords were accompanied by a difference in graphemic spelling accuracy. In parallel to the pseudoword tasks, no difference between DYS and RA was observed in the Time 1 passage spelling task; that is, spelling differences emerged only at Time 2. This finding highlights the need for a nuanced interpretation of the entire pattern of differences, because the spelling tasks did not involve any pseudowords. Therefore, succumbing to the temptation to interpret the reading and awareness differences as resulting from some core deficit involving pseudoword processing would leave us at a loss regarding the spelling difference, calling for a (nonparsimonious) separate explanation. Rather, the emerging difference in graphemic spelling at the time of the second assessment is consistent with an underlying phonological explanation for the observed differences.

Specifically, it has long been known that adequate phonological processing is critical for the development of spelling skills, as phonological awareness performance is a strong concurrent and longitudinal predictor of spelling across orthographies (e.g., Caravolas, Hulme, & Snowling, 2001; Furnes & Samuelsson, 2010). The association between phonology and spelling transcends phonographemic transcription, because it is not only related to phonologically accurate spelling but also to orthographically accurate spelling, which might seem superficially to be unrelated to phonology. However, Protopapas et al. (2013) hypothesized that spelling-match designs have proved useful in spelling development research, compared to reading-match designs, because of the involvement of phonological processing, beyond reading skill. This hypothesis was supported in their analysis of spelling performance by Greek children with and without dyslexia, in that matching a younger group in both reading and phonological awareness to the group with dyslexia resulted in indistinguishable spelling performance, evidently equivalent to a spelling match. Thus, overall spelling performance, including not only phonological but also orthographic accuracy, must be seen as closely dependent on the development of reading and phonological skill, to sustain the increased demands of producing accurate spellings based on dictated phonological representations. This interpretation is also consistent with the finding that Time 2 graphemic accuracy of DYS children was not as high as expected on the basis of their Time 1 passage spelling performance, compared to the RA group, hypothesizing that slow phonological development also results in delayed spelling improvement despite early skill attainment.

The close connection between phonological awareness and spelling cannot be one of direct application, because graphemic accuracy depends mainly on orthographic representations rather than phonographemic conversions. Moreover, the connection cannot be a proxy of orthographic skill, because it does not appear (or at least is not as strongly expressed) in orthographic choice tasks, which tap orthographic representations without the heavy demands of production. This was true in our data as well, at both time points, and suggests that children with dyslexia could bring adequate orthographic representations to bear on the task, leading to performance that was not different from that of the younger RA group, at either time point. Recall, also, that word reading (accuracy and time) as well as phonological awareness tasks involving words (phoneme deletion and spoonerisms) did not differ between the DYS and RA groups at either time point, further arguing for sufficient lexical resources to support adequate performance. Rather, it seems that the link between phonological processing and spelling must be of an indirect nature, perhaps through notions of lexical quality.

Lexical quality refers to the stability, precision, coherence, and redundancy among the representations of the phonological and orthographic forms of words and their meanings and their interconnections (Perfetti, 2007; Perfetti & Hart, 2001, 2002). High quality representations support efficient word reading, spelling, and text understanding. Phonological decoding plays a very important role in establishing high-quality word representations (Perfetti, 2007). Therefore, reduced efficiency of phonological processing or diminished rate of phonological development can be expected to hamper the formation of high-quality lexical representations. This would have adverse consequences for reading efficiency and orthographic choice accuracy, as well as text understanding. However, the domain in which poor lexical quality is expected to be most detrimental is spelling, because spelling to dictation poses increased demands on the lexical representations: When a word is given orally and must be spelled, the phonology-to-orthography connections (directly, as well as indirectly via semantics) must be sufficiently strong and stable so as to produce the appropriate output. In comparison, reading and orthographic choice are supported by the input orthographic representation and pose relatively limited demands, permitting accurate (if inefficient) recognition. The lack of external support for spelling is the reason spelling is sometimes considered to be useful index of lexical quality and thus spelling performance is used as a proxy for the assessment of lexical quality (e.g., Hersch & Andrews, 2012; Martin-Chang, Ouellette, & Madden, 2014).

Finally, with respect to spelling, we note the preponderance of graphemic, compared to phonemic errors in spelling to dictation by children with dyslexia in Time

2. This is consistent with the analysis of Protopapas et al. (2013) who made a distinction between two types of analyses: On the one hand, comparisons between groups with and without dyslexia show differences in phonological spelling performance, indicating the existence of some deficits. On the other hand, comparisons among error types show relatively little difficulty with phonological spelling, even by children with dyslexia, and provide no support for a specifically phonological deficit in spelling performance. That is, phonological spelling errors do appear in dyslexia (pace Nikolopoulos et al., 2003) but are minor compared to orthographic and grammatical spelling errors (see also Diamanti et al., 2014).

In conclusion, in this study we have followed Greek children with dyslexia and two comparison groups, one matched in age and one matched in reading performance, over an 18-month period. We have documented the longitudinal progression of phonological, reading, and spelling skills, and we have identified group differences in tasks relying on the development of phonological processing skill, such as phoneme deletion in pseudowords, pseudoword reading accuracy and time, as well as in graphemic spelling accuracy. Although the study is limited by a small sample size, which precludes more sophisticated analyses and also limits statistical power, potentially obscuring differences between and within groups, it is nevertheless advantaged by a wide-ranging match achieved between the DYS and RA groups, which enabled Time 2 comparisons on essentially identical Time 1 performance profiles of these two groups. Because of the common starting point and longitudinal design, our study effectively overcomes major limitations arising from regression-based reading-match designs involving a single assessment time point (Van den Broeck & Geudens, 2012) and from comparison of ordinal-scaled psychoeducational metrics across performance ranges (Protopapas, Parrila, & Simos, 2016). Our results confirm findings from cross-sectional studies of reading difficulty in the relatively transparent Greek orthography and are consistent with a phonological processing deficit underlying and reciprocally interacting with underdevelopment of reading and spelling skills in the impaired population.

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Table 1

Demographic and profile information for each group, and comparisons between groups

	CA		DYS		RA		CA vs. DYS		RA vs. DYS	
	M	*SD*	*M*	*SD*	*M*	*SD*	*t*	*p*	*t*	*p*
Grade	4.5	1.2	4.8	1.1	2.1	0.4	−1.03	.305	−9.96	< .001*
Age (years)	10.1	1.2	10.3	1.1	7.6	0.5	−0.83	.407	−10.29	< .001*
Reading efficiency	73.3	7.2	55.4	8.3	55.6	7.4	7.93	< .001*	0.09	.929
Estimated IQ	115.0	16.6	104.5	16.5	111.9	17.3	2.12	.038	1.58	.119
Digit span	14.6	1.6	11.9	2.2	10.5	1.6	5.02	< .001*	−2.74	.008*

* significant after Holm correction for 5 comparisons (adjusted $p < .05$)

Note. DYS=group with dyslexia ($N = 24$); CA=chronological age match control group ($N = 22$); RA=reading match control group ($N = 28$).

Table 2

Mean performance per group on the experimental measures, and comparisons between groups, for each time of testing

	CA		DYS		RA		CA vs. DYS		RA vs. DYS	
	M	*SD*	*M*	*SD*	*M*	*SD*	*t*	*p*	*t*	*p*
Time 1										
Phoneme deletion, words	.98	.03	.85	.13	.86	.10	4.67	< .001*	0.33	.745
Phoneme deletion, pseudowords	.97	.06	.83	.14	.83	.13	4.07	< .001*	−0.21	.835
Spoonerisms	.95	.05	.57	.24	.56	.22	6.64	< .001*	−0.09	.928
Rapid naming of digits (log time)	3.37	.15	3.58	.18	3.62	.15	−4.37	< .001*	0.89	.377
Word reading accuracy	.97	.03	.91	.07	.93	.06	3.86	< .001*	1.24	.220
Pseudoword reading accuracy	.92	.06	.78	.11	.81	.11	4.77	< .001*	0.86	.393
Word reading (log) time	2.93	.25	3.44	.37	3.47	.25	−5.79	< .001*	0.37	.714
Pseudoword reading (log) time	3.60	.31	4.05	.24	3.99	.21	−6.01	< .001*	−0.85	.396
Word prefix orthographic choice	.88	.12	.63	.21	.52	.23	4.31	< .001*	−1.96	.054
Pseudoword prefix orthographic choice	.84	.15	.54	.18	.48	.20	5.76	< .001*	−1.20	.234
Stem orthographic choice	.79	.11	.60	.16	.59	.12	5.03	< .001*	−0.08	.936
Spelling of suffixes	.86	.08	.63	.18	.63	.15	5.26	< .001*	0.06	.955
Time 2										
Phoneme deletion, words	.95	.07	.87	.11	.91	.08	2.97	.004*	1.39	.168
Phoneme deletion, pseudowords	.95	.05	.82	.15	.89	.10	4.01	< .001*	2.26	.027

Spoonerisms	.92	.06	.68	.24	.75	.15	4.85	< .001*	1.55	.126
Rapid naming of digits (log time)	3.19	.15	3.38	.17	3.36	.18	−3.96	< .001*	−0.40	.691
Word reading accuracy	.99	.02	.97	.04	.97	.04	2.54	.013*	0.97	.337
Pseudoword reading accuracy	.96	.05	.82	.12	.89	.10	5.00	< .001*	2.56	.013
Word reading (log) time	2.71	.23	3.12	.26	3.11	.20	−5.98	< .001*	−0.21	.838
Pseudoword reading (log) time	3.45	.27	3.82	.25	3.68	.18	−5.51	< .001*	−2.32	.023
Word prefix orthographic choice	.92	.11	.70	.26	.75	.19	3.80	< .001*	0.95	.347
Pseudoword prefix orthographic choice	.82	.17	.66	.24	.67	.23	2.52	.014*	0.16	.871
Stem orthographic choice	.86	.11	.67	.18	.72	.12	4.49	< .001*	1.17	.248
Spelling of suffixes	.87	.10	.69	.15	.74	.18	3.92	< .001*	0.98	.330
Phonemic spelling accuracy	419.32	1.09	413.50	6.01	415.89	5.74	3.98	< .001*	1.72	.090
Graphemic spelling accuracy	407.64	11.26	378.79	20.32	390.48	16.24	5.93	< .001*	2.53	.014

* significant after Holm correction for 12 comparisons (adjusted $p < .05$)

Note. DYS=group with dyslexia (N = 24); CA=chronological age match control group (N = 22); RA=reading match control group (N = 28).

Table 3

Partial non-parametric (Spearman's) longitudinal correlations for the experimental measures, controlling for age at Time 1

	All participants		Typical readers	
	PPC	*p*	PPC	*p*
Phoneme deletion, words	.553	< .001	.326	.022
Phoneme deletion, pseudowords	.567	< .001	.503	< .001
Spoonerisms	.658	< .001	.460	.001
Rapid naming of digits (log time)	.792	< .001	.673	< .001
Word reading accuracy	.443	< .001	.356	.012
Pseudoword reading accuracy	.512	< .001	.313	.029
Word reading (log) time	.732	< .001	.521	< .001
Pseudoword reading (log) time	.746	< .001	.568	< .001
Word prefix orthographic choice	.620	< .001	.453	.001
Pseudoword prefix orthographic choice	.382	.001	.230	.111
Stem orthographic choice	.592	< .001	.320	.027
Spelling of suffixes	.728	< .001	.523	< .001

Note. PPC = pairwise partial correlation

Table 4

Comparison of linear models for longitudinal prediction of each experimental variable, testing the effects of group, with (right) and without (left) control for age and IQ

	Without age and IQ as predictors					With age and IQ as predictors				
	R_0^2	R_1^2	ΔR^2	F	p	R_0^2	R_1^2	ΔR^2	F	p
Phoneme deletion, words	.34	.42	.07	2.13	.086	.36	.43	.07	2.12	.088
Phoneme deletion, pseudowords	.29	.37	.08	2.12	.087	.36	.39	.04	1.04	.391
Spoonerisms	.46	.55	.08	3.18	.019	.48	.56	.08	3.14	.020
Rapid naming of digits (log time)	.64	.66	.01	0.68	.611	.64	.66	.02	1.03	.400
Word reading accuracy	.14	.17	.04	0.74	.571	.15	.19	.04	0.73	.574
Pseudoword reading accuracy	.28	.41	.13	3.72	.009	.30	.41	.11	3.08	.022
Word reading (log) time	.60	.65	.05	2.55	.047	.60	.65	.05	2.41	.058
Pseudoword reading (log) time	.66	.70	.04	2.50	.050	.67	.71	.04	2.32	.066
Word prefix orthographic choice	.39	.48	.09	2.89	.028	.44	.50	.06	2.04	.100
Pseudoword prefix orthographic choice	.23	.24	.01	0.26	.904	.25	.30	.05	1.10	.363
Stem orthographic choice	.41	.46	.05	1.48	.219	.43	.47	.04	1.23	.308
Spelling of suffixes	.48	.49	.02	0.54	.708	.49	.50	.01	0.46	.765

Note. R_0^2, excluding effects of group; R_1^2, including effects of group. Effects of group include one linear term for each group difference (CA vs. DYS and RA vs. DYS) and one linear term for each interaction between group difference and Time 1 performance, for a total of 4 degrees of freedom. None of these were significant after Holm correction for 12 comparisons (all adjusted $p > .05$).

Table 5

Partial non-parametric (Spearman's) longitudinal correlations for selected pairs of measures, controlling for age at Time 1

		All participants		Typical readers	
Time 1 variable	Time 2 variable	PPC	*p*	PPC	*p*
Rapid naming of digits	Reading time composite	.635	< .001	.499	< .001
Rapid naming of digits	Reading accuracy composite	−.400	< .001	−.096	.512
Phonological awareness composite	Reading time composite	−.739	< .001	−.590	< .001
Phonological awareness composite	Reading accuracy composite	.556	< .001	.348	.014

Note. PPC = pairwise partial correlation

Table 6

Comparison of linear models for longitudinal prediction of selected pairs of variables, testing the effects of group, with (right) and without (left) control for age and IQ

		Without age and IQ as predictors					With age and IQ as predictors				
Time 1 variable	Time 2 variable	R_0^2	R_1^2	ΔR^2	F	p	R_0^2	R_1^2	ΔR^2	F	p
Rapid naming of digits	Reading time (comp)	.39	.53	.14	5.14	.001*	.39	.54	.15	5.42	.001*
Rapid naming of digits	Reading accuracy (comp)	.09	.26	.17	3.84	.007*	.16	.27	.11	2.44	.055
Phonological awareness (comp)	Reading time (comp)	.49	.54	.06	2.09	.092	.51	.60	.09	3.59	.010*
Phonological awareness (comp)	Reading accuracy (comp)	.28	.36	.07	1.96	.110	.32	.36	.04	0.96	.434

* significant after Holm correction for 4 comparisons (adjusted $p < .05$)

Note. R_0^2, excluding effects of group; R_1^2, including effects of group. Effects of group include one linear term for each group difference (CA vs. DYS and RA vs. DYS) and one linear term for each interaction between group difference and Time 1 performance, for a total of 4 degrees of freedom. comp = composite score

Table 7

Partial non-parametric (Spearman's) longitudinal correlations for Time 2 spelling, controlling for age at Time 1

		All participants		Typical readers	
Time 1 variable	Time 2 variable	PPC	*p*	PPC	*p*
Passage spelling	Phonemic spelling accuracy	−.569	< .001	−.381	.011
Passage spelling	Graphemic spelling accuracy	−.721	< .001	−.557	< .001
Reading time composite	Phonemic spelling accuracy	−.525	< .001	−.305	.035
Reading time composite	Graphemic spelling accuracy	−.604	< .001	−.516	< .001
Phonological awareness composite	Phonemic spelling accuracy	.676	< .001	.502	< .001
Phonological awareness composite	Graphemic spelling accuracy	.670	< .001	.450	.001

Note. PPC = pairwise partial correlation

Table 8

Comparison of linear models for longitudinal prediction of Time 2 spelling, testing the effects of group, with (right) and without (left) control for age and IQ

		Without age and IQ as predictors					With age and IQ as predictors				
Time 1 variable	Time 2 variable	R_0^2	R_1^2	ΔR^2	F	p	R_0^2	R_1^2	ΔR^2	F	p
Passage spelling	Phonemic spelling accuracy	.29	.33	.04	0.86	.495	.41	.44	.04	0.97	.432
Passage spelling	Graphemic spelling accuracy	.56	.62	.06	2.62	.044	.57	.64	.07	3.01	.025
Reading time (comp)	Phonemic spelling accuracy	.15	.23	.08	1.71	.158	.31	.34	.03	0.72	.582
Reading time (comp)	Graphemic spelling accuracy	.32	.43	.11	3.14	.020	.37	.44	.07	2.05	.097
Phonological awareness (comp)	Phonemic spelling accuracy	.39	.42	.03	0.81	.526	.46	.48	.01	0.34	.850
Phonological awareness (comp)	Graphemic spelling accuracy	.46	.53	.07	2.44	.055	.47	.53	.05	1.86	.128

Note. R_0^2, excluding effects of group; R_1^2, including effects of group. Effects of group include one linear term for each group difference (CA vs. DYS and RA vs. DYS) and one linear term for each interaction between group difference and Time 1 performance, for a total of 4 degrees of freedom. None of these were significant after Holm correction for 6 comparisons (all adjusted $p > .05$). comp = composite score.

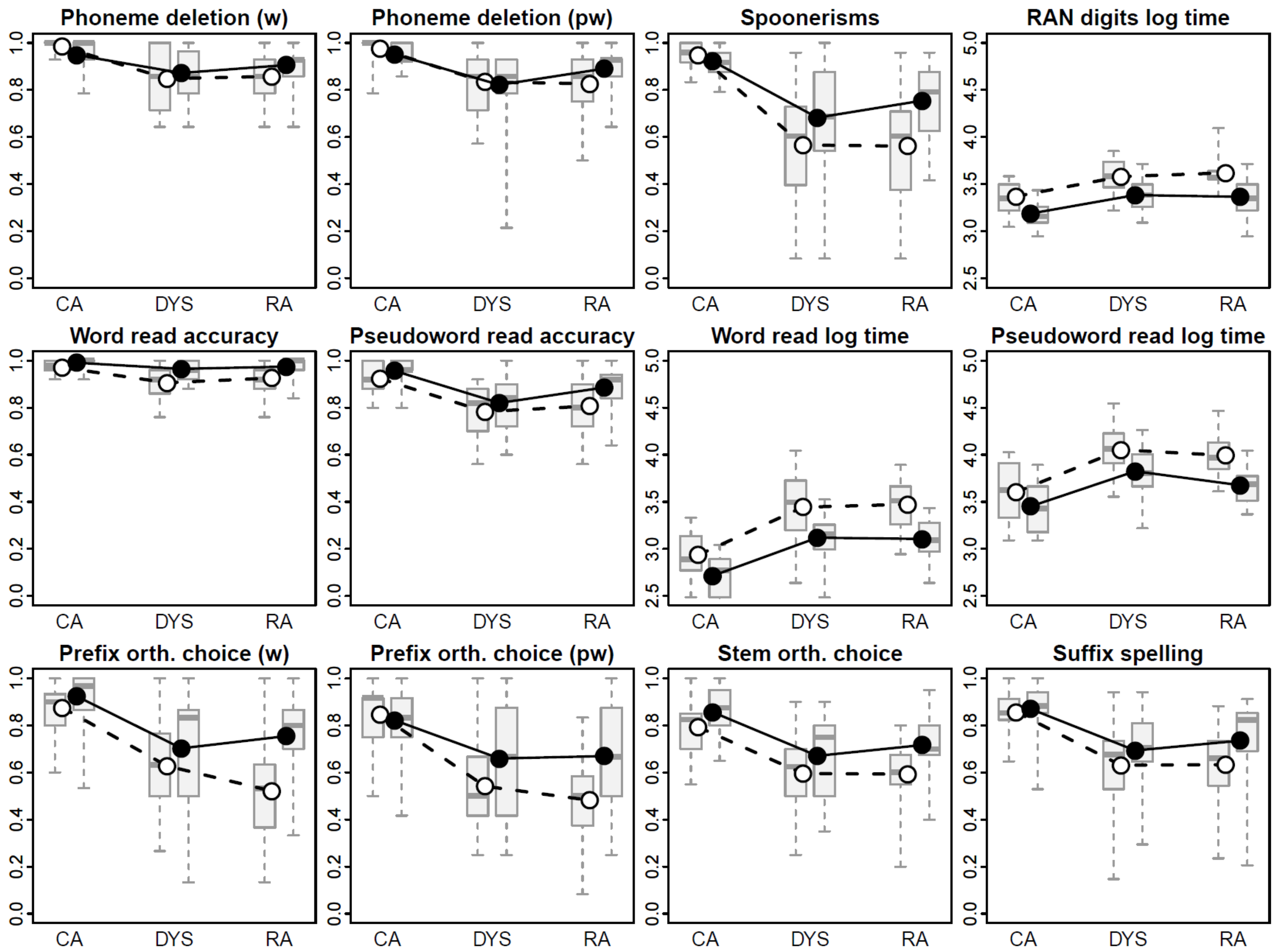
Figure caption

Figure 1. Mean performance (circles joined by lines) and quartile distribution (faint gray boxplot pairs) on phonological, orthographic choice, and reading measures for each group at Time 1 (white circles and dashed lines; left-side boxplots) and Time 2 (black circles and continuous lines; right-side boxplots). In the boxplots, thick horizontal lines indicate the median; whiskers extend to the full range. CA = chronological age control group; RA = reading age control group; DYS = group with dyslexia; w = words; pw = pseudowords; orth. = orthographic.

Figure 2. Performance at Time 2 (on the vertical axis) plotted against performance at Time 1 (on the horizontal axis) for each experimental measure, distinguishing participants in the dyslexia group (DYS; red asterisks) from participants in the age-matched (CA; green diamonds) and reading-matched (RA; blue circles) groups. w = words; pw = pseudowords; orth. = orthographic.

Figure 3. Longitudinal relationships between normalized composite measures of rapid naming (left column) and phonological awareness (right column) at Time 1 versus reading time (top row) and accuracy (bottom row) at Time 2, distinguishing participants in the dyslexia group (DYS; red asterisks) from participants in the age-matched (CA; green diamonds) and reading-matched (RA; blue circles) groups.

Figure 4. Longitudinal relationships between normalized measures of spelling, reading time, and accuracy at Time 1, on the horizontal axis, versus phonemic and graphemic spelling accuracy at Time 2, on the vertical axis, distinguishing participants in the dyslexia group (DYS; red asterisks) from participants in the age-matched (CA; green diamonds) and reading-matched (RA; blue circles) groups. comp. = composite, norm. = normalized.


Phoneme deletion (w)
Phoneme deletion (pw)
Spoonerisms
RAN digits log time
Word read accuracy
Pseudoword read accuracy
Word read log time
Pseudoword read log time
Prefix orth. choice (w)
Prefix orth. choice (pw)
Stem orth. choice
Suffix spelling
CA
DYS
RA
0.0
0.2
0.4
0.6
0.8
1.0
2.5
3.0
3.5
4.0
4.5
5.0

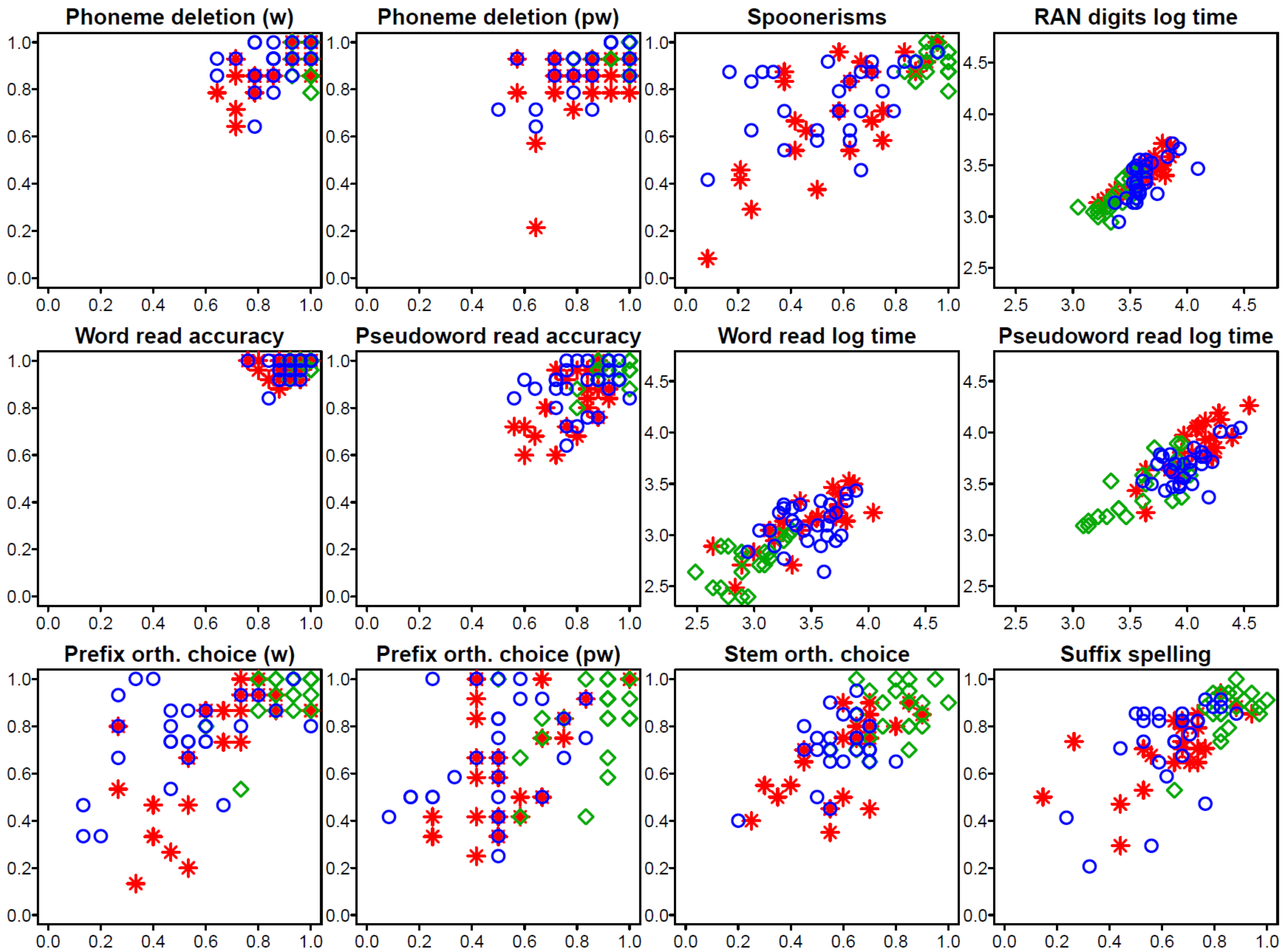
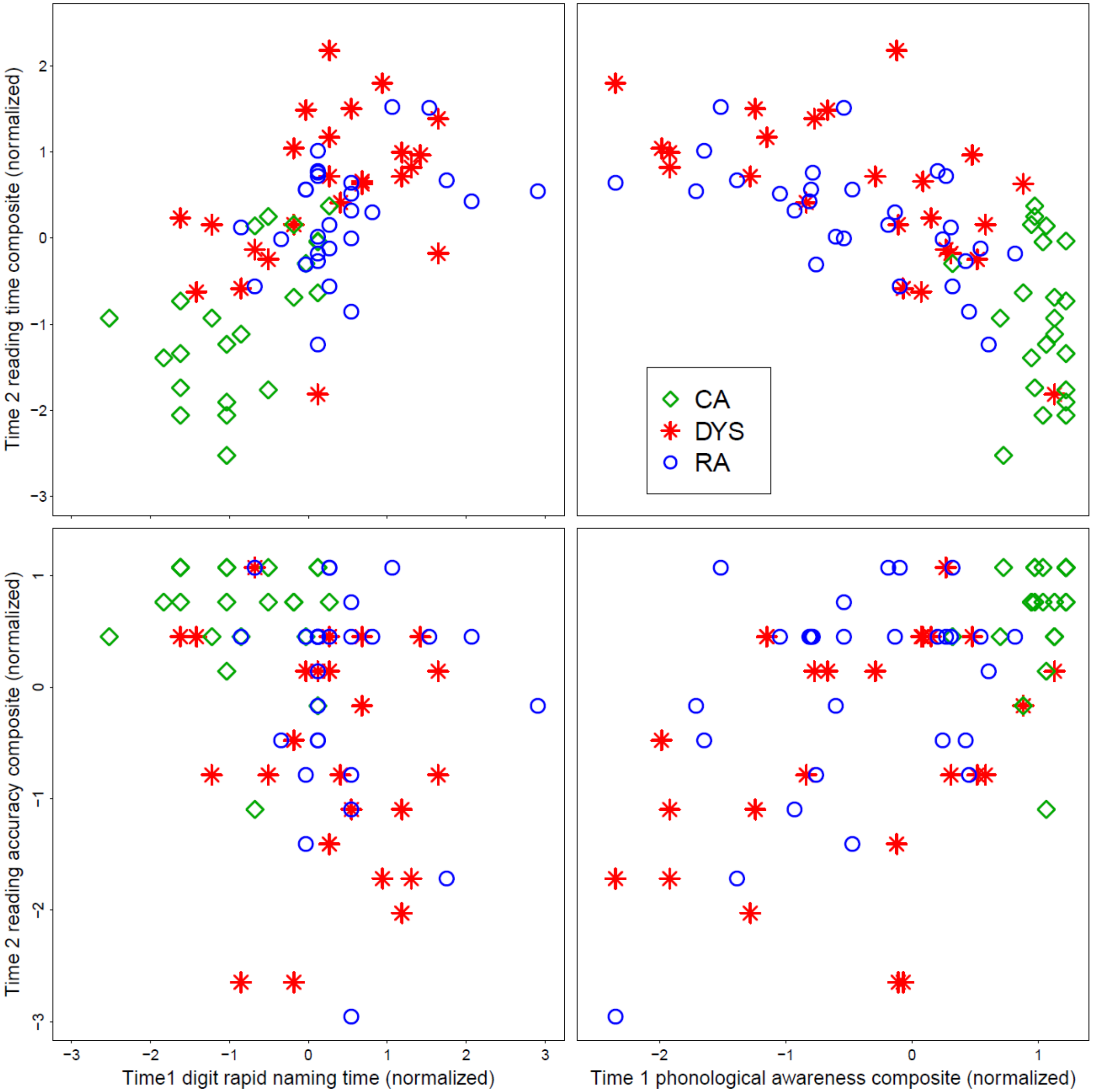
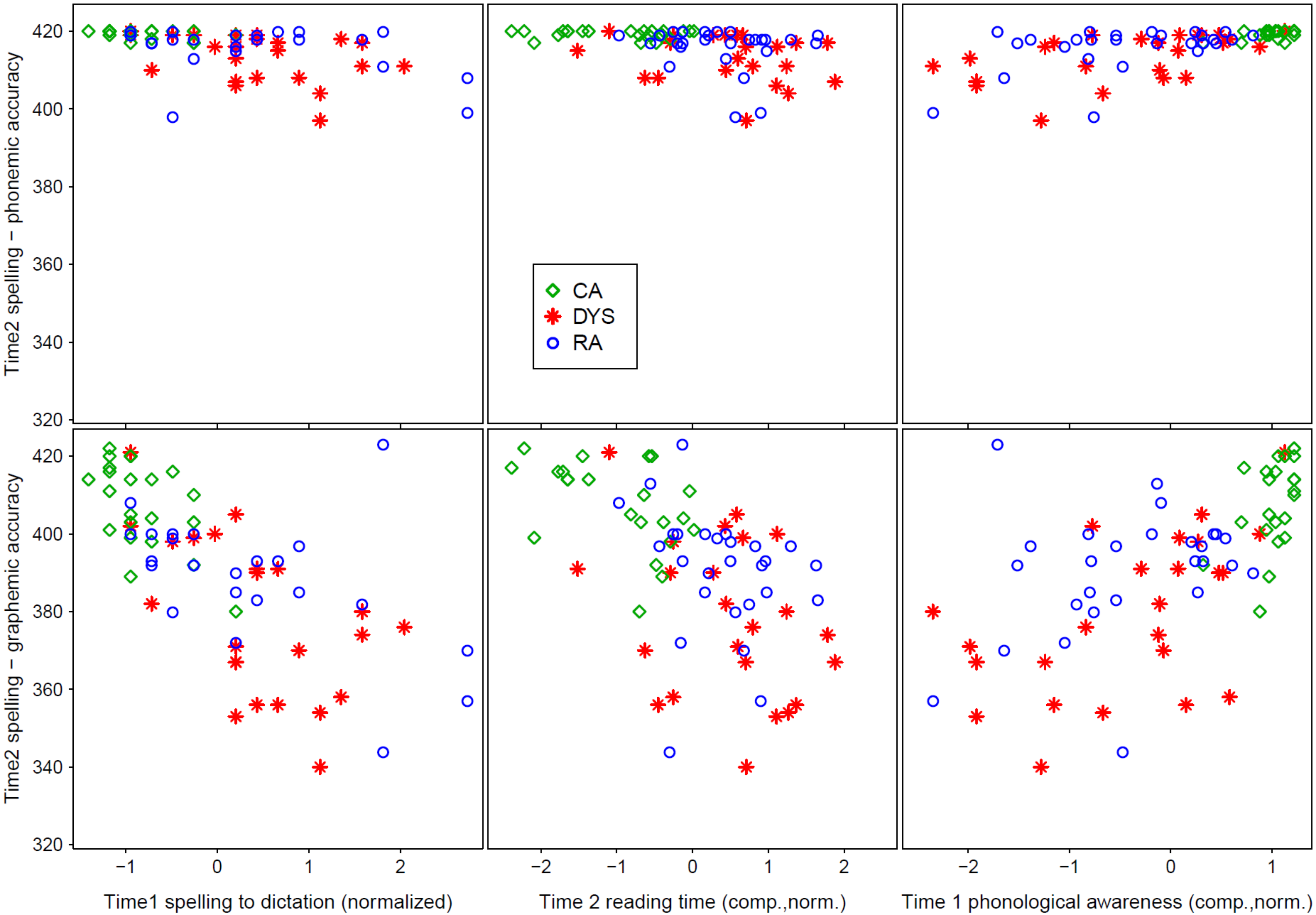

Phoneme deletion (w)
Phoneme deletion (pw)
Spoonerisms
RAN digits log time
Word read accuracy
Pseudoword read accuracy
Word read log time
Pseudoword read log time
Prefix orth. choice (w)
Prefix orth. choice (pw)
Stem orth. choice
Suffix spelling
0.0
0.2
0.4
0.6
0.8
1.0
2.5
3.0
3.5
4.0
4.5

Figure 3


Time 2 reading time composite (normalized)
Time 2 reading accuracy composite (normalized)
Time1 digit rapid naming time (normalized)
Time 1 phonological awareness composite (normalized)
CA
DYS
RA


Time2 spelling – phonemic accuracy
Time2 spelling – graphemic accuracy
420
400
380
360
340
320
CA
DYS
RA
−1
0
1
2
−2
Time1 spelling to dictation (normalized)
Time 2 reading time (comp.,norm.)
Time 1 phonological awareness (comp.,norm.)