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What do spelling errors tell us? Classification and analysis of errors made by Greek schoolchildren with and without dyslexia

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Abstract In this study we propose a classification system for spelling errors and determine the most common spelling difficulties of Greek children with and without dyslexia. Spelling skills of 542 children from the general population and 44 children with dyslexia, Grades 3–4 and 7, were assessed with a dictated common word list and age-appropriate passages. Spelling errors were classified into broad categories, including phonological (graphophonemic mappings), grammatical (inflectional suffixes), orthographic (word stems), stress assignment (diacritic), and punctuation. Errors were further classified into specific subcategories. Relative proportions for a total of 11,364 errors were derived by calculating the opportunities for each error type. Nondyslexic children of both age groups made primarily grammatical and stress errors, followed by orthographic errors. Phonological and punctuation errors

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were negligible. Most frequent specific errors were in derivational affixes, stress diacritics, inflectional suffixes, and vowel historical spellings. Older children made fewer errors, especially in inflectional suffixes. Dyslexic children differed from nondyslexic ones in making more errors of the same types, in comparable relative proportions. Spelling profiles of dyslexic children did not differ from those of same-age children with poor reading skills or of younger children matched in reading and phonological awareness. In conclusion, spelling errors of both dyslexic and non-dyslexic children indicate persistent difficulty with internalizing regularities of the Greek orthographic lexicon, including derivational, inflectional, and word (stem) families. This difficulty is greater for children with dyslexia.

Keywords Spelling · Spelling errors · Error classification · Dyslexia · Greek

Introduction

Spelling errors are a rich source of information. Systematic spelling failures are thought to reveal aspects of the cognitive mechanisms of spelling and learning to spell. Moreover, spelling errors may be strongly dependent on the language-specific orthographic system and on the individual level of competence. In the present study we examine patterns of spelling errors, in search for information specifically related to the cognitive processes of spelling, the properties of the orthographic system, and specific reading disability (dyslexia). We work in a language with a moderately transparent orthography in the feedback (spelling) direction. The properties of Greek allow many opportunities for errors while generally supporting a phonographemic strategy. In a comprehensive classification and analysis of individual errors, we address the question: What are spelling errors informative about?

Classification and scoring systems

The simplest way to evaluate spelling is to note if words have been written correctly or incorrectly. This dichotomous approach provides minimal information because it fails to distinguish (a) single from multiple spelling errors on the same word, (b) subtle from egregious errors, and (c) errors related to different types of information processing. As a first step towards individuation and classification, spelling errors can be individually categorized as either orthographic or phonological. Orthographic errors maintain the word's correct pronunciation but alter its written representation by substituting alternative graphemes for the same phonemes. Phonological errors alter the word's phonological form, so that the written word is pronounced differently from the one intended.

The majority of classification schemes for spelling errors have concerned English words and are therefore limited to the linguistic and orthographic idiosyncrasies of this language. In an early attempt, Moats (1995; also Sawyer, Wade, & Kim, 1999) considered three main error categories: orthographic (phonetically accurate), phonological (phonetically inaccurate), and morphological errors. Phonological errors were subdivided into legal or illegal, depending on phonemic violations. Only

illegal spellings were thought to indicate deficient learning of phoneme-to-grapheme correspondences (Treiman, 1993). Other studies have considered letter overlap between the actual and correct letter string (Bruck & Waters, 1988; Siegel, Share, & Geva, 1995) or particular features of the target words (Tangel & Blachman, 1992, 1995; Treiman and Bourassa, 2000).

Landerl and Wimmer (2000) analyzed spelling errors in German using the "phoneme distance" scoring method introduced by Bishop (1985). A score was assigned to each incorrect spelling, expressing phonological deviation. Similarly, Angelelli, Judica, Spinelli, Zoccolotti, and Luzzatti (2004; Angelelli, Notarnicola, Judica, Zoccolotti, and Luzzatti, 2010) divided spelling errors in Italian into (a) phonologically plausible surface errors, (b) "minimal distance" substitutions, differing in a single distinctive feature, (c) failure to apply context-dependent spelling rules, and (d) other errors, including non-minimal distance substitutions, omissions, insertions, and transpositions. In Spanish, Justicia, Defior, Pelegrina, and Martos (1999 ; Defior and Serrano, 2005) classified early spelling errors by grapheme into seven categories, ostensibly representing different learning stages.

Other studies in orthographies more transparent than English have focused more on errors in orthography, morphology, and grammatical parts of the words instead of (or in addition to) phonological errors. Caravolas and Volín (2001) classified spelling errors in Czech into phonological, orthographic, morphological, grammatical and lexical categories. Hoefflin and Frank (2005) distinguished lexical root errors violating general or grammatical conventions from word-specific, punctuation, and capitalization errors, in order to examine the effects of different sources of potential confusion inherent in the orthographic system.

In sum, a variety of classification schemes have been used for the measurement of spelling skill or for research into more focused language-specific issues. Most classifications have either remained at a coarse level of distinction, potentially missing fine-grained information about deficient information processing, or have defined error types without primary regard to sources of information needed for spelling. For example, it is not clear whether single-grapheme deletions are in any theoretical sense different from insertions, insofar as both may indicate a difficulty at the level of grapheme-phoneme correspondence. On the other hand, if spelling a word stem requires word-specific orthographic information, but spelling an inflectional ending requires morphological awareness, then different spelling errors may be indicative of different kinds of difficulty. More recent studies have increasingly tailored error classification schemes not only to the properties of the spelling systems but also to the presumed levels of necessary linguistic and orthographic representations. In the present study we have taken this trend to its fullest extent. We attempt to remedy shortcomings of earlier approaches by proposing a systematic, theoretically founded, two-pronged classification scheme, addressing both the coarse and the fine-grained level of analysis.

Spelling in dyslexia

Spelling performance is longitudinally predicted by phonological awareness across languages and (transparent or opaque) alphabetic orthographic systems (Caravolas,

Hulme, & Snowling, 2001; Furnes & Samuelsson, 2010), including Greek (Aidinis & Nunes, 2001; Georgiou, Manolitsis, Nurmi, & Parrila, 2010), even beyond the first school years (Caravolas, 2004; Caravolas, Volín, & Hulme, 2005; Landerl & Wimmer, 2008; for Greek, Nikolopoulos, Goulandris, Hulme, & Snowling, 2006). Thus, it seems reasonable to assume that spelling skills hinge critically on phonological skills, perhaps expressed primarily in phonological recoding and phonographemic mapping. To the extent that dyslexia is considered a difficulty arising from—or at least mainly related to—impaired phonological processing, one may hypothesize that spelling difficulties of children with dyslexia will concern primarily the mapping between phonological and orthographic representations, resulting in many phonologically illegal misspellings.

Consistent with this hypothesis, some studies in English have reported increased proportions of phonological spelling errors by children with dyslexia (Bruck & Treiman, 1990; Curtin, Manis, & Seidenberg, 2001; Lennox & Siegel, 1996) or with spelling difficulties (Friend & Olson, 2008). However, other studies have not borne out this prediction (Moats, 1983; Nelson, 1980). In particular, more recent studies that have taken reading level into account have failed to identify patterns of spelling and orthographic processing specifically related to dyslexia, such as an excess of phonological spelling errors. For example, Katzir, Kim, Wolf, Kennedy, Lovett, and Morris (2006) found no difference in orthographic choice between 17 pairs of dyslexic and younger reading level-matched non-impaired readers. Kemp, Parrila, and Kirby (2008) found sufficient development of high functioning adult dyslexics' phonological skills, at least for writing simple words using phonological spellings, in contrast to particular difficulties reproducing orthographic patterns. Bourassa and Treiman (2003) found no differences in the phonological or orthographic processing of 30 children with reading and spelling problems, compared to younger spelling-matched controls. Subsequently, Cassar, Treiman, Moats, Pollo, and Kessler (2005) found no significant differences in the spelling errors produced by 25 pairs of dyslexic and typical younger readers individually matched on spelling ability. Moreover, the error profiles of the two groups were indistinguishable when blindly assessed by experienced teachers. In a similar vein, Bernstein (2009) found that vowel spelling errors made by dyslexic children were appropriate for their level of literacy development, not differing from those made by a younger reading-matched control group of children.

Mixed findings are also evident in languages with more transparent orthographies than English. An elevated frequency of phonological spelling errors has been observed in French and Czech children with dyslexia around 10 years old (Hoefflin & Franck, 2005; Caravolas & Volín, 2001). In contrast, German children with dyslexia apparently do not exhibit persistent deficiencies in phonological spelling after the first few years of schooling (Landerl & Wimmer, 2000). In Italian, Angelelli et al. (2004, 2010) compared the spelling errors produced by dyslexic children to an age-matched group. Dyslexic participants performed especially poorly on spelling words with unpredictable orthographic patterns, but the majority of their spelling errors were phonologically plausible. Qualitative analysis suggested overreliance on phonological spellings and impairment of lexical processes. Thus,

the Italian data are inconsistent with a primary phonological spelling deficit and indicative of difficulties in orthographic processing.

In sum, there is some disagreement regarding the effect of phonological processing weaknesses on spelling performance. Although it remains indisputable that children with dyslexia make many more spelling errors than same-age typically developing readers, studies with spelling-match designs often find no difference between the groups and no spelling patterns specifically associated with dyslexia. In particular, there seems to be insufficient support for the contention that dyslexia is associated especially with phonologically inappropriate spellings. Studies suggest that spelling performance is closely associated with overall phonological and reading attainment, thus being delayed rather than deviant for poor readers. Because of the relatively few and sometimes contradictory findings reported over the last decade, it is important to address this issue systematically in a range of orthographies using well-characterized participant groups. Thus, one of the main goals of the present study is to examine the details of spelling performance of Greek children with dyslexia, in order to determine if there are any specific patterns associated with dyslexia beyond what can be predicted simply from the level of reading development and the properties of the Greek orthography.

The Greek orthography

Greek is considered relatively transparent orthographically, occupying the second place, behind Finnish, among the group of languages with simple syllable structure in the classification of Seymour, Aro, and Erskine (2003). Although the transparency of the Greek orthography may have been somewhat exaggerated, a recent quantitative study has calculated its consistency to be around 95 % in the feedforward direction (i.e., for reading) and about 80 % in the feedback direction (for spelling) (Protopapas & Vlahou, 2009). There is thus a substantial asymmetry between reading and spelling, mainly arising from the fact that there are alternative spellings for the vowels. There are 27 consonant and 5 vowel phonemes in standard modern Greek, which are written with 24 letters (plus a final-only variant), resulting in a phoneme-to-letter ratio of 1.33, lower than English or French but higher than Czech (1.7, 1.5, and 1.0, respectively; Caravolas, 2004). Treating letters with diacritics as distinct letters, there are 84 graphemes (including standard digraphs and other combinations), participating in a total of 118 unique grapheme-phoneme mappings (see complete analysis in Protopapas & Vlahou, 2009). Crucially, sequential mapping is always possible in Greek, that is, (a) multi-letter graphemes are never separated or split around other graphemes, and (b) context-dependent graphemes refer only to adjacent and not more distant context.

A full treatment of Greek spelling is beyond the scope of this article, but some basic information is necessary. Briefly, 2 vowels have unique spellings (a single letter for /a/ and a digraph for /u/) while there are 2 alternative spellings for /ε/ and /o/ and 6 for /i/. Vowel spellings are typically phonologically unpredictable but can be determined on the basis of (a) grammatical type, when on an inflectional suffix, (b) derivational family, when on a derivational affix, or (c) lexical identity, when on a word root. For example, words ending in /o/ are spelled with a final ω (omega) if

they are verbs or feminine nouns but with *ο* (omicron) if they are masculine or neuter nouns or adjectives. Open-class parts of speech are always inflected, therefore there is always a grammatical suffix attached to a stem. There are also some inconsistencies in consonant spelling, such as double letters (of no phonological consequence) and a context-dependent spelling of /v/ using the vowel letter *υ* (upsilon). Spelling of palatal consonants often involves one of the /i/ graphemes, lexically determined.

An important feature of the Greek orthography is that feedforward consistency at the grapheme level is high (95 %), that is, a given grapheme usually corresponds to a single phoneme. For example, even though there are two ways to spell /ε/ (*ε* and *αι*), both of these spell only /ε/ and no other phoneme. Ignoring complications arising from the two component letters of the digraph *αι* and from effects of the stress diacritic, this suggests that ambiguities in Greek spelling typically correspond to selections among mutually exclusive sets of graphemes. This allows many incorrect choices, resulting in phonologically acceptable misspellings. However, distinction among phoneme sets is facilitated, diminishing the possibility for phonological errors. Thus, Greek offers the opportunity to study spelling development and difficulties in a system with few cross-phoneme ambiguities but many within-phoneme alternatives. Finally, Greek marks stress in the orthography with an obligatory accent diacritic, which is perfectly predictable, and uses a diaeresis diacritic to split digraphs. This enables us to study nonletter spelling in relation to overall spelling development.

Spelling development and difficulties in Greek

The study of spelling development in Greek has provided evidence consistent with the effective use of phonological strategies at the phoneme and syllable level very early on. Like Spanish children (Defior, Jiménez-Fernández, & Serrano, 2009), Greek children in Grades 1 and 2 spell words mainly based on phoneme-grapheme correspondences and not on orthographic lexical representations (Harris & Giannouli, 1999; Porpodas, 1999, 2001). Consistent with the aforementioned findings in German, Greek children with reading or spelling difficulties do not seem to have problems with phonemic decoding, even when their reading and spelling is effortful and slow (Porpodas, 1999) and despite associated difficulties in phonological and orthographic choice tasks (Papadopoulos, Georgiou, & Kendeou, 2009). Phonological spelling strategies are gradually supplemented by morphological and lexical strategies to allow spelling of grammatical suffixes (Diakogiorgi, Baris, & Valmas, 2005; Nunes, Aidinis, & Bryant, 2006) and irregular stems (Loizidou-Ieridou, Masterson, & Hanley, 2010), as children gradually associate specific spellings with the appropriate grammatical types (Harris & Giannouli, 1999). Bryant, Nunes, and Aidinis (1999; see also Chliounaki & Bryant, 2002) documented that children start off with a preferred grapheme for each phoneme, and pass through a stage of indiscriminate alternation among phonemically equivalent graphemes, before reaching the final stage of morphologically appropriate spelling towards the end of elementary school. A reciprocal relationship among reading and spelling development is evident in the predictive power of orthographic processing for word reading fluency (Georgiou, Parrila, & Papadopoulos, 2008).

With respect to spelling in dyslexia, Nikolopoulos, Goulandris, and Snowling (2003) tested 28 Greek dyslexic children and found their reading accuracy comparable to that of an age-matched control group of average readers in the context of substantially inferior spelling performance. Spelling errors were primarily orthographic and morphological; no phonological errors were observed. Dyslexic children exhibited particular difficulties with the spelling of multi-letter inflectional morphemes, revealing a particular weakness of knowledge for recurring spelling patterns. In a multiple case-study approach, Douklias, Masterson, and Hanley (2010) found that children who match a "surface dyslexia" reading profile make a lot of orthographic spelling errors (in irregular words) whereas those who match a "phonological dyslexia" reading profile make phonological spelling errors (in nonwords). Diamanti (2005) attempted to disentangle sources of spelling ambiguity by distinguishing among errors on word roots (verbs, nouns, and adjectives), derivational affixes, and inflectional suffixes. She tested 23 schoolchildren with dyslexia 11–13 years old in comparison with an age-matched and a younger reading-matched control group. She found that dyslexics made more errors than both control groups. All 3 groups made the highest proportion of errors on the derivational suffixes and the lowest on the inflectional suffixes. This suggests that different parts of Greek words, which require different metalinguistic knowledge to be spelled correctly, do not develop homogeneously and are differentially affected in reading disability. Diamanti also observed a substantial proportion of phonological spelling errors. She concluded that Greek dyslexics exhibit "persistent phonological spelling difficulties…[in]…representing the phonological structure of words" (p. 243). This is consistent with Caravolas and Volín (2001; for Czech) but not with Landerl and Wimmer (2000; for German).

There remains, therefore, a discrepancy in Greek findings, which parallels comparable reports in other languages, necessitating a systematic approach to error classification and sample selection.

Approach and aims of the present study

In the present study we undertook an analysis of spelling errors made by children in two dictation tasks (a passage and an isolated word list). Because spelling development of Greek children in Grades 1 and 2 has been studied before, we focused on older children, namely Grades 3–4 and 7. In these ages we would not observe the instabilities of early orthographic construction but more stable aspects of the maturing orthographic system. We applied a detailed classification of spelling errors into specific subtypes, to discern systematic patterns of performance. We studied the distribution of error types in the general population, to gain insight into the difficulties faced by the schoolchildren in relation to the specific features of the Greek orthographic system. We also compared the distributions of error types between children with and without dyslexia, looking for possible signature differences in the dyslexic spelling profile that might be informative for the understanding of dyslexia.

Cassar et al. (2005) argued that matching experimental groups on spelling ability provides a tighter control of the students' phonological development than the more

commonly used reading-level match, because spelling is more demanding and more dependent on phonological skills. Poor readers' low performance in phonemic decoding and word spelling stands in contrast with their nondistinctive spelling error patterns, compared with younger spelling level-matched controls. This suggests that deficient phonological skills may have a greater impact on spelling than on reading ability. If this is the case, then results comparable to spelling match might be obtained when poor readers are matched with younger controls simultaneously on reading and phonological awareness rather than on spelling. In this way we circumvent the potential circularity of a spelling match design while controlling for possible differences in reading and phonological development between different age groups.

Our study is quantitative, focusing on the distribution of errors across well-defined categories, and not on qualitative analysis of what children write in place of the correct target. In sum, our aim is to determine the extent to which analyzing spelling errors in a relatively transparent orthographic system can inform us about (a) spelling development, (b) the orthographic system, and (c) dyslexia.

Method

Participants

Data from a total of 586 children in Grades 3, 4, and 7 were analyzed in this study, including a *school sample* of 542 children and a *clinical sample* of 44 children.

The school sample was recruited from the general school population with the sole restrictions of native language (Greek), no repeated grades, and parental consent. Children were recruited in schools of the province of Attica (including the Athens metropolitan area) and in the city of Patra.

The clinical sample was recruited at special education services units in Attica, including the Medical-Pedagogical Centers of Rafina and Athens. Children were diagnosed with dyslexia prior to this study, primarily on the basis of poor reading and spelling performance.[1] All were of at least average intelligence and free from primary behavioral, emotional, psychiatric or neurological problems as determined by multidisciplinary expert assessment at the centers.

The spelling performance criterion used in the diagnosis of dyslexia is not circular with respect to the ensuing analysis because it only reflects the amount of spelling errors whereas our analysis examines the distribution of errors over categories. Moreover, the analysis is corroborated in groups of children selected specifically by nonspelling criteria, as detailed below.

[1] Although diagnosis is typically given without formal testing, due to lack of standardized testing batteries at the time of the study, this population is fully characterized in terms of reading, spelling, and cognitive performance, in comparison to the general population. Further discussion of the diagnostic tests and criteria can be found in Protopapas and Skaloumbakas (2007). See also Anastasiou and Polychronopoulou (2009) for diagnostic practices and associated problems.

Materials

All children were tested with an extensive battery assessing reading, spelling, and cognitive performance, allowing us to characterize the participants' profiles and to select well-matched subgroups. The following tests were administered: Pseudoword repetition, pseudoword reading, word reading, passage reading and comprehension, phoneme deletion, speech sound discrimination, nonverbal ability, digit span, and arithmetic. A presentation of the testing battery and descriptive statistics for each subgroup of children on every test can be found in the online supplementary materials. More information about the construction and validation of these tests can be found in Protopapas and Skaloumbakas (2007) and Protopapas, Skaloumbakas, and Bali (2008).

Two spelling tests were administered, analyzed in detail in the present study. The complete tests and relevant word and subword statistics are also provided in the supplementary materials.

Word spelling. A list of 22 words were individually dictated at a pace determined by the child's writing. Words were chosen to be frequent and to provide opportunities for a variety of spelling errors. The number of spelling errors of each error type was noted (see error classification below), allowing the possibility of more than one error in each word (on the basis of number of words correct, actual range 0–21, $\alpha = .87$ for both groups).

Passage spelling. An age-appropriate passage from Zahos and Zahos (1998) was dictated at a pace determined by the child's writing. Each passage contained well-known words (33 words for Grades 3–4 and 49 for Grade 7) and its meaning was easy for the target age. The words provided many opportunities for spelling errors. The number of spelling errors of each error type was noted.

Procedure

Children from the school sample were tested individually in a quiet room at the school during regular school hours by a specially trained graduate or senior undergraduate research assistant. Children from the clinical sample were tested individually at the center by a special education professional. Testing did not exceed two 40-min class periods, with a break in between. Additional breaks were provided when children became tired.

Error classification

Individual spelling errors were classified into 7 major and 37 minor categories (error types). Major categories were defined on the basis of the type of knowledge necessary for correct spelling (graphophonemic mappings, grammatical types, orthographic word knowledge, diacritic and punctuation conventions). Minor categories were defined on the basis of specific grapheme or morpheme properties, as indicated in the "Appendix". A detailed analysis of this classification system with explanations and examples in Greek is provided in Protopapas and Skaloumbakas (2010).

Phonological. Phonological errors were defined as spellings that affected the pronunciation of the word, altering its phonological identity (e.g., θάλασσα /θalasa/ "sea" spelled φάλασσα /falasa/; αντί /adi/ "instead" → ατί /ati/). Phonological errors are thought to reflect difficulty in representations and processes that are not specific to words and ostensibly independent of lexical knowledge. Because sublexical processes suffice to produce phonologically acceptable spellings, presence of phonological errors is indicative of sublexical, phonographemic deficits, regardless of any word-specific deficits.

The amount of phonological deviation was not taken into account. Any phonologically unacceptable spelling was considered a phonological error regardless of phonological distance from the target, word type, or within-word position. The phonological error category takes precedence in classification, subsuming any phonologically illegal misspellings. Thus, all following error categories concern *phonologically legal* (Treiman, 1993) spellings only. This precludes classification ambiguity and maximizes the number of phonological errors. Therefore, if only few phonological errors are recorded in the data, this cannot be ascribed to bias due to overly stringent criteria.

Grammatical. Grammatical (alternatively termed *morphological*) errors concerned alternative, phonologically equivalent, spellings of inflectional suffixes (e.g., δέντρων → δέντρον /ðɛdron/ "trees"—omega is appropriate for the plural genitive case). Grammatical errors may reflect insufficient mastery of inflectional morphology. Word-specific knowledge is unlikely to help with spelling of inflectional suffixes. General morphological knowledge, properly applied, can determine correct spelling unambiguously. Therefore, this category indicates deficient processing at a particular domain of linguistic representation, presumably extra-lexical or at least separate, extra-lexemic.

Orthographic. Orthographic (alternatively termed *etymological*, *historical*, or *visual*) errors concerned alternative, phonologically equivalent, spellings of word stems, including roots and any derivational morphemes preceding the obligatory inflectional suffix (e.g., όμορφη → ώμορφη /omorfi/ "beautiful"; μυρίζω → μυσ ρεύζω /mirizo/ "I smell"—the affix /iz/ -ιζ- produces a verb). Orthographic errors indicate imperfect registration of word-specific (or root-specific) knowledge. Therefore, these errors index the maturity and specificity of the developing orthographic lexicon. A preponderance of orthographic errors would be consistent with difficulties in memorizing information relevant for particular items. In contrast, phonological or grammatical errors reflect difficulty in employing mechanisms that apply over large classes of items.

Stress. Stress errors concerned the stress diacritic, which obligatorily marks the vowel of the stressed syllable in every Greek word with two or more syllables (e.g., όταν → οταν; συνεπής → συνέπης). Stress errors may be related to metrical sensitivity and suprasegmental awareness or information processing.

Punctuation. Punctuation errors concerned primary (period, comma, exclamation, question) and secondary (hyphen, colon, etc.) punctuation marks. They may indicate difficulties in phrase-level grouping, intonation, mastery of writing conventions, or perhaps inattention due to increased load, stress, or poor

concentration. They are not theoretically informative for word-level or sublexical spelling difficulties as examined in this study.

Other. This category included well-defined error types observed in children's writings that did not fit in the aforementioned categories. They may indicate misapplication or insufficient knowledge of print conventions at and around the word level.

Unclassifiable. This category included miscellaneous infrequent errors, e.g., mirrored letters.

Relative proportion calculation

To permit comparisons between error types and dictated materials, spelling error counts were normalized by the number of corresponding opportunities provided in each type of material. Opportunities were defined as a precise count of the total number of graphemes (or appropriate units) that could be misspelled, when feasible, or a reasonable approximation based on the possible locations and number of errors. Opportunity counts were made separately for major and minor categories. For example, opportunities for the general major category of phonological errors were defined as the total number of letters, because every misspelled (or omitted) letter could lead to different pronunciation. However, for the specific minor category of grapheme substitution the number of opportunities equaled the number of graphemes (not letters), so that each digraph counted as one opportunity. For the minor category of consonant digraph inversion, the number of opportunities equaled the number of consonant digraphs, and so on. The definition of the number of opportunities for each major and minor category of spelling error is listed in the "Appendix".

Statistical comparisons

There are large differences in the number of opportunities for different error types and in the number of spelling errors made by different children. This led to highly skewed distributions, with a few outliers having potentially excessive effects. In some minor categories very few or no errors were made. We were interested in retaining all error types, however infrequent, because they might prove revealing of specific deficits. Therefore, to preserve the integrity of the results without sacrificing too much power, statistical comparisons reported below employed nonparametric criteria such as the Mann–Whitney test, for between-group comparisons, and the Wilcoxon test, for within-group comparisons (with associated two-tailed asymptotic probabilities). We have verified that none of the main findings are affected by the choice to use nonparametric tests over more standard analyses of variance. When an ANOVA (not reported here) has also revealed a corresponding significant interaction, we report the Z statistic as a rough indicator of relative effect size across factors.

Table 1 Total number of errors made in each major category by each grade group

	Grades 3–4		Grade 7	
	Passage	Word list	Passage	Word list
Phonological	223	203	592	152
Grammatical	609	1,152	612	652
Orthographic	966	453	1,240	224
Stress	811	618	1,361	647
Punctuation	92	1	130	0
Other	245	18	287	26
Unclassifiable	21	4	24	1
Total	2,967	2,449	4,246	1,702

Results

The following analyses are based on 11,364 individual spelling errors. Table 1 lists the total number of errors in each major category for each grade group.

Special subgroups

On the basis of the children's performance profiles, we created a number of informative subgroups of the school sample: (a) The *general population* group comprises the entire school sample of the corresponding grade group. (b) The *nondyslexic* subgroup includes children well separated (nonoverlapping) from the clinical sample. That is, the tests best distinguishing the school from the clinical sample, at each grade group, were first determined by linear discriminant function analysis.[2] (They included the number of spelling errors but not their distribution.) The nondyslexic group was then formed by selecting school-sample children scoring outside the clinical-sample range on these tests. These children are definitely neither poor readers nor poor spellers. (c) The *dyslexic profile* group includes children with low (at the 25 % percentile) performance on 4 non-spelling measures best distinguishing the school and clinical samples in each grade group.[3] Because spelling measures were not considered in forming this group, there is no circularity in examining the spelling patterns of these "dyslexic-like" children. (d) The *reading match* group, for Grades 3–4 only, includes children matched one-to-one with children in the Grade 7 clinical sample on the reading and phonological measures that were common for the two samples, namely, word and pseudoword reading accuracy and time, phoneme deletion, and speech discrimination. Finally,

[2] Validation of the discriminant function against expert judgment for Grade 7 has indicated 99.1 % agreement for cases deemed unambiguous (by two experts); see Protopapas & Skaloumbakas (2007) and Protopapas, Skaloumbakas, & Bali (2008) for the details of these discriminant analyses.

[3] The distinguishing measures included, for Grades 3–4: pseudoword repetition, word reading accuracy, passage reading time, and phoneme deletion (based on Protopapas, Skaloumbakas, & Bali, 2008); for Grade 7: pseudoword reading time, word reading accuracy, word reading time, passage reading time (based on Protopapas & Skaloumbakas, 2007).

Table 2 Number of children in each special subgroup

	Grades 3–4	Grade 7
General population (school)	266	276
Nondyslexic	138	107
Dyslexic profile	15	16
Reading match	29	–
Diagnosed dyslexia (clinical)	15	29

(e) the *diagnosed dyslexia* group includes the entire clinical sample. Table 2 shows the number of children in each subgroup.

The results of comparisons among subgroups are found in the online supplementary materials (Table S3). Applying a Bonferroni correction for 14 pairwise comparisons in each pair of subgroups ($\alpha = .0036$), it seems that children with diagnosed dyslexia (clinical sample) in both grade groups are indistinguishable from the corresponding school sample children with a dyslexic profile (except that the latter in Grades 3–4 seem to be performing somewhat *more* poorly on word reading accuracy and phoneme deletion). Grade 7 children with diagnosed dyslexia are indistinguishable from the reading match group on all matching variables.[4] The differences between the children with diagnosed dyslexia and those from the school sample without dyslexia concern primarily reading speed and are greater and more extensive (including reading accuracy and digit span) in Grade 7, due to a larger clinical sample and lower variability in the school sample for this age group.

Patterns in the general population

Table 3 shows the median error proportion, as a percentage of corresponding opportunities, for each major type and each subgroup. It is notable that most children, even without any reading problems, make at least some errors (a few percent) in the main major categories when spelling a normal age-appropriate passage not including particularly tricky items. Figure 1 plots the distribution of mean relative error proportions over major categories for the general population on the top row and for the nondyslexic subgroup on the second row. Figure 2 plots the distribution of mean relative error proportions[5] over minor types for the nondyslexic children with open (unfilled) circles joined by continuous lines. Because proportions are normalized by the number of opportunities, a value of 1.0 in the graphs would indicate an error in every possible occasion for the corresponding type.

It is evident that the relative proportion of phonologically unacceptable spellings (phonological errors) is quite small, particularly for the nondyslexic children, compared to sizeable proportions of grammatical, orthographic, and stress errors. Note also the highly skewed distributions, indicating that relatively few children

[4] Naturally, they differ in age, passage reading (because passages were different in the two grade groups), and Raven's matrices (because it is a raw score, unstandardized for age).

[5] In Figs. 2 and 3 we report mean proportions because most medians are zero and their display would be less informative. It should be kept in mind, however, that error distributions were highly skewed in many error categories, making patterns of means difficult to interpret directly.

Table 3 Median proportions of spelling errors (percent of opportunities) in the passage and word list spelling tasks for each subgroup of children and each major category

	School sample		Nondyslexic		Clinical sample		Dyslexic profile		Reading match
	Grades 3–4	Grade 7	Grades 3–4	Grade 7	Grades 3–4	Grade 7	Grades 3–4	Grade 7	Grades 3–4
Passage									
Phonological	.0	.3[a]	.0	.0	.6	.7	1.3	.7	.0
Grammatical	4.0	3.7	4.0	.0	20.0	18.5	24.0	18.5	4.0
Orthographic	4.1	2.0	4.1	1.0	14.3	10.2	18.4	11.2	4.1
Stress	3.0	2.0	3.0	.0	24.2	22.4	12.1	6.1	3.0
Punctuation	.0	.0	.0	.0	2.6	.0	.0	.0	.0
Other	.0	.0	.0	.0	3.0	2.0	3.0	2.0	.0
Word list									
Phonological	.0	.0	.0	.0	.7	.0	.7	.3	.0
Grammatical	12.5	4.2	16.7	4.2	29.2	16.7	33.3	18.8	12.5
Orthographic	2.2	.0	2.2	.0	8.9	4.4	8.9	4.4	2.2
Stress	.0	.0	.0	.0	18.2	13.6	13.6	.0	.0
Punctuation	.0	.0	.0	.0	.0	.0	.0	.0	.0
Other	.0	.0	.0	.0	.0	.0	.0	.0	.0

[a] Mainly omissions of the diaeresis diacritic

made many errors. This pattern is particularly striking for stress errors, where a small minority of children evidently fail to use the diacritic while spelling, resulting in a maximum individual proportion of stress errors approaching or even reaching 1.0.

The distribution of the main error types traditionally considered problem areas for Greek spelling, that is, the grammatical and orthographic errors, seems balanced for the passages, both within and across grade groups, indicating that the passages were constructed appropriately for the corresponding ages. The proportion of grammatical errors exceeded that of orthographic errors for Grade 7 ($Z = 7.088$, $p < .0005$) but not for Grades 3–4 ($Z = 1.184$, $p = .236$). Naturally, Grade 7 children made fewer errors than Grade 3–4 children. The latter comparison is more meaningful for the word list, which was the same for the two grade groups (Phonological: $Z = 2.715$, $p = .007$; Grammatical: $Z = 9.738$, $p < .0005$; Orthographic: $Z = 8.904$, $p < .0005$; Stress: $Z = 2.551$, $p = .011$). The difference between grade groups was greater for grammatical and orthographic errors, compared to phonological errors. The difference was minimal for stress errors, not surviving Bonferroni correction for the comparison of multiple categories, indicating that a comparable proportion of children omit or otherwise misuse stress diacritics across grades.

Among the minor categories of spelling errors for the general population and in particular for the nondyslexic children, the most common types for both grade groups concerned the inflectional suffixes (both subtypes of grammatical errors), derivational morphemes, root vowel substitutions, and stress omissions. Other types

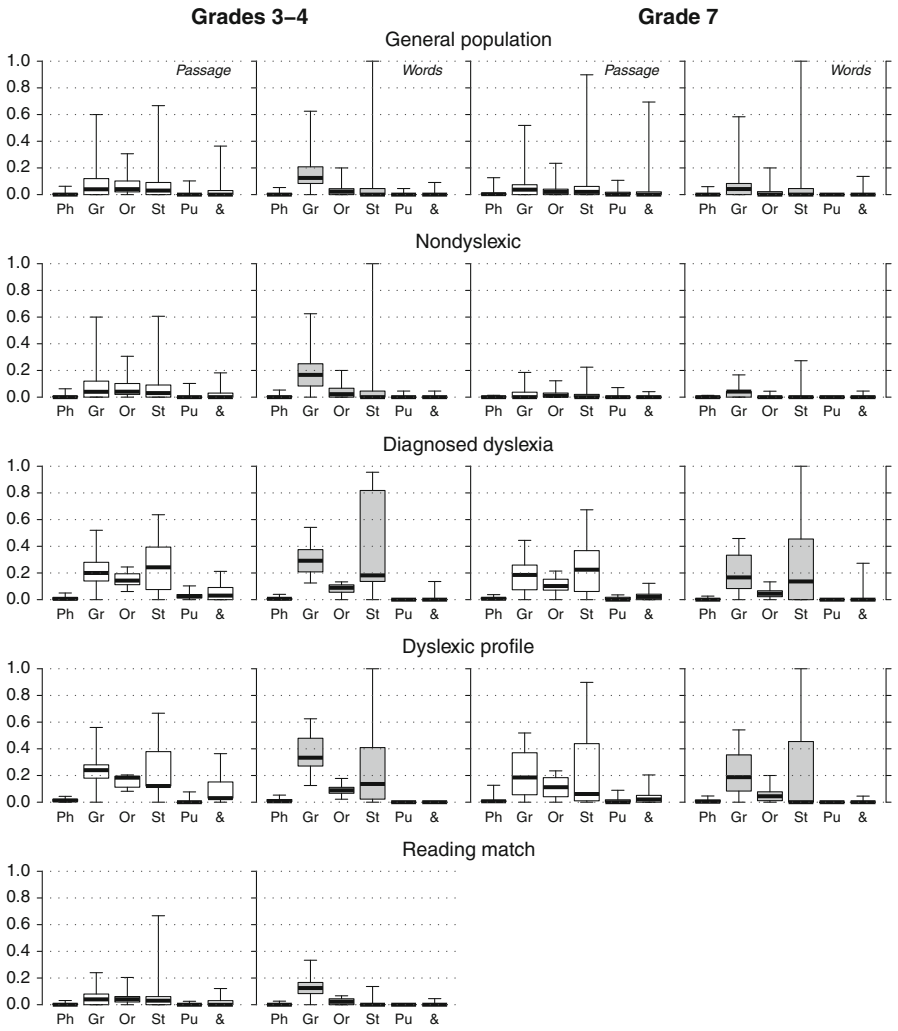

Fig. 1 Distributions of relative proportions (absolute number of errors divided by corresponding number of opportunities) of major categories of spelling errors for each task (word list and passage spelling) and subgroup of children. *Thick lines* indicate the median. *Bars* extend to the full range of the data. "General population" refers to the entire school sample; "diagnosed dyslexia" refers to the entire clinical sample. *Ph* phonological, *Gr* grammatical, *Or* orthographic, *St* stress, *Pu* punctuation, &: other

of errors were negligible, with the notable exception of the diaeresis diacritic, an instance of which appeared in the Grade 7 passage and was frequently omitted.

Patterns associated with reading difficulty

Figure 1 shows the distribution of mean relative error proportions over the major categories for children with dyslexia in the middle row, while Fig. 2 plots the distribution of mean error proportions over minor categories for children with

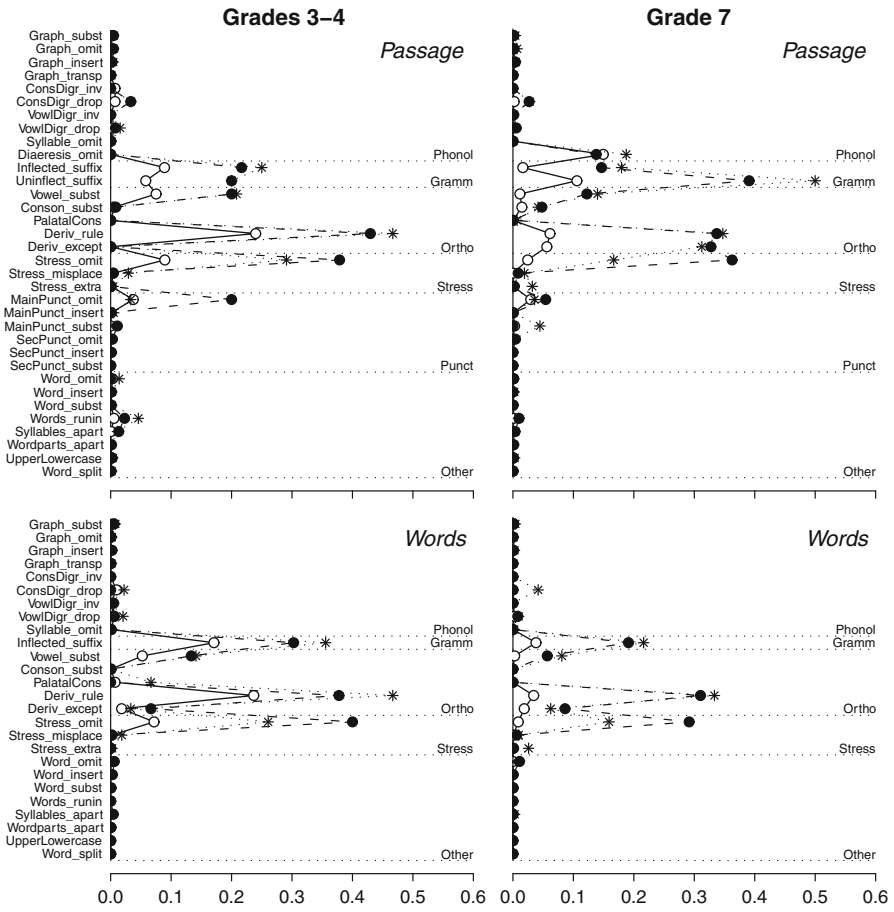

Fig. 2 Mean relative proportions (absolute number of errors divided by corresponding number of opportunities) of minor categories of spelling errors for each task, for children with dyslexia (entire clinical sample; *black circles* joined by *dashed lines*), children without dyslexia (selected from the school sample; *white circles* joined by *continuous lines*), and children with a dyslexic profile (selected from the school sample; *asterisks* joined by *dotted lines*). See "Appendix" for error type abbreviations

dyslexia with filled circles joined by dashed lines. Table 4 shows the results of nonparametric comparisons between the clinical sample (with diagnosed dyslexia) and each subgroup of the school sample (nondyslexic, dyslexic profile, and reading match).

It is notable that phonological errors are substantially fewer than grammatical, orthographic or stress errors. Even comparing absolute numbers of errors (listed in the online supplementary materials, Table S4), which are expected to be less different than proportions, due to the much higher number of opportunities for phonological errors than for other types, phonological errors in passage spelling were significantly fewer for children with dyslexia, both in Grades 3–4 (compared

Table 4 Nonparametric comparison (Mann–Whitney Z and associated two-tailed asymptotic significance) between the clinical sample in each age group and selected subgroups of the school sample on the major categories of spelling error types for each spelling task (passage and word list)

	Passage				Word list					
	Nondyslexic		Dyslexic profile		Nondyslexic		Dyslexic profile		Reading match	
	Z	p	Z	p	Z	p	Z	p	Z	p
Grades 3–4										
Phonological	2.265	.024	1.124	.261	1.696	.090	.673	.501		
Grammatical	3.731	.000	.710	.478	3.628	.000	1.025	.306		
Orthographic	4.081	.000	.314	.754	3.749	.000	.211	.833		
Stress	3.807	.000	.167	.868	4.540	.000	.607	.544		
Punctuation	4.300	.000	2.596	.009	.330	.742	.000	1.000		
Other	1.715	.086	1.293	.196	2.314	.021	1.793	.073		
Grade 7										
Phonological	4.103	.000	.048	.961	2.267	.023	1.473	.141	1.361	.173
Grammatical	6.469	.000	.679	.497	5.451	.000	.430	.667	1.451	.147
Orthographic	7.209	.000	.285	.776	7.127	.000	.434	.664	1.791	.073
Stress	6.665	.000	1.275	.202	6.533	.000	1.173	.241	4.025	.000
Punctuation	2.740	.006	.482	.629	.000	1.000	.000	1.000	.000	1.000
Other	5.137	.000	.149	.882	1.059	.289	.577	.564	.608	.543

with grammatical: $Z = 3.304$, $p = .001$; orthographic: $Z = 3.425$, $p = .001$; stress: $Z = 3.078$, $p = .002$) and in Grade 7 (vs. grammatical: $Z = 2.798$, $p = .005$; orthographic: $Z = 4.523$, $p < .0005$; stress: $Z = 4.183$, $p < .0005$). Moreover, the difference between dyslexic and nondyslexic children in phonological errors is smaller than the difference in these other three major categories, consistent with the lack of prominence of phonological errors in the general population.

The differences between the two grade groups for dyslexic children were only marginal (for the common isolated-word list, Phonological: $Z = 2.102$, $p = .036$; Grammatical: $Z = 2.254$, $p = .024$; Orthographic: $Z = 2.374$, $p = .018$; Stress: $Z = .754$, $p = .451$), not surviving Bonferroni correction for multiple comparisons. This is probably due in part to the small size of these groups. However, taking into account the great difference in spelling performance distributions between children with and without dyslexia, shown in Fig. 1, this finding may also indicate that the developmental rate of spelling improvement in children with dyslexia is depressed relative to that of children with typical reading and spelling development. This hypothesis must await future confirmation in larger samples because in these data, by 2-way MANOVA of spelling errors in the major categories, the interaction between sample and grade group was not significant.

Comparison of the clinical sample with the dyslexic profile subgroup suggests that these two groups of children are indistinguishable in terms of the distribution of their spelling errors over major categories (Fig. 1) and minor categories (Fig. 2,

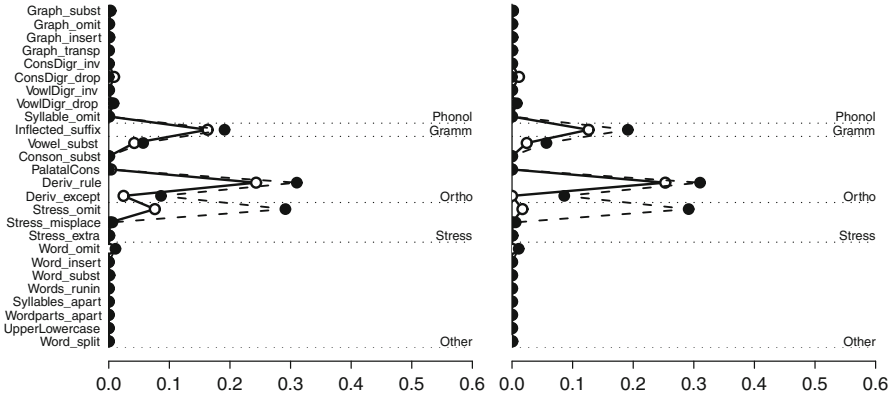

Fig. 3 Mean relative proportions (absolute number of errors divided by corresponding number of opportunities) of minor categories of spelling errors for the isolated word list only, for Grade 7 children with dyslexia (entire clinical sample; *black circles* joined by *dashed lines*) and children from the general population of Grades 3–4 (*white circles* joined by *continuous lines*). *Left* the entire Grade 3–4 school sample. *Right* the reading match subgroup of Grades 3–4. See "Appendix" for error type abbreviations

filled circles vs. asterisks). Therefore, non-spelling criteria including primarily low reading performance suffice to define a group of children in the general population with the spelling error profile of children with dyslexia, including amount and distribution of errors. This suggests that there is not much that is special about the diagnosis of dyslexia beyond impaired reading, at least as far as spelling is concerned.

To further corroborate this observation and address the issue of lagging versus deviant spelling development, Fig. 3 shows the spelling profile of Grade 7 children with dyslexia in comparison with the general school population in Grades 3–4 (left) and the reading-match subgroup[6] (right) on the isolated word list only (which was identical in the two grade groups). It is evident that these profiles are indistinguishable, with the sole exception of a significant difference in stress diacritic omissions, arising from a larger proportion of older children with dyslexia neglecting to use the diacritic than younger children without dyslexia. A second point of discrepancy is evident in Fig. 2: Specifically, there is no difference in diaeresis omissions between children with and without dyslexia. This diverges from the general pattern of larger error proportions by dyslexic children.

As an index of concordance among patterns of spelling errors, we calculated a nonparametric correlation coefficient (Spearman's ρ) between the number of errors made by the children with dyslexia (clinical sample) in each minor category and the corresponding number of errors made by children without dyslexia and by children with a dyslexic profile. We included only error types for which at least 10 errors were made in total by both samples, to prevent extremely small numbers from unduly influencing the analysis. Error type counts in passages and words were

[6] The reading-match group does not seem to depart in any way from the general population of Grades 3–4, so the matching process has not resulted in selection of unrepresentative outliers.

treated as distinct data points. The correlations were, for Grades 3–4, .855 with the dyslexic profile group and .864 with the nondyslexic group, based on 28 counts exceeding 10; and for Grade 7, .816 and .802, respectively, based on 39 counts, indicating high agreement among subgroups on the ranking of error types.

Discussion

In this study we have analyzed the spelling errors made by Greek schoolchildren with and without dyslexia in Grades 3–4 and 7, on the basis of a dictated age-appropriate passage and a list of isolated words common for the two age groups. Assuming that errors are unlikely to stem from lack of teaching, how is the observed pattern to be attributed to the characteristics of Greek orthography?

Phonological errors and orthographic consistency

As noted in the introduction, Greek is generally consistent at the grapheme-phoneme level for reading, with most graphemes corresponding unambiguously to one phoneme. The lower consistency in spelling is due to the fact that several phonemes can be spelled in different ways. Therefore, it is possible to make many spelling errors without affecting the segmental identity of the words. It is also possible to make any number of phonological errors, by simply using graphemes for the wrong phonemes, that may be similar visually, otherwise familiar, or just random. However, this is not in fact observed. Apparently, the properties of the orthography make phonological errors unlikely, because there are few cross-phoneme inconsistencies, in contrast to less transparent orthographies such as English, where different phonemes can be spelled with the same letter or letter combinations. As in German and French, word recognition in Greek may facilitate spelling development by providing transparent links for structuring bidirectional graphophonemic relationships and building advanced spelling skills (cf. Caravolas, 2004; Wimmer & Landerl, 1997).

This idea is further supported by considering digraphs, which introduce letter-level inconsistencies because letters used in isolation to spell one phoneme are also used in combination to represent a different phoneme. Despite widespread occurrence of digraphs in Greek, there is no evidence that they constitute a significant challenge to the developing speller. In our data, there were very few errors in digraph spellings, almost none of which concerned the (much less consistent) vowels. The only nonnegligible digraph error concerned consonant digraph simplifications, that is, dropping one of the two letters making up a voiced stop consonant and spelling it with the unvoiced stop consonant alone (i.e., $\mu\pi$ /b/ $\rightarrow \pi$ /p/). It is uncertain whether this constitutes a frank spelling error or, alternatively, whether stop consonant voicing is inadequately represented phonologically by some small proportion of children (cf. Treiman, Broderick, Tincoff, & Rodriguez, 1998).

Grammatical and orthographic errors

Grammatical and orthographic errors make up the bulk of significant misspellings in our sample. It is informative to split the orthographic major category into (a) spellings of word roots and (b) spellings of derivational morphemes. Root spellings are largely arbitrary and apply to specific word families containing the same lexical morpheme. Derivational spellings are also arbitrary but apply to larger classes of words with similar type relations, so they are necessarily more frequent and range over a variety of lexical roots. For example, in the word *ειδικές* (/iðicɛs/, feminine plural of "special," used in the Grade 7 passage), knowledge that the initial /i/ is spelled with *ει* is specific to this root. Correct spelling requires knowledge either of this particular word or of its relation with a few related words such as *είδος* (/iðos/ "species"). Either way, it must come from a specific entry in the orthographic lexicon. In contrast, knowledge that the second /i/ is spelled with *ι* does not require knowledge of the specific word (although that would obviously suffice). It may be derived from knowledge of the *–ικ–* affix, which is common to a large class of derived words (similar to English –ic) and may be represented at a morphological level within or connected to the lexicon. Finally, knowledge that the /ɛ/ is spelled with *ε* is not related to any particular lexical item(s) but to understanding that this is a feminine plural form of the word, which completely determines the spelling of the ending. In this sense, derivational morphemes are perhaps somewhat like inflectional morphemes, in terms of the diversity of root contexts with which they may appear.

Thus, spelling errors in both inflectional and derivational morphemes may reflect failures to internalize the *systematicity* of the orthographic system, whereas spelling errors in word roots may reflect failures to adequately represent the *particularity* of the system. These two aspects are likely intertwined but far from equivalent. Orthographic knowledge is built from experience with particular word tokens. It can directly support *particular* representations to the extent that repeated exposure adequately reinforces specific unitary entries. In contrast, *systematic* representations are supported to the extent that a variety of instances can lead to the formation of an adequate basis for generalization beyond past experience. Thus, although specific instances are the necessary entry point for all orthographic knowledge, the mechanisms required to support these kinds of knowledge and, hence, spelling development, may be distinct, at least in part.

The usefulness of this distinction becomes apparent by scrutinizing the distribution of errors over minor categories displayed in Fig. 2. Errors in inflectional and derivational morphemes figure prominent in the profiles of children with and without dyslexia in both grade groups. In contrast, root vowel substitutions are comparable in number to inflectional and derivational errors only in Grades 3–4 for children without dyslexia, and are greatly diminished in Grade 7. A plausible interpretation of this pattern may attribute the lasting problems in Greek spelling to difficulty with the systematic—rather than the idiosyncratic—aspects of inflection and derivation, consistent with the recent emphasis on the role of morphological awareness for spelling development (Bryant et al., 1999; Chliounaki & Bryant, 2007; Green, McCutchen, Schwiebert, Quinlan, Eva-Wood, & Juelis, 2003; Harris

& Giannouli, 1999) and on the use of morphological strategies in spelling (Diakogiorgi et al., 2005; Nunes, Bryant, & Bindman, 1997; Treiman, Cassar, & Zukowski, 1994; Waters, Bruck, & Malus-Abramovitz, 1988). In support of this view, Hoefflin and Franck (2005) also reported a preponderance of grammatical errors in the spellings of normally developing Grade 3–4 French children.

An alternative interpretation is that internalization of systematicities may not be achieved by capitalizing on explicit rules but on extensive practice with items exhibiting the systematicities. Consistent with the idea, Chliounaki and Bryant (2007) found that Greek children's word-specific spelling in Grade 1 predicted nonword inflection spelling in Grade 2. They concluded that children discover the regularities of inflection spelling through experience with specific inflected words. If this approach is on the right track then the emphasis on morphological awareness may be misplaced, because rote memorization of explicit rules may not lead to spontaneous application of the rules when spelling. Perhaps instead of teaching rules it may prove beneficial to encourage practice with individual words, enabling implicit learning of spelling patterns (Deacon, Conrad, & Pacton, 2008; Pacton & Deacon, 2008; cf. Pacton & Fayol, 2003; Pacton, Perruchet, Fayol, & Cleeremans, 2001).

Examination of the error distribution over minor categories reveals a preponderance of derivational suffix errors in comparison with errors on inflectional suffixes of inflected words and orthographic errors on stem vowels and consonants. This finding is in agreement with Diamanti (2005), who found a higher proportion of misspelled derivational than inflectional suffixes in the spellings of Greek children with and without dyslexia. It is also consistent with the finding in Spanish of Jiménez, O'Shanahan, Tabraue, Artiles, Muñeton, et al. (2008), who examined regular and arbitrary word spelling. As in Greek, certain phonemes in Spanish can be spelled with multiple graphemes. In some cases the correct spelling is lexically determined, hence arbitrary, whereas others are systematically determined by spelling rules, hence regular. Jiménez et al. found that correct regular spelling lags behind correct arbitrary spelling. They concluded that children have difficulty attending to the spelling rules while developing unimpeded in their lexical orthographic skills.

An apparent paradox arises when the differential development of spelling stems, derivational suffixes, and inflectional suffixes is considered alongside strong evidence for the unidimensionality of spelling ability, which is observed in structural analyses of spelling tests. For example, Notenboom and Reitsma (2003) and Keuning and Verhoeven (2008) found word spelling performance in Dutch to be largely accounted for by a single dominant latent factor after Grade 1. Comparable findings have been reported for a Greek spelling test including 60 items selected to pose a variety of difficulties on lexical roots as well as on derivational and inflectional morphemes. Rasch modeling revealed a single dimension accounting for a very large proportion of the variance across Grades 2–4 (Sideridis, Mouzaki, Protopapas, & Simos, 2008). These results indicate that as soon as basic graphophonemic mappings are mastered, in Grade 1, the distinct phonological component of individual differences in spelling disappears. A single dominant component is left, which captures the gradual mastery of rule-based, analogy-based,

and visual/orthographic strategies in an overlapping, predictable progression, at a pace dictated by reading development (cf. Keuning & Verhoeven).

The dyslexic spelling profile

On the basis of our data, perhaps the most striking characteristic of the spelling profile of children with dyslexia is its nondistinctiveness. In agreement with Bourassa and Treiman (2003), Bourassa, Treiman, & Kessler, (2006) and Cassar et al. (2005), we have failed to identify specific elements of spelling performance pertaining to theories of dyslexia. Children with dyslexia exhibited spelling performance fully in accord with their level of reading and phonological development. This was evident in comparing the distribution of errors made by children with dyslexia with those of (a) same-age children selected from the general population on the basis of their non-spelling performance (Fig. 2); (b) the general school population of younger children (Fig. 3, left), and (c) younger children individually matched on reading and phonological awareness (Fig. 3, right). The error pattern for Grade 7 children with dyslexia is more similar to the patterns for Grade 3–4 children with and without dyslexia than to the pattern for Grade 7 children without dyslexia. This is consistent with an interpretation of delayed rather than deviant spelling development.

In particular, we found no evidence for a preponderance of phonological errors in children with dyslexia. Our findings are not consistent with Hoefflin and Franck (2005), who reported a much higher proportion of phonetic spelling errors for dyslexic children in French (a less transparent orthography). Greek children with dyslexia seem to have made disproportionately *few* phonological errors, compared with their difference from children without dyslexia in grammatical, orthographic, and stress errors. Evidently, Greek children with dyslexia can apply an alphabetic spelling strategy correctly, spelling words and nonwords in phonologically acceptable ways, even when they cannot follow the morphological rules or historical conventions for specific grammatical types and root families (Porpodas 1999, 2001). Thus, there is no basis to support a phonological deficit hypothesis in the phonographemic performance of these children, in agreement with Nikolopoulos et al. (2003; for Greek) and Angelelli et al. (2004, 2010; for Italian). On the other hand, children with dyslexia did make significantly more phonological errors than children without dyslexia, and in this sense our results are also consistent with Diamanti (2005; for Greek) and with Caravolas and Volín (2001; for Czech). The discrepancy is only apparent, underscoring a distinction between (a) comparing among populations, in which case phonological spelling problems are evident, and (b) comparing among error types, in which case phonological spelling seems least affected in dyslexia.

The good match of spelling error profiles between children with dyslexia and children selected for exhibiting a (non-spelling) dyslexic profile also serves to alleviate concerns stemming from the small number of participating children with dyslexia, especially in the lower grades. There is no reason to suppose that testing more children would lead to any different results, since the error profile seems well defined and stable on the basis of reading and phonological performance.

There is, however, one domain of potential difference between spelling patterns of children with and without dyslexia, namely that a larger proportion of children with dyslexia neglect to use the stress diacritic, indicating that perhaps there is something special about spelling the diacritics.

The case of diacritics

Both diacritics of the modern Greek spelling appear to be in some sense outliers. The diaeresis was omitted by a similar proportion of children in the general population and children with dyslexia. This diacritic appeared only once, in the Grade 7 passage, so it is difficult to draw general conclusions because error proportions may be specific to the particular word. Still, it is notable that there were not more such errors in the clinical sample than in the school sample.

Exhibiting the opposite pattern, stress diacritics were omitted at a strikingly high rate by children with dyslexia, in both grade groups and for both spelling materials. This discrepancy might be considered as supporting a specific deficit in dyslexic performance, perhaps relating to poor sensitivity to stress patterns (e.g., Gutiérrez-Palma, Raya-García, & Palma-Reyes, 2009; Holliman, Wood, & Sheehy, 2010). However, the extreme individual variability evident in Fig. 1 for stress errors suggests that the high overall proportion of stress diacritic omission is not due to a widespread stress-related difficulty among children with dyslexia but, rather, a result of a minority of children neglecting the diacritic. Figure 4 plots the relative proportions of stress errors in words versus passages for each child in a way that allows deviant individual performance to stand out.[7] Note that, in Grades 3–4 some dyslexic and some nondyslexic children fail to use the diacritic much or most of the time, whereas in Grade 7 only some dyslexic (or dyslexic profile) children do. The overall appearance is suggestive of severe and persistent delay for a minority of dyslexic children. In a related approach, Defior et al. (2009) also found the stress diacritic to be very hard for Spanish children to learn.

However, evidence from reading suggests an alternative interpretation. Stress diacritics are underutilized in reading. Children in Grades 2–4 place more weight on the segmental identification of the words than on the diacritic for stress assignment (Protopapas & Gerakaki, 2009). Only highly proficient adult readers rely strongly on the diacritic (Protopapas, Gerakaki, & Alexandri, 2007). This is consistent with the hypothesis that processing of the diacritic is not only challenging but also largely unnecessary, insofar as the occasions requiring decoding of the diacritic for lexical disambiguation have been estimated at less than 1 % for isolated words (Protopapas, 2006).

Might the diaeresis diacritic also be redundant for word disambiguation? A search through the 217,664 word forms of the IPLR C corpus (Protopapas, Tzakosta, Chalamandaris, & Tsiakoulis, in press) returns a single word pair[8] that

[7] The maximum proportion of stress errors in the passage is lower than for the word list because the passage included monosyllabic words, written without a diacritic. A stress error on those would have to be an extraneous diacritic. Such errors were rare, vastly outnumbered by omissions.

[8] The two words are παιδάκια (/pεðaca/ "kids"), with 143 occurrences (4.84 per million tokens), and παϊδάκια (/paiðaca/ "chops"), with 16 occurrences (0.54 per million).

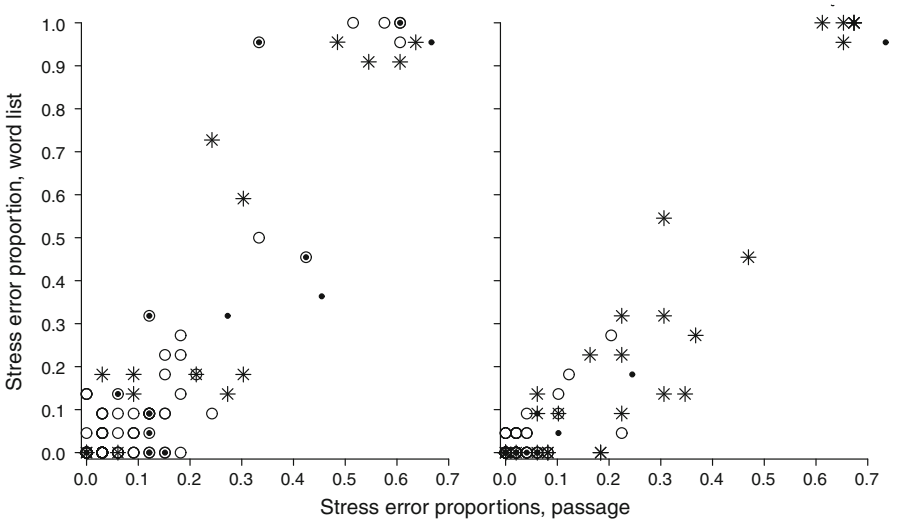

Fig. 4 Relative proportion of stress errors of individual children with dyslexia (*asterisks*), without dyslexia (*empty circles*), and with a dyslexic profile (*black dots*) in the word list plotted against their relative proportion of stress errors in the passage. *Left* grades 3–4. *Right* grade 7. Each data point may correspond to any number of children from the same group with the same proportions

requires the diacritic for disambiguation, as all other instances of the diaeresis do not result in existing words when the diacritic is removed. Therefore, even though the diaeresis has clear phonological consequences in decoding at the grapheme-phoneme level, its role in lexical access seems negligible.

In sum, use of both diacritics in spelling seems to be distinct from segmental phonographemic encoding and from morphological and lexical considerations. The diaeresis diacritic is omitted disproportionately few times by children with dyslexia compared to children without dyslexia, whereas the stress diacritic is omitted disproportionately more frequently. The stress diacritic is also omitted by a sizeable proportion of the general population, especially in the younger group. However, whatever is special about spelling of the diacritics does not appear specific to dyslexia but, rather, to their function and distribution in the orthographic system.

Limitations on item difficulty and reliability

Our findings suggest that difficulties with spellings of inflectional and derivational suffixes are more extensive and more long-lasting than difficulties with historical spellings of word roots for the general population and even more so for children with dyslexia. However, it may be impossible to conclude with certainty whether grammatical or orthographic errors predominate in children's spellings. The problem originates in creating comparable stimuli to assess different kinds of errors, such that the comparison will be representative and generalizable. For example, each particular inflectional suffix may be associated with a level of spelling

difficulty, perhaps related to its frequency of occurrence, the commonality and simplicity of its critical grapheme and its consistency relative to other suffixes. Likewise, each word root component with multiple phonologically equivalent spellings may also be associated with a level of spelling difficulty, relative to factors such as frequency, consistency, and family size. Thus, there may be multiple spelling challenges within a single word, associated with different levels of difficulty. These within-word differences preclude any fine-grain definition of word-level spelling difficulty.

To the extent that spelling difficulty, either for an entire word or for a single component thereof, can be estimated by the probability of being spelled correctly by a reference population, it becomes clear that any attempt to circumvent empirically the variability conundrum will result in circularity: if proportion of correct spellings determines level of difficulty, as commonly understood by psychometric standards, then difficulty levels become normalized to be equivalent by reference to a population and cannot subsequently be used for between-category comparisons. The psychometric approach may be recommended for determining the level of spelling performance for individual children and individual error types. A nuanced approach to spelling assessment, with separate standardization for specific error categories, may provide a more accurate picture of spelling performance for individual children. However, it will not answer which are the most frequent or most important error types in any general sense.

Therefore, representative texts may be the only valid recourse for investigating, however imperfectly, differences between error types. This is the approach we have taken, basing our analyses on passages composed by experts with longstanding experience. In this respect, between-category comparisons—as well as overall levels of performance—are more reliable when based on the dictated passages rather than on the isolated word list. This is because the list was designed to be especially challenging, even for Grade 7 children, placing special emphasis on commonly misspelled inflectional suffixes. Future work should verify our findings using a larger array of age-appropriate texts.

An additional limitation of our study stems from the uneven distribution of error opportunities over the major and minor categories, which was also different between materials (see "Appendix"). For categories with very few opportunities, it is impossible to disentangle difficulty related to the general knowledge in question versus knowledge of the specific dictated words. Estimates based on low opportunity counts need to be examined further using specially designed materials. However, it may prove overly challenging to construct properly counterbalanced yet natural age-appropriate materials.

The number of opportunities for each type of error, in conjunction with the difficulty of individual elements within a word, may affect the pattern of results. Choice of a relatively easy inflectional suffix will naturally cause the grammatical error count to diminish, whereas a more unusual or otherwise challenging suffix will cause the corresponding count to increase. Each word can have at most one inflectional suffix, usually allowing a single opportunity for a grammatical error, whereas there is no limit on the number of stem phonemes with alternative spellings. Therefore, the absolute number of orthographic errors will be higher than

the absolute number of grammatical errors in most noncontrived materials. However, the conclusion that spelling lexical roots is more severely compromised than spelling inflectional suffixes will be unwarranted based on absolute numbers. If we are looking to identify impaired cognitive processes, it is important to consider the probability of failure based on error opportunities rather than raw counts.

A limitation of our methodology arises from the necessity to individuate spelling errors in order to classify them. This necessarily excludes participants with spelling so poor that misspellings cannot be unambiguously itemized. Although such extremely poor spelling is uncommon, even for children with dyslexia, it remains a potential threat to the generality of our conclusions that children with the most severe difficulties cannot be included in the analysis. Finally, it should be noted that our data do not allow us to control for differences in print exposure that might underlie some of the differences in spelling performance or partially account for the observed patterns of apparently delayed spelling in children with a dyslexia profile or diagnosis.

Conclusion

In this study we classified children's spelling errors according to the information thought necessary for spelling correctly each part or aspect of a word or text—a theoretical cognitive-linguistic distinction. Results indicate that spelling errors can be informative about the aspects of the orthographic system that pose the greatest difficulties for developing spellers. Specifically, the high feedforward (reading) consistency of Greek diminishes the opportunity for phonological errors, resulting in high phonological accuracy by children of the general population as well as by children with dyslexia. The low utility of the diacritics for lexical disambiguation may underlie their erratic use by a nonnegligible proportion of children with or without reading difficulties. The dependence of spelling ambiguities on morphological awareness is consistent with difficulties in spelling inflectional suffixes, which persist through a long period of morphological development, whereas lexical idiosyncrasies determining word root spellings seem to be mastered more readily by the general population. Spelling of derivational suffixes proved to be the most challenging component of spelling development, as an apparently systematic domain that fails to benefit sufficiently from extensive school drilling, presenting the largest problems for children with and without dyslexia. Thus, spelling errors may point towards models of implicit learning as opposed (or in addition) to explicit rules.

This study suggests that spelling errors are not informative about the existence or nature of reading and spelling difficulties. The relative proportions of spelling errors distributed among the major and minor categories failed to establish a dyslexic profile that might distinguish children with dyslexia from younger children with matched, age-appropriate, reading and phonological awareness skills. Spelling profiles of children diagnosed with dyslexia were also indistinguishable from those of same-age children with the lowest reading and phonological awareness performance, suggesting that reading and phonological development drives spelling

performance. Our study confirms this oft-questioned hypothesis at an unprecedented level of detail and analysis, demonstrating it clearly in a less-researched orthography of intermediate spelling transparency. That there is nothing special about the spelling profiles of children with dyslexia may have significant educational implications insofar as the requirements for targeted intensive remediation should focus on the same aspects of the Greek orthographic system that present the greatest difficulties for the general population.

Specifically, teachers working with children with dyslexia or spelling difficulties should pay special attention to systematic patterns in the orthography, such as derivational and inflectional suffixes. The greatly diminished rate of orthographic learning exhibited by children with dyslexia indicates that greater persistence and repetition may be necessary than is possible within a regular classroom environment. In particular, deficits in the internalization of orthographic systematicities indicate that spelling patterns are not spontaneously applied but must be individually and explicitly emphasized in supporting educational activities. Further research focusing on intervention will be necessary to identify and document efficient procedures associated with positive spelling outcomes.

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Appendix

See Table 5.

Table 5 Opportunities for spelling errors: definitions and counts

Error type	Abbreviation	Definition of opportunity count (number of…)	Passages		Word list
			G7	G34	
Phonological	*Phonol*	*Letters*	*292*	*160*	*151*
Grapheme substitution	Graph subst	Graphemes	255	140	136
Grapheme omission	Graph omit	Graphemes	255	140	136
Grapheme insertion	Graph insert	Letters	292	140	151
Grapheme transposition	Graph transp	One less than graphemes	206	107	114
Consonant digraph inversion	ConsDigr inv	Consonant digraphs	9	2	3
Consonant digraph simplification	ConsDigr drop	Consonant digraphs	9	2	3
Vowel digraph inversion	VowlDigr inv	Vowel digraphs	25	17	13
Vowel digraph simplification	VowlDigr drop	Vowel digraphs	25	17	13
Syllable omission	Syllable omit	Syllables	117	68	66
Diaeresis omission	Diaeresis omit	Letters with diaeresis diacritic	1	0	0
Grammatical	*Gramm*	*Graphemes with M.P.E.S. in grammatical suffixes*	*27*	*25*	*24*

Table 5 continued

Error type	Abbreviation	Definition of opportunity count (number of…)	Passages		Word list
			G7	G34	
Inflected suffix	Inflected suf	Graphemes with M.P.E.S in inflectional suffixes of inflected parts of speech (articles, verbs, nouns, adjectives)	24	24	24
Uninflected suffix	Uninflect suf	Graphemes with M.P.E.S. in inflectional suffixes of uninflected parts of speech (adverbs, gerunds)	3	1	0
Orthographic	*Ortho*	*Graphemes with M.P.E.S. in stem morphemes*	*98*	*49*	*45*
Root vowel substitution	Vowel subst	Root vowel graphemes with M.P.E.S.	42	16	17
Consonant substitution	Conson subst	Words plus double consonant letters	36	23	22
Consonant palatalization	Palatal cons	Palatal consonant graphemes	9	1	1
Derivational/rule	Deriv rule	Graphemes with M.P.E.S. in derivational morphemes taught in school as rules	9	9	3
Derivational/exception	Deriv except	Graphemes with M.P.E.S. in derivational morphemes violating school rules (taught exceptions)	2	0	2
Stress diacritic	*Stress*	*Words*	*49*	*33*	*22*
Stress diacritic omission	Stress omit	Stressed words (two or more syllables plus exceptions)	33	22	22
Stress diacritic misplacement	Stress misplace	Stressed words (two or more syllables)	92	50	58
Superfluous stress diacritic	Stress extra	Syllables in stressed words minus stressed words	113	64	58
Secondary stress omissions	SecStress omit	Words with secondary stress	0	0	0
Punctuation	*Punct*	*Words plus punctuation marks*	*56*	*39*	*22*
Primary punctuation omission	MainPunct omit	Primary punctuation marks	7	6	0
Primary punctuation insertion	MainPunct insert	Words plus punctuation marks	56	39	0
Primary punctuation substitution	MainPunct subst	Primary punctuation marks	7	6	0
Secondary punctuation omission	SecPunct omit	Secondary punctuation marks plus average lines of text	33	22	0
Secondary punctuation insertion	SecPunct insert	Words plus punctuation marks	33	22	22
Secondary punctuation substitution	SecPunct subst	Secondary punctuation marks plus average lines of text	33	22	0
Miscellaneous	*Other*	*Words*	*49*	*33*	*22*

Table 5 continued

Error type	Abbreviation	Definition of opportunity count (number of…)	Passages		Word list
			G7	G34	
Word omission	Word omit	Words	49	33	22
Word insertion	Word insert	Words plus punctuation marks	56	33	22
Word substitution	Word subst	Words	49	39	22
Phrase omission	Phrase omit	N/A	0	0	0
Missing interword space	Words runin	One less than words	48	32	0
Space between syllables	Syllables apart	Syllables minus words	68	35	44
Intraword space within syllable	Word break	Letters minus syllables	175	92	85
Case substitution upper/lower	UpperLower	Letters	292	160	129
Inappropriate word split at line end	Word split	Letters minus syllables	175	92	85

Major categories in italics

M.P.E.S., multiple phonologically equivalent spellings; G34, Grades 3–4; G7, Grade 7

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