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Dyslexia Profiles Across Orthographies Differing in Transparency: An Evaluation of Theoretical Predictions Contrasting English and Greek

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ABSTRACT

We examined the manifestation of dyslexia in a cross-linguistic study contrasting English and Greek children with dyslexia compared to chronological age and reading-level control groups on reading accuracy and fluency, phonological awareness, short-term memory, rapid naming, orthographic choice, and spelling. Materials were carefully matched across languages in item properties and structure. English children with dyslexia were more impaired on reading accuracy and phoneme deletion but not on reading fluency, memory, naming, or orthographic choice. No differences in impairment were observed between words and pseudowords across languages. Orthographic tests targeted specific morphemes to examine the accessibility of functionally distinct word parts across languages. There were no differences in prefix and stem orthographic choice, but English children were less successful in spelling inflectional suffixes despite greater morphological richness in Greek, highlighting the need for additional considerations beyond grain size in cross-linguistic work.

In this study we compare Greek and English children with dyslexia on a battery of reading and associated tasks, aiming to understand the relationship between properties of the languages and patterns of difficulty. Theories for the cause of dyslexia are dominated by the phonological deficit hypothesis (Ramus et al., 2003; Snowling, 2000; Wagner & Torgesen, 1987; see also Bishop & Snowling, 2004; Vellutino, Fletcher, Snowling, & Scanlon, 2004), which posits a core deficit affecting the representation of phonological elements. Because written language is based on mappings between orthographic units (i.e., in alphabetic systems, letters, and their combinations) and corresponding phonological units (phonemes), a deficit in the representation of the latter will affect the mapping between the two, hampering the development of reading and spelling skills (see Elliott & Grigorenko, 2014, for extensive discussion, and Parrila & Protopapas, 2017, for a brief review). The effects of such a deficit can be modulated by the consistency of the mapping. So, if the cognitive representations and processes underlying reading follow similar developmental routes across languages and orthographic systems, the comparative study of reading failure across languages can illuminate both typical and impaired reading development.

A number of cross-linguistic studies have established a near-universal pattern of literacy development and associate concurrent and longitudinal predictors across languages with alphabetic orthographic systems (Caravolas, Lervåg, Defior, Málková, & Hulme, 2013; Caravolas et al., 2012; Furnes & Samuelsson, 2009; Landerl et al., 2013; Liversedge et al., 2016; Moll et al., 2014; Ziegler et al., 2010; Ziegler, Perry, Ma-Wyatt, Ladner, & Schulte-Körne, 2003), subject to effects of orthographic consistency modulating the rate of development and prevalent patterns of relative performance and impairment (Durgunoğlu & Öney, 1999; Ellis & Hooper, 2001; Furnes & Samuelsson, 2010; Georgiou,

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Torppa, Manolitsis, Lyytinen, & Parrila, 2012; Marinelli, Romani, Burani, McGowan, & Zoccolotti, 2016; Marinelli, Romani, Burani, & Zoccolotti, 2015; Näslund, 1999; Paulesu et al., 2001; Seymour, Aro, & Erskine, 2003; see Share, 2008; Ziegler & Goswami, 2005, for reviews and discussion).

A consistent pattern of differences across languages concerns the size of the phonological and orthographic units on which readers rely for mapping across the two domains. Specifically, readers of English, an outlier orthography renowned for inconsistent mappings and abundance of exceptional spellings (Share, 2008), cannot rely entirely on phoneme-size units, because mappings at this level are not very reliable. Instead, they must acquire sets of mappings over larger groupings of letters and phonemes to achieve successful reading and spelling. The "psycholinguistic grain size theory" (Ziegler & Goswami, 2005) posits that phonological development and graphophonemic mappings will be largely determined by the size of the units maximizing the reliability of cross-domain mappings. This size will be smaller for consistent orthographies, in which letters or letter groups consistently map onto single phonemes. This hypothesis has been supported by studies examining potential processing consequences of unit size, such as effects of word length (Marinelli et al., 2016), word frequency and regularity (Marinelli et al., 2015), body neighborhood (i.e., words sharing orthographic rimes; Ziegler et al., 2003), correlations of reading and spelling with rapid serial naming (van den Boer, Georgiou, & de Jong, 2016) and with phonological awareness (Furnes & Samuelsson, 2010), eye movement patterns (Rau et al., 2016), and more (see Ziegler & Goswami, 2005, for a review of earlier studies).

Direct comparisons between children with dyslexia and typical readers across languages have confirmed and extended the general picture of a largely universal pattern of impairment and specific cross-linguistic differences attributable to properties of the phonological and orthographic structure of the language and the consistency of the mapping between them (e.g., Landerl et al., 2013). However, only few studies of dyslexia have used cross-linguistic designs to assess relative impairments in different orthographic systems with comparable materials directly contrasting groups of impaired readers across languages. Specifically, Landerl, Wimmer, and Frith (1997; followed up by Landerl & Wimmer, 2000) compared English and German children with dyslexia to control groups matched on age or reading level in reading and phonological tasks, focusing on the phonological deficit underlying difficulties in learning to read. To address the universality of the deficit, Ziegler et al. (2003) also compared German and English children with dyslexia examining effects of lexicality, length, and large orthographic units on reading aloud words and pseudowords. Focusing on spelling, Caravolas, Bruck, and Genesee (2003) compared English and French poor spellers, examining the relative proportions of spelling errors with respect to age-matched control groups. Finally, Katzir, Shaul, Breznitz, and Wolf (2004) focused on reading fluency in comparing English- to Hebrew-speaking reading-disabled children, using norm-referenced (standardized) scores instead of matched control groups. Despite differences in interpretation regarding the nature of the phonological deficit, these studies demonstrated similar patterns of impairment across languages, differing in severity and in effects attributable to orthographic transparency. These studies have highlighted the importance of assessing multiple skills and have revealed the role of domains beyond phonological awareness, such as rapid naming and phonological memory.

A common finding in direct cross-linguistic comparisons involving English and a language with a more transparent orthography is the relatively lower performance of English children, with or without dyslexia, on a variety of tasks, especially (but not limited to) measures related to reading accuracy. However, there has been little principled cross-linguistic research examining the effects of linguistic or orthographic structure on reading development and difficulties beyond the phonological deficit. Moreover, despite efforts to conduct studies with controlled materials, language groups are rarely matched in performance across multiple cognitive and reading measures. Matching of reading level is typically achieved using a measure of word accuracy, leaving open the question of differences in experience and efficiency underlying realistic reading behavior. Finally, even wide-ranging assessments have not examined the effects of morphological structure.

Thus, many questions remain open regarding the extent and severity of reading deficits across languages in different kinds of materials and tasks. In the present study we begin to address some of these questions by applying a wide range of assessments, using well-matched groups and materials across languages, and focusing on morphological orthographic spelling, that is, orthographic knowledge about word parts with different functional roles, such as prefixes, stems, and (inflectional and derivational) suffixes. In our study, English children with dyslexia were compared to Greek children with dyslexia and corresponding control groups matched in age or reading level. The comparison between English and Greek permits a contrast of morphological effects in addition to orthographic transparency.

Greek is a language with average-size vowel and consonant inventories, complex syllable structure, and lexical stress (Dryer et al., 2011). With few exceptions, content words are multisyllabic. Syllables are predominantly open (with CV accounting for 56% and V for 17%; Protopapas, Tzakosta, Chalamandaris, & Tsiakoulis, 2012), allowing only a few codas but a large variety of complex onset clusters (Holton, Mackridge, & Philippaki-Warburton, 1997). An extensive system of inflectional morphology affects the suffixes of nouns, adjectives, and verbs, while systematic derivational processes form nouns (based on verb stems) and adjectives (based on verb and noun stems); compounding is highly productive (Ralli, 2003, 2005). The orthography is relatively transparent at the grapheme-phoneme level (estimated consistency 95% for reading and 80% for spelling; Protopapas & Vlahou, 2009). Alphabetic strategies for reading words and pseudowords are effective as early as mid–first grade, with high performance (98%) on simple monosyllables (Seymour et al., 2003; cf. Porpodas, 1999). Morphology has extensive orthographic consequences insofar as derivational and inflectional suffixes are associated with specific spellings, disambiguating homonyms. Knowledge of the inflectional type is often required for correct spelling of adjective, noun, and verb suffixes (see Papanastasiou, 2008, and Protopapas, 2017, for examples and discussion).

Consistent with findings in other languages, Greek children with dyslexia have deficits in phonological awareness, word and pseudoword reading accuracy and speed, spelling, rapid naming, stress assignment, and verbal working memory, through primary and secondary education (see Protopapas, 2017, for references). 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, Goulandris, Stuart, & Campbell, 2014; Protopapas, Fakou, Drakopoulou, Skaloumbakas, & Mouzaki, 2013).

Beyond a documentation of performance profiles across languages, the specific goals of this study included an assessment of the effects of lexicality and morphology. Regarding lexicality, although a nonword deficit has long been considered a hallmark of dyslexia (a contention apparently supported in cross-linguistic dyslexia research, e.g., Landerl et al., 1997; Ziegler et al., 2003), it has recently been recognized that scaling and group matching issues may have obscured performance comparisons on familiar words versus pseudowords (van den Broeck & Geudens, 2012). Thus it is important to reevaluate the deficits in phonological awareness and reading tasks using matched stimuli.

With respect to morphology, it has long been recognized that the lack of grapheme-phoneme consistency in opaque orthographies is not haphazard but often expresses linguistic regularity at higher levels, such as morphology; English is but one example of morpho-phonemic orthography (Share, 2008; Venezky, 1970). Despite its greater transparency, the Greek orthography is also to some extent morphologically motivated (Porpodas, 1999), as there are different ways to spell several phonemes (especially vowels), thus preserving morphological differences in spelling. This is particularly evident in inflectional suffixes, causing difficulties in learning to spell (Diamanti et al., 2014; Protopapas et al., 2013). The question thus arises: Does the greater variety of Greek inflectional and derivational suffixes, and their orthographic diversity, cause additional difficulty in children with dyslexia, compared to the limited grammatical morphology found in English? To address this question we administered orthographic tasks targeting specific morphemes (prefixes, stems, and suffixes) across languages, taking care to match materials and task requirements as much as possible.

Matching materials across languages is particularly challenging. Because of inherent linguistic differences, stimuli that are equated in psycholinguistic variables, such as syllabic complexity and word frequency or length, may be unequally typical or unequally difficult in the two languages. Conversely, matching for difficulty on the basis of performance by a reference group may result in materials with different composition and processing demands. Some studies have approached this problem by focusing on closely related languages that differ in orthographic transparency, such as German and English (Landerl & Wimmer, 2000; Landerl et al., 1997; Ziegler et al., 2003), permitting comparisons with comparably representative materials. An alternative approach was taken by Katzir et al. (2004), who (in addition to psycholinguistic matching) compared norm-referenced—rather than raw—performance between the groups. This allowed matching of difficulty across languages differing in morphological and orthographic structure, such as English and Hebrew, and permitted evaluation of relative impairments, compared to the norm. However, this precludes comparison of task difficulty across orthographies because difficulty is equated by norm referencing.

In the absence of extensive sets of phonologically and orthographically similar cognates, in the present study we have opted to maximize matching on form properties and psycholinguistic variables, taking care to employ ranges of parameters that are overlapping in typical materials for the two languages. By design, this approach does not match item difficulty. Therefore, any observed differences in difficulty are theoretically interpretable if participant groups are matched across languages. The effectiveness of matching is evaluated post hoc by comparing performance between the reference groups. The homogeneous process of creating matched stimuli across tasks suggests that differences in relative performance are more likely attributable to differences in the tasks rather than in material construction.

In cross-linguistic studies of dyslexia, participant selection is a nontrivial issue. 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). It does not ensure general uniformity of reading skill (assuming such a notion is realistic across languages). Similarly, matching on standardized measures of performance or on grade levels, with the aim of forming "equally impaired" groups relative to norming populations, fails to account for potentially unequal variances and/or rates of development. Taking into account the protracted rate of reading development in English, compared to other European languages (Seymour et al., 2003), such that progress achieved within a year of schooling in the more transparent systems takes 3 or 4 years in English, it becomes evident that a "3-year difference" in performance can amount to widely divergent performance differences across languages. These issues create insurmountable barriers in cross-linguistic group matching. In the present study we have aimed to minimize these problems by comparing groups that perform similarly on multiple measures, striving to achieve cross-linguistically uniform profiles to the greatest extent possible.

Method

Participants

There were three participant groups in each language. The Greek sample included 26 children with dyslexia 9–12 years old (DYS), a chronological age (CA) control group of 29 same-age typically developing children, and a reading age (RA) control group of 28 younger children group-matched for reading level to the children with dyslexia. The English sample included 17 children with dyslexia 9–12 years old, 17 same-age typically developing children, and 16 younger children group-matched for reading level to the children with dyslexia.

Greek and English children with dyslexia were group-matched on chronological age, short-version IQ, and reading ability. All had verbal and nonverbal IQ within the normal range (> 85; based on Block Design and Similarities of the Wechsler Intelligence Scale for Children–III; Georgas, Paraskevopoulos, Besevegis, & Giannitsas, 1997, for Greek; Wechsler, 1991, for English) and reading score at least 1.5 *SD* below the normative mean on a sight word efficiency test (TOWRE, for English; Torgesen, Wagner, & Rashotte, 1999; for Greek, normative data for a 104-word adaptation of the same test were collected from 151 children from the general population attending Grades 2–6 in Thessaloniki).

Children with a history of sensory deficits, behavioral or emotional difficulties, or irregular school attendance were excluded from the sample. The Greek participants were recruited from three state primary schools in central Thessaloniki. The English participants with dyslexia were recruited from a private school (specialized in educating children with dyslexia of middle-to-high socioeconomic background) and a state school. Participants in the control groups were recruited from two state primary schools, representing a wide range of ethnic and socioeconomic backgrounds (like the Greek schools). In both languages, control groups were selected from larger groups of screened children on the basis of normal IQ and either age (CA) or reading ability (RA). Table 1 lists demographic information of the participant groups.

Materials

Experimental tasks were constructed to be equivalent in English and Greek as much as possible. Stimuli were matched on word frequency (based on Francis & Kučera, 1982, for English, and on word counts of primary school textbooks, for Greek), syllable length, imeageability, and phonemic similarity, whenever feasible.

Phoneme deletion, words

Children were asked to remove a phoneme from a set of words (14 Greek and 17 English) one to three syllables long. Target phonemes occurred in a variety of positions (initial, middle, final) and structures (CV, CC). Five practice items preceded testing. The number of correct answers was noted. Internal reliability (Cronbach's alpha) was .61 and .86 for the Greek and English version, respectively.

Phoneme deletion, pseudowords

This was identical to the word test except that items were formed from the same words by replacing consonants and vowels while retaining the syllabic structure and target phoneme to the extent possible (Cronbach's α = .68, for Greek; .82 for English).

Spoonerisms

Children had to transpose the initial sounds of 12 pairs of spoken words, following three practice trials. The number of correctly transposed items was noted (α = .91, for Greek; .88 for English).

Table 1. Participant Demographics.

Group		Age (Years;Months)				Group Size (*N*)	
		M	*SD*	Min	Max	Boys	Girls
Greek	CA	9;11	1.2	8;2	11;10	13	16
	RA	7;8	0.5	7;0	8;9	14	14
	DYS	10;5	1.2	8;6	12;10	17	8
English	CA	9;9	1.5	7;8	13;3	9	8
	RA	8;0	0.9	6;9	9;8	11	5
	DYS	9;11	1.4	7;10	12;6	13	4

Note. CA = chronological age control group; RA = reading age control group; DYS = group with dyslexia.

Digit span

Children's memory span was tested with the Digit Span subtest of the Wechsler Intelligence Scale for Children–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 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 one to six syllables long, with gradually increasing number of syllables and phonological complexity and decreasing frequency of occurrence, printed vertically on an A4 page. Words were either nouns or adjectives (except one article) and were matched across languages on syllable length, syllable structure, phonemic similarity, grammatical class, and frequency of occurrence. Children were asked to read the words accurately as quickly as possible. Their reading time and number of words read correctly were noted (accuracy: α = .54 for Greek; .89 for English).

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: α = .68 for Greek; .91 for English).

Spelling to dictation

This test was not matched across languages and is included only for within-language comparisons. For Greek, a 32-word passage was dictated at a pace determined by the child's writing. The number of spelling errors was noted. For English, the Spelling subscale from Wechsler Objective Reading Dimensions (Rust, Golombok, & Trickey, 1993) was used, which includes 50 words dictated in isolation and in a sentence. A stopping criterion of six consecutive errors was applied. To scale similarly to the Greek data, the number of correct words was subtracted from 50.

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 (e.g., "blurch" from "church"). English and Greek pseudowords were matched on word class, grammatical type, and degree of visual and phonological similarity with real words. Target suffixes encoded noun number and possessive (genitive case), and verb person, tense, number, and voice.

Context sentence meaning was as similar as possible across languages. Materials were printed in 14-point Times New Roman on three A4 pages and were group-administered to whole classes. Children were instructed to fill in the spaces. The number of correct spellings was noted (α = .85 for Greek; .79 for English).

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 20 groups of one target word with three pseudohomophones printed in 14-point Times New Roman in 20 rows on an A4 page. Children were instructed to tick the correct word. The number of correct choices was noted (α = .75 for Greek; .80 for English).

Word prefix orthographic choice

This was the same as Stem Orthographic Choice except that there were 15 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 in each language. Prefixes were matched across languages on syllable length, frequency of occurrence in words, and word frequency (α = .82 for Greek; .88 for English).

Pseudoword prefix orthographic choice

This was the same as Word Prefix Orthographic Choice except that there were 12 test trials and the stimuli were pseudowords derived from real words by substituting letters in the stem. The same prefixes were used (α = .72 for Greek; .69 for English).

Procedure

Children were assessed individually (or, in some cases, in groups) in a quiet room of their school in three 30- to 40-min sessions. Selection measures were administered in the first session, phonological and reading measures in the second session, and spelling measures in the third (group) session. Task order was counterbalanced within sessions.

Results

There were 116 complete cases, 12 cases missing one measure (seven English, of which five were in the DYS group, and five Greek, of which four were in the RA group), and five cases missing two or more data points (four English, of which three were in the RA group). Missing data were not replaced, as separate analyses were conducted for each measure. Times (from digit naming and word and pseudoword reading) were logarithmically transformed to better approximate the normal distribution. Accuracy was transformed to proportion by dividing by the number of items. Figure 1 shows the means and distributions of performance for each group in each language. From the top row of panels it is clear that the groups were well matched within as well as across languages, not only in the selection measures but also in verbal short-term memory and rapid naming as well.

For each task an omnibus analysis of variance was conducted with two between-subjects factors, namely language (English vs. Greek) and group (DYS, CA, RA). Results are shown in Table 2. We followed up with planned comparisons between languages, for each group, and within languages, comparing the group with dyslexia to each of the control groups. Within each measure, p values were adjusted with the Holm method for seven tests. The results are shown in Tables 3 and 4.

There was no difference between languages for any pair of groups (CA, RA, DYS) in the pairwise comparisons and no interaction of group with language in the analysis of variance for the selection measures, confirming the comparability of the samples between the two languages. There were also no language differences for rapid automatized naming, digit span, and the orthographic choice tasks (stem and prefix). In both languages, there were differences between the CA and DYS groups in all experimental measures, as expected (except for word reading accuracy in Greek, due to a ceiling effect). There were no differences between the RA and DYS groups in either language for spoonerisms, spelling, orthographic choice, and reading time. In fact there were no differences between the Greek RA and DYS groups for any measure. In contrast, the English RA and DYS groups differed in phoneme deletion and reading accuracy (for both words and pseudowords), confirming the typical pattern observed in English-speaking children with dyslexia.

To further examine this apparent cross-linguistic difference, we fit generalized linear mixed-effects models for binomial responses, via a logit link, to the accuracy data for these two types of tasks, with crossed random effects for participants and items and with interacting between-subjects

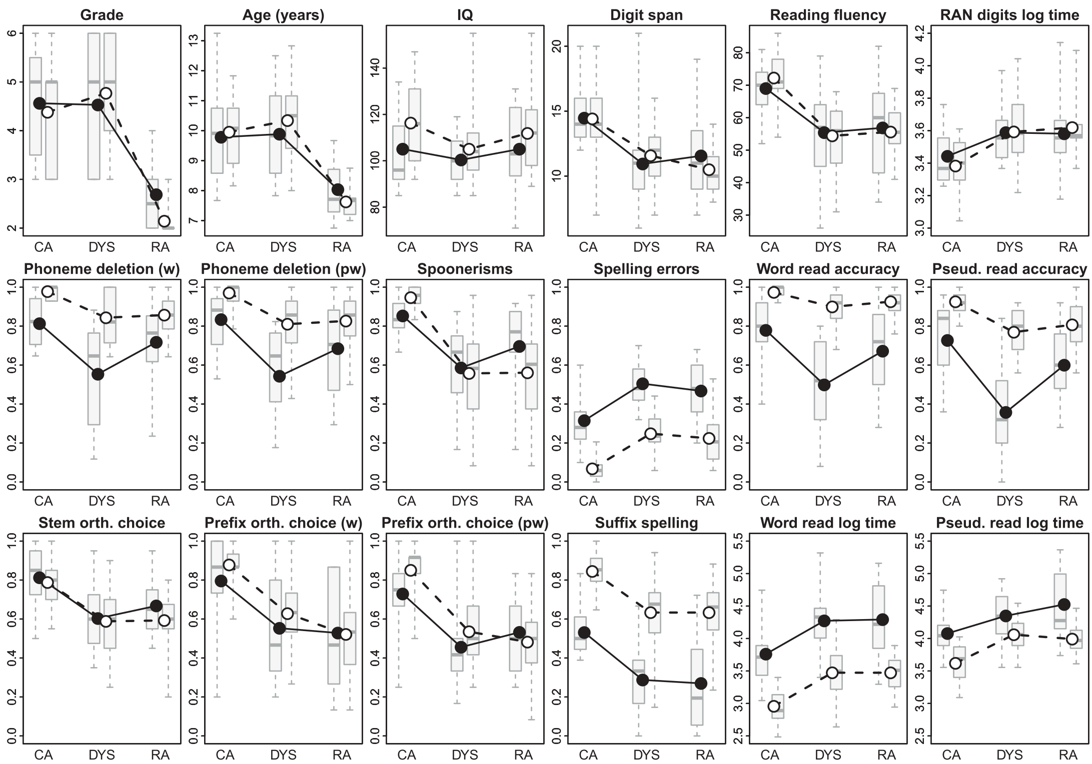

Figure 1. Mean performance (circles joined by lines) and quartile distribution (faint gray boxplot pairs) for each group in English (black circles and continuous lines; left-side boxplots) and Greek (white circles and dashed lines; right-side boxplots). *Note*. In the boxplots, thick horizontal lines indicate the median; whiskers extend to the full range. The spelling errors measure is not matched between languages and is only included for within-language comparisons. RAN = rapid automatized naming; CA = chronological age control group; DYS = group with dyslexia; RA = reading age control group; w = words; pw = pseudowords; pseud. = pseudowords; orth. = orthographic.

fixed effects of language and group and within-subject fixed effects of lexicality, using function glmer of package lme4 version 1.1–12 (Bates, Maechler, Bolker, & Walker, 2015) in R version 3.3.0 (R Core Team, 2016). In R notation, the model was specified as

acc ~ group * lang * lex + (lex|subject) + (1|item).

In this formula, the dependent binomial variable is accuracy (in either phoneme deletion or reading), coded as 1 (correct) or 0 (incorrect). Fixed effects factors included group (CA vs. DYS or RA vs. DYS, analyzed separately), language (English vs. Greek), and lexicality (words vs. pseudowords), fully interacting (as denoted by the asterisks). Random slopes for lexicality by participants were also included.

For phoneme deletion, there was a significant difference between CA and DYS (effect of group, $\beta = 1.91$, $z = 4.32$, $p < .001$) but only a marginal difference between RA and DYS ($\beta = 0.79$, $z = 1.89$, $p = .063$). There was a significant difference between languages ($\beta = 1.91$, $z = 2.89$, $p = .004$, and $\beta = 1.84$, $z = 2.77$, $p = .006$, respectively) but no effect of lexicality and no interaction ($p > .2$). In contrast, for reading accuracy, in addition to the significant effect of language ($\beta = 2.37$, $z = 4.60$, $p < .001$, and $\beta = 2.35$, $z = 4.59$, $p < .001$) there were significant differences between DYS and both control groups (DYS vs. CA: $\beta = 2.19$, $z = 5.47$, $p < .001$; DYS vs. RA: $\beta = 1.45$, $z = 3.83$, $p < .001$) and a significant effect of lexicality ($\beta = 1.14$, $z = 2.44$, $p = .015$; and $\beta = 1.18$, $z = 2.30$, $p = .022$, respectively). Moreover, there was a significant interaction between group and language in the comparison between groups DYS and RA ($\beta = 1.09$, $z = 2.30$, $p = .022$), consistent with a larger difference between the groups in English than in Greek. There was no other significant interaction.

Table 2. Results of Omnibus Analyses of Variance for Each Measure.

		Group			Language			Group × Language		
Measure	Residual *df*	*F*	*p*	ω^2	*F*	*p*	ω^2	*F*	*p*	ω^2
Grade	126	68.02	< .001	.502	0.75	.388	.000	1.48	.232	.004
Age	127	59.42	< .001	.467	0.14	.714	.000	1.57	.213	.005
IQ	125	3.26	.042	.032	6.74	.011	.041	0.44	.648	.000
Digit span	127	27.98	< .001	.289	0.13	.722	.000	1.23	.295	.003
Reading fluency	127	33.92	< .001	.334	0.04	.841	.000	0.62	.539	.000
Phoneme deletion, words	126	19.29	< .001	.159	58.78	< .001	.250	3.20	.044	.019
Phoneme deletion, pseudowords	125	23.24	< .001	.201	43.94	< .001	.194	2.44	.092	.013
Spoonerisms	124	44.01	< .001	.390	0.27	.606	.000	3.67	.028	.024
RAN digits time	127	17.48	< .001	.200	0.04	.836	.000	0.80	.449	.000
Word reading accuracy	125	16.16	< .001	.101	130.69	< .001	.430	6.21	.003	.035
Pseudoword reading accuracy	126	27.29	< .001	.183	92.89	< .001	.321	6.09	.003	.036
Word reading time	125	24.91	< .001	.161	120.85	< .001	.404	0.01	.993	.000
Pseudoword reading time	125	21.88	< .001	.183	54.85	< .001	.237	1.52	.222	.005
Spelling errors	122	35.52	< .001	.206	141.10	< .001	.418	0.03	.966	.000
Stem orth. choice	123	26.93	< .001	.287	2.04	.156	.006	0.50	.608	.000
Suffix spelling	124	30.40	< .001	.182	136.15	< .001	.419	0.25	.779	.000
Prefix orth. choice, words	124	25.94	< .001	.278	1.65	.202	.004	0.49	.616	.000
Prefix orth. choice, pseudowords	123	40.21	< .001	.371	2.62	.108	.008	2.18	.117	.011

Note. Significance values not corrected for multiple (within analysis of variance) comparisons (see Cramer et al., 2016). Numerator *df* = 1 for language and 2 for group and interaction comparisons. RAN = rapid automatized naming; orth = orthographic.

Table 3. Group Comparisons Between Languages.

	CA			RA			DYS		
Measure	est.	*t*	*p*	est.	*t*	*p*	est.	*t*	*p*
Grade	−0.18	−0.57	1.000	−0.54	−1.68	.475	0.24	0.74	1.000
Age	0.17	0.49	1.000	−0.41	−1.16	.988	0.45	1.30	.988
IQ	11.25	2.25	.156	6.79	1.33	.748	4.64	0.88	1.000
Digit span	−0.06	−0.08	1.000	−1.06	−1.38	.681	0.64	0.83	1.000
Reading fluency	3.24	1.02	1.000	−1.27	−0.39	1.000	−0.99	−0.30	1.000
Phoneme deletion, words	0.16	3.75	.001	0.14	3.04	.006	0.29	6.47	< .001
Phoneme deletion, pseudowords	0.14	2.95	.015	0.14	2.86	.015	0.27	5.65	< .001
Spoonerisms	0.09	1.62	.430	−0.14	−2.18	.155	−0.03	−0.47	1.000
RAN digits time	−0.06	−1.09	1.000	0.04	0.68	1.000	0.00	0.08	1.000
Word reading accuracy	0.19	4.68	< .001	0.25	5.82	< .001	0.40	9.35	< .001
Pseudoword reading accuracy	0.20	4.14	< .001	0.21	4.13	< .001	0.41	8.42	< .001
Word reading time	−0.80	−6.47	< .001	−0.82	−6.31	< .001	−0.80	−6.26	< .001
Pseudoword reading time	−0.46	−4.72	< .001	−0.53	−5.23	< .001	−0.29	−2.86	.020
Spelling errors[a]	—	—	—	—	—	—	—	—	—
Stem orth. choice	−0.02	−0.56	1.000	−0.08	−1.62	.539	−0.01	−0.33	1.000
Suffix spelling	0.31	6.31	< .001	0.36	6.96	< .001	0.35	6.95	< .001
Prefix orth. choice, words	0.08	1.19	.941	−0.01	−0.10	1.000	0.08	1.09	.941
Prefix orth. choice, pseudowords	0.12	2.11	.186	−0.05	−0.80	.798	0.08	1.38	.686

Note. Multiple comparisons with Holm-adjusted *p* values. CA = chronological age control group; RA = reading age control group; DYS = group with dyslexia; est. = contrast estimate; RAN = rapid automatized naming; orth. = orthographic.
[a]Spelling not compared across languages due to mismatched materials.

Discussion

Performance profiles of children with dyslexia were examined across languages differing in orthographic transparency by matching testing materials and procedures over a wide range of tasks and by testing matched and well characterized groups of children. The results confirmed successful group matching within and across languages: Besides grade, age, reading fluency, and IQ, all pairs of English and Greek groups (CA, RA, and DYS) turned out to be statistically indistinguishable in digit span and rapid naming. This effectively establishes a common profile across the observed ranges of performance for these tests, permitting confident interpretation of cross-linguistic similarities and differences, unencumbered by reservations regarding homogeneity and comparability across

Table 4. Group Performance Comparisons Within Languages.

	English						Greek					
	CA vs. DYS			RA vs. DYS			CA vs. DYS			RA vs. DYS		
Measure	est.	*t*	*p*	est.	*t*	*p*	est.	*t*	*p*	est.	*t*	*p*
Grade	0.03	0.09	1.000	−1.84	−5.12	< .001	−0.39	−1.40	.659	−2.63	−9.33	< .001
Age	−0.10	−0.26	1.000	−1.85	−4.73	< .001	−0.39	−1.27	.988	−2.71	−8.87	< .001
IQ	4.66	0.80	1.000	4.66	0.79	1.000	11.27	2.55	.083	6.82	1.53	.640
Digit span	3.53	4.19	< .001	0.62	0.73	1.000	2.84	4.27	< .001	−1.08	−1.61	.551
Reading fluency	13.59	3.81	.001	1.46	0.40	1.000	17.82	6.34	< .001	1.18	0.42	1.000
Phoneme deletion, words	0.26	5.27	< .001	0.16	3.22	.005	0.13	3.47	.003	0.01	0.35	.726
Phoneme deletion, pseudowords	0.29	5.59	< .001	0.14	2.59	.022	0.16	3.91	.001	0.02	0.39	.697
Spoonerisms	0.27	4.04	.001	0.11	1.59	.430	0.39	7.60	< .001	0.00	0.06	1.000
RAN digits time	−0.15	−2.36	.118	−0.01	−0.11	1.000	−0.21	−4.32	< .001	0.03	0.55	1.000
Word reading accuracy	0.28	5.99	< .001	0.17	3.59	.001	0.07	2.01	.094	0.03	0.71	.481
Pseudoword reading accuracy	0.37	6.87	< .001	0.24	4.36	< .001	0.16	3.69	.001	0.04	0.89	.376
Word reading time	−0.51	−3.68	.001	0.02	0.14	1.000	−0.52	−4.66	< .001	0.00	0.00	1.000
Pseudoword reading time	−0.27	−2.44	.048	0.18	1.54	.253	−0.44	−5.13	< .001	−0.07	−0.78	.437
Spelling errors	−0.19	−4.77	< .001	−0.04	−0.92	.715	−0.18	−5.71	< .001	−0.02	−0.73	.715
Stem orth. choice	0.21	4.19	< .001	0.06	1.25	.854	0.20	5.22	< .001	0.00	0.11	1.000
Suffix spelling	0.24	4.39	< .001	−0.02	−0.31	1.000	0.21	4.91	< .001	0.00	0.00	1.000
Prefix orth. choice, words	0.24	3.15	.012	−0.02	−0.30	1.000	0.25	4.18	< .001	−0.11	−1.77	.397
Prefix orth. choice, pseudowords	0.27	4.24	< .001	0.08	1.12	.798	0.32	6.31	< .001	−0.05	−1.05	.798

Note: Multiple comparisons with Holm-adjusted *p* values. CA = chronological age control group; DYS = group with dyslexia; RA = reading age control group; est. = contrast estimate; RAN = rapid automatized naming; orth. = orthographic.

orthographies. Consistent with the typical dyslexic profile and with expectations from the phonological deficit hypothesis, children with dyslexia performed poorly in phoneme deletion and reading tasks, compared to the CA groups. However, further discussion is warranted regarding performance relative to the RA groups and the effects of language and lexicality.

Naturally, there were no differences between the DYS and RA groups in the reading fluency selection measure, because of matching. Moreover, there were no differences between languages on this measure for any group, confirming that a set of words controlling difficulty for typically developing children also results in indistinguishable performance for reading impaired children. Thus, the finding that word and pseudoword reading (and phoneme deletion) accuracy of the English DYS group was lower than that of the English RA group might be taken to indicate a primary phonological deficit at the phoneme level that is greater than expected on the basis of the overall reading skill (indexed by the fluency measure). However, the picture is complicated by the (lack of) lexicality effects and the findings from the Greek sample.

Specifically, scaling considerations regarding comparison groups have led to the conclusion that differences between groups matched in reading level but differing in age depend entirely on the relative growth slopes and standard deviations of the tasks and are not informative about the groups (van den Broeck & Geudens, 2012). Additional considerations arise from accuracy metrics (such as proportion correct), which are subject to ceiling effects. This quantification not only precludes applicability of analysis of variance, due to violation of the variance homogeneity assumption, but also can create artifactual differences due to variance compression near the scale endpoints. These problems are alleviated to some extent in binomial approaches via transformation to a logit scale, with accuracy rescaled into an unbounded “response-strength” measure (Dixon, 2008).

Using this method, we found a greater difference between DYS and RA in English than in Greek. This stands in contrast to the results of a meta-analysis (Melby-Lervåg, Lyster, & Hulme, 2012), in which there was no moderating effect of orthography on the difference in phonemic awareness between children with and without dyslexia. However, the reading tasks used to form reading- match groups were likely different across studies in the meta-analysis, targeting accuracy in English but speed in consistent orthographies, leading to differences in the “matched” groups. In contrast, matching in our study was based on the same task across languages, permitting valid comparisons.

Our finding is consistent with different rates of development for phoneme deletion and reading accuracy between the two languages. Rather than indicating that a phonological awareness deficit originates sublexically and causes reading difficulties unidirectionally, the results suggest that development of phoneme-level phonological awareness trails behind reading development (and depends on it; Castles & Coltheart, 2004). Therefore, as reading lags behind in less transparent orthographies, full-blown phonemic awareness is also relatively delayed. Thus, the results from both languages, taken together, point to an interactive, rather than unidirectional, causal relationship between phonological awareness and reading skill.

There was no lexicality effect (or interaction) in phoneme deletion, suggesting that this demanding task tapping phoneme-level awareness does not depend on whether the manipulated item is a known word or not. As pseudoword phoneme deletion receives no lexical support, and so is expected to depend more on verbal memory, the lack of lexicality effects in phoneme deletion is consistent with a lack of short-term verbal memory differences, evidenced in the digit span results. This can also explain the lack of between-language differences in spoonerisms, a test highly dependent on verbal memory.

In contrast, we found a main effect of lexicality in reading accuracy, consistent with a trivial effect of reduced difficulty in decoding familiar—compared to unfamiliar—letter strings, but no interaction of lexicality with either language or group. The lack of lexicality effects is inconsistent with a specific nonword deficit (cf. van den Broeck & Geudens, 2012) and consistent with previous comparisons of Greek children with dyslexia to typically developing readers, in which the effect sizes were not greater for pseudowords than for words (Protopapas & Skaloumbakas, 2007, 2008; Protopapas, Skaloumbakas, & Bali, 2008). It is also consistent with words and pseudowords aligning along common factors of accuracy and fluency rather than forming separable domains of performance (Protopapas, Simos, Sideridis, & Mouzaki, 2012).

Main effects of language were revealed in both types of tasks, consistent with a protracted rate of development of reading and phonological awareness skills in the opaque English orthography (Caravolas et al., 2013; Seymour et al., 2003). This relative slowness in developing phoneme-level decoding and awareness skills may justify the preoccupation with accuracy in English language studies of reading (Share, 2008) and is consistent with expectations from the psycholinguistic grain size theory (Ziegler & Goswami, 2005) that larger units are favored in English because of inconsistencies at the grapheme-phoneme level.

Notably, a preference for processing units larger than single phonemes in the inconsistent English orthography is primarily a within-language hypothesis. That is, English readers rely on larger units because the smaller units are not very reliable. This implies a difference from readers in more consistent orthographies, who can rely on phoneme-sized processing units. That is, higher performance in phoneme-level awareness and decoding tasks may be expected from Greek than from English children, with or without dyslexia, because the accessibility of smaller phonological units to awareness, as a response to literacy instruction, is facilitated by systematic phoneme-level mappings (cf. Ziegler & Goswami, 2005). However, this does not imply that English readers surpass readers of consistent orthographies on larger unit processing. Greek readers may rapidly develop mappings among larger orthographic and phonological units, not by necessity but by successful performance. Thanks to the consistency in the smaller-unit mappings, larger orthographic chunks that are frequent and reliable can form the substrate for rapid development of multiple levels of systematic graphophonemic mappings and, eventually, sight word reading (Ehri, 2005, 2014).

Therefore, grain size theory does not predict differences in the effectiveness of large-unit strategies that underlie successful orthographic choice performance. Accordingly, no differences were observed between languages in our orthographic choice tasks, regardless of age or reading level. In both English and Greek the DYS group performed more poorly than CA group, indicating deficient orthographic representations, as expected. There were no differences from the RA groups, suggesting that rates of development and associated individual differences in orthographic processing were commensurate with overall reading skill, indexed by fluency.

Why then was there a difference between languages in spelling suffixes? The materials for suffix spelling were not less carefully matched between languages than those for other tasks. Rather, this task was evidently very difficult for English children. One might be tempted to say that low performance was observed in English suffix spelling *despite* the apparent simplicity of this task, as there are few suffixes to be learned. However, other theoretical considerations might lead to the suggestion that performance was low precisely *because of* the lack of morphological richness in English and the consequent lack of attention to—or practice with—suffixes. Specifically, the competition model (Bates & MacWhinney, 1989) pits cue validity against cue cost in determining the mappings between linguistic forms and linguistic functions as arising in language acquisition, activated in real-time processing, and failing in language disorders. Cue validity refers to the reliability of a given form whereas cue cost refers to the processing required for using that form (Bates, Devescovi, & Wulfeck, 2001). In richly inflected languages, such as Greek, suffixes are ubiquitous, obligatory, and reliable cues to syntactic and semantic functions and are therefore acquired rapidly and used correctly early on. In contrast, in languages with sparse grammatical morphology, speakers must rely on context to achieve the same functions, thereby effectively learning to pay little attention to the suffixes and, consequently, taking longer to acquire them. This may be amplified if the reliability of the cues is further reduced by ambiguities and irregularities, as in English.

Applying this rationale to orthographic learning is straightforward: The ubiquity and consistency of suffixes in Greek spelling will result in higher learning rates, compared to English, in which there are fewer suffixes to learn, applying in fewer situations and subject to exceptions. This explains why suffix spelling is a difficult task for English children, compared to Greek, despite complexities in spelling Greek grammatical suffixes across tenses, numbers, and cases (Diamanti et al., 2014; Papanastasiou, 2008; Protopapas et al., 2013). The role of language, rather than individual ability, in determining patterns of spelling performance is evident in the lack of group effects: Suffix spelling is commensurate with reading and spelling performance, as indexed by the fluency and spelling tasks. Thus, there is no difference in suffix spelling between DYS and RA and no interaction of language with group.

As noted, matching materials across languages (especially not closely related ones) presents inherently insurmountable difficulties. Test equivalence is impossible to achieve because it presupposes equality of performance and common patterns of correlations, a demand at odds with differentially varying rates of development across tasks and orthographies. Therefore, it cannot be precluded that differences between language groups observed in our study reflect differences in test properties rather than in children's ability levels. This is partially circular: Children's skills depend in part on language features that cause differential demands in similarly constructed tests (as argued for reading accuracy, phonological awareness, and suffix spelling) and are the reason cross-linguistic studies are interesting to begin with.

Although no single between-language difference—or even single study—is individually interpretable, and can be considered only in the context of complementary comparisons, our approach has sought to establish comparable scales based on (a) expert judgment and psycholinguistic variable control, regarding face validity of the tasks, and (b) two-step group matching. Specifically, the lack of between-language differences in reading fluency for all three groups establishes a common baseline using a well-studied kind of task known to be reliable. Therefore, when *both* CA and RA groups perform equally across languages in other tasks, establishing task-specific reference, this ensures that relative differences between groups (DYS–CA or DYS–RA) are cross-linguistically interpretable as demonstrating convergent of divergent patterns of impairment. This noncircular approach does not guarantee that test scores are equivalent across languages (a feat impossible to achieve, due to linguistic and orthographic differences); however, it suffices to establish relevant cross-linguistic similarities and differences to the extent the tasks are valid.

In conclusion, despite limitations arising from cross-linguistic comparability and small sample sizes (especially of the English groups), our results are consistent with the psycholinguistic grain size theory but also highlight additional issues of theoretical importance. The lack of a specific nonword deficit highlights the need to specify more precisely the nature of the phonological impairment. Moreover, the pattern of performance in orthographic tasks concerning different morphemes is consistent with the competition model, rather than with expectations based on orthographic transparency alone. This suggests that a richer network of psycholinguistic considerations is needed to understand the manifestations and ramifications of dyslexia across languages.

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