Developmental Surface and Phonological Dyslexia in both Greek and English

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Abstract

The hallmark of developmental surface dyslexia in English and French is inaccurate reading of words with atypical spelling-sound correspondences. According to Douklias, Hanley and Masterson (2008), surface dyslexia can also be observed in Greek (a transparent orthography for reading that does not contain words of this kind). Their findings suggested that surface dyslexia in Greek can be characterized by slow reading of familiar words, and by inaccurate spelling of words with atypical sound-spelling correspondences (Greek is less transparent for spelling than for reading). In this study, we report seven adult cases whose slow reading and impaired spelling accuracy satisfied these criteria for Greek surface dyslexia. When asked to read words with atypical grapheme-phoneme correspondences in English (their second language), their accuracy was severely impaired. A co-occurrence was also observed between impaired spelling of words with atypical phoneme-grapheme correspondences in English and Greek. These co-occurrences provide strong evidence that surface dyslexia genuinely exists in Greek and that slow reading of real words in Greek reflects the same underlying impairment as that which produces inaccurate reading of atypical words in English. Two further individuals were observed with impaired reading and spelling of nonwords in both languages, consistent with developmental phonological dyslexia. Neither of the phonological dyslexics read words slowly. In terms of computational models of reading aloud, these findings suggest that slow reading by dyslexics in transparent orthographies is the consequence of a developmental impairment of the lexical (Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001; Perry, Ziegler, & Zorzi, 2010) or semantic reading route (Plaut, McClelland, Seidenberg and Patterson, 1996). This outcome provides evidence that the neurophysiological substrate(s) that support the lexical/semantic and the phonological pathways that are involved in reading and spelling are the same in both Greek and English.

Introduction

Children with developmental dyslexia in English-speaking countries generally experience difficulties with reading and spelling familiar words and unfamiliar word-like letter strings (nonwords). Nevertheless, two distinct patterns of selective impairment can be observed in some individuals. Cases of developmental *surface* dyslexia read and spell nonwords relatively well. However, these individuals have difficulties in learning to read and spell inconsistent or irregular words (e.g. Castles & Coltheart, 1996; Coltheart, Masterson, Byng & Riddoch, 1983; Goulandris & Snowling, 1991; Hanley, Hastie & Kay, 1992; Hanley & Gard, 1995; Romani, Ward & Olson, 1999; Temple, 1985). Irregular words (e.g. *come*) contain one or more atypical correspondences between their spelling and their sound. Surface dyslexia is also associated with regularization errors (the inappropriate assignment of typical spelling-sound correspondences to irregular words during reading, and the inappropriate assignment of typical sound-spelling correspondences to irregular words during spelling). In contrast, individuals with developmental *phonological* dyslexia have a difficulty in reading and spelling nonwords despite relatively good reading and spelling of familiar words (e.g. Campbell & Butterworth, 1985; Funnell & Davidson, 1989; Howard & Best, 1996; Snowling & Hulme, 1989; Temple & Marshall, 1983; Wang, Nickels & Castles, 2015). Both surface (e.g. DiBetta & Romani, 2006; Romani, DiBetta, Tsouknida, & Olson, 2008) and phonological dyslexia (e.g. Howard & Best, 1996) have been shown to persist into adulthood.

Differences of this kind have also been observed amongst groups of people with dyslexia (Castles & Coltheart, 1993; Castles, Bates & Coltheart, 2006). Castles and her colleagues administered tests of irregular word and nonword reading to a large number of dyslexic children and compared their performance with normally developing readers with whom they were matched for chronological age (CA controls). Although the majority of dyslexic children were significantly impaired at both irregular word reading and nonword reading, substantial numbers of surface dyslexics (selectively impaired at irregular word reading) and phonological dyslexics (selectively impaired at nonword reading) were observed in both studies. The use of CA controls in studies of this kind was criticized by Snowling, Bryant and Hulme (1996), and numbers of surface dyslexics are substantially reduced when reading-age (RA) matched controls are used instead (Manis, Seidenberg, Doi, McBride-Chang & Peterson, 1996; Stanovich, Siegel and Gottardo, 1997). Nevertheless, the use of RA controls in the identification of surface dyslexia is itself controversial (e.g. Douklias, Masterson & Hanley, 2009; Jackson & Coltheart, 2001; McDougall, Borowsky, MacKinnon, & Hymel, 2005), and approximately equal numbers of surface and phonological dyslexics were observed when dyslexics and controls were more appropriately matched for reading ability (Wybrow & Hanley, 2015).

These two dyslexic subtypes can be understood as a selective developmental impairment to one of two reading routes in computational models of reading aloud. In the DRC model (Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001) and the CDP++ model (Perry, Ziegler, & Zorzi, 2010), the lexical route can accurately process familiar regular and irregular words, and the non-lexical route can accurately process nonwords and regular words irrespective of their level of familiarity. Phonological dyslexia is consistent with a selective impairment to the development of the nonlexical route, whereas surface dyslexia can be conceptualized as a selective impairment to the development of the lexical route. In the *Triangle* model (Plaut, McClelland, Seidenberg & Patterson, 1996; Harm & Seidenberg, 1999; Woollams, 2014), there is a semantic reading route that can generate the correct pronunciations for both regular and irregular words by activating their meaning from their orthography. This pathway is particularly important for the accurate reading of irregular words of relatively low frequency that cannot be read correctly by the phonological route. Impaired development of this pathway is generally associated with surface dyslexia (e.g. Woollams, 2014). Nonwords, regular words and irregular words of high familiarity can be read on the basis of direct mappings between orthography and phonology (the phonological route). Phonological dyslexia in the triangle model is attributed to impaired development of the phonological units themselves (Harm & Seidenberg, 1999). This impairment will have particularly severe implications for the development of the phonological pathway and means that phonological dyslexics will rely disproportionately on the semantic pathway for reading (Woollams, 2014).

Surface dyslexia in English (e.g. Castles & Coltheart, 1993) and French (Ziegler, Castel, Pech-Georgel, George, Alario, & Perry, 2008) is identified by examining the accuracy of irregular word reading. An important issue is whether the distinction between surface and phonological dyslexia can also be applied to those who are learning to read more transparent alphabetic orthographies that contain relatively few words that have atypical spelling-sound correspondences. Following Wimmer (1993), it is now well established that dyslexia in transparent orthographies is more strongly associated with slow than with inaccurate reading (e.g., Greek: Porpodas, 1999; Italian: Zoccolotti, De Luca, Di Pace, Judica, Orlandi, & Spinelli, 1999; Dutch: Yap & Van der Leij, 1993; Van den Bos, 1998; Norwegian: Lundberg & Hoien, 1990; German: Wimmer, 1993; Spanish: Gonzalez & Valle, 2000). One possibility is that these longer reading times indicate an overreliance on the slower phonological/ nonlexical route, and therefore reflect impaired development of the lexical or semantic route, consistent with surface dyslexia. Alternatively, Ziegler and Goswami (2005) suggested that slow reading in transparent orthographies might be the consequence of a phonological impairment. They argued that impaired development of the phonological/nonlexical reading route might allow accurate reading of words and nonwords in a transparent orthography because the consistent grapheme-phoneme correspondences are relatively easy to acquire. A phonological impairment might nevertheless produce slow reading of both words and nonwords in a transparent orthography if it prevented people with dyslexia from applying letter-sound correspondences as quickly as ordinary readers.

Many shallow orthographies, including German, are less transparent for writing than for reading and contain many words with atypical sound-spelling correspondences. Bergmann and Wimmer (2008) found that German-speaking dyslexics had particular problems in spelling irregular German words and argued that dyslexia in German is associated with a lexical rather than a phonological impairment. The assumption here is that the same orthographic units support both reading and spelling. Consequently, the deficit in dyslexia/dysgraphia is in those representations themselves (rather than in their input or output pathways, which might affect one task but not the other). Further evidence for a lexical rather than a phonological impairment emerged when the German-speaking dyslexics found it difficult to distinguish correctly spelled words from pseudohomophones on a written lexical decision task but were able to distinguish pseudohomophones from phonologically incorrect spellings. Bergmann and Wimmer concluded that dyslexia in German more closely resembles surface than phonological dyslexia.

Nevertheless, it might be also be possible to identify poor readers who experience a selective phonological impairment when learning to read a transparent orthography. In contrast to those with a selective lexical impairment, those with a selective phonological impairment might read real words relatively quickly and spell atypical words relatively accurately, but experience selective difficulties in reading and spelling nonwords. In order to address this issue, Douklias, et al. (2009) investigated whether distinct types of dyslexia could be identified within groups of dyslexic children who were learning to read Greek. Greek is considered to be one of the most transparent of alphabetic orthographies for the purposes of reading (Seymour, Aro, & Erskine, 2003). However, like German, Greek is much less transparent when it comes to spelling. The spelling of three of the five vowels is not predictable from phonology alone. For instance, the phoneme "e" can be represented by five different graphemes: ι, η, υ, ει and οι, with the appropriate spelling being determined by principles of morphology and etymology (Chliounaki & Bryant, 2002; Porpodas, 1999). Douklias et al. referred to words that contained less frequent spellings of these vowels as being irregular. Because this terminology differs from how the term 'irregular' is generally used in English, we instead refer to these words as being *atypical*. Douklias et al. identified two Greek dyslexic children with accurate nonword reading and spelling who read words relatively slowly. Consistent with a lexical impairment, these slow readers also made a relatively large number of errors when spelling Greek words with atypical sound-spelling correspondences. Douklias et al. concluded that these children were suffering from a form of developmental surface dyslexia. Two additional children were identified who performed quickly and accurately when reading familiar words but made a relatively large number of errors when reading and spelling nonwords, consistent with developmental phonological dyslexia. Using the same criteria, Niolaki, Terzopoulos and Masterson (2014) identified three Greek children with characteristics of phonological dyslexia and two Greek children with characteristics of surface dyslexia among a sample of nine dyslexic children.

It therefore appears that cases of both surface and phonological developmental dyslexia can be identified amongst individuals who are learning to read Greek. The present study examined whether individuals who suffer from surface and phonological dyslexia in Greek would also suffer from surface and phonological dyslexia respectively in English when it is learnt as a second language. That is, would individuals with good lexical processing who read and spelt nonwords inaccurately in Greek be selectively impaired at reading and spelling English nonwords? Moreover, would individuals with accurate nonword reading who showed relatively slow reading of real Greek words and a strong typicality effect when spelling Greek words perform poorly at reading and spelling irregular words in English?

Such an outcome would indicate that individuals who are categorized by these criteria as having surface or phonological dyslexia in Greek experience a similar underlying impairment as readers who are categorized as having surface or phonological dyslexia in English. This result would provide important information about the nature of dyslexia in transparent orthographies and about the relationship between dyslexia in transparent alphabetic orthographies and dyslexia in an opaque alphabetic orthography such as English. It would also follow that the Greek and English reading systems, including their lexical/semantic and phonological pathways are supported by the same underlying neurobiological substrate. So, when a part of this substrate is weak, it manifests in Greek and English in an analogous fashion.

The first step in the investigation was to identify cases of developmental phonological and surface dyslexia in Greek among Greek university students who were studying in the UK. The critical question was whether these individuals would show an analogous pattern of impairment when reading and spelling words in English (their second language). A cross-cultural comparison of this kind requires adult readers as participants. The use of adult dyslexics ensures that the Greek participants have received sufficient exposure to the English orthography to have allowed them an opportunity of becoming competent readers and spellers of English. Nevertheless, it can be difficult to investigate the original distal causes of an adult dyslexic’s reading impairment when so much time has elapsed since he or she started to learn to read. A potential concern is that an intervention in childhood might have influenced the reading strategies that a dyslexic individual adopts as an adult. This issue appears less problematic for the purposes of the present study because it is investigating the co-occurrence in different languages of specific dyslexic sub-types. It seems unlikely that an intervention could induce an individual with dyslexia to produce a consistent reading and spelling pattern across Greek and English given the differences in the transparency of the two orthographies.

Method

Participants

The participants were 34 Greek nationals who were students at British Universities. They were aged between 20 and 38 years-old, and their first language was Greek. Twenty-five participants had normal reading and spelling ability and acted as controls. The remaining nine participants were significantly impaired at both reading and spelling in Greek.

The nine poor readers/spellers were recruited as part of a doctoral study that investigated the nature of developmental dyslexia in Greek (Sotiropoulos, 2015). A total of 30 Greek students who had experienced developmental literacy difficulties were tested. Nine of these 30 cases were included in the present report because they met the criteria for either surface or phonological dyslexia in Greek (see below), and because they were available to undergo a further series of reading and writing tasks in English. They all performed within the normal range on a test of Greek vocabulary that was based on a translation of the English items in the vocabulary sub-test of the WAIS (Wechsler, 1999). They had all been classified as dyslexic by educational psychologists in Greece during their school years. None of them could recall have undergone any reading remediation as children that emphasised either phonological or orthographic processing strategies. The remaining 21 students with literacy problems in Greek were not included in the present report because they were mixed dyslexics with significant impairments on tests associated with both surface and phonological dyslexia (n= 9), because they were significantly impaired at reading only (n=6), because they were significantly impaired at spelling only (n=5), or because they were unavailable for further testing (n=1). Approval for the study was obtained from the Ethics Committee of the University of Essex.

Cases of Surface and Phonological Dyslexia in Greek

Greek word lists

A list of 54 real Greek words was used to assess reading and spelling (see appendix 1). The 54 items were all regular (typical) for reading due to the high grapheme-to-phoneme (feed-forward mapping) transparency of the Greek writing system. However, because Greek is less transparent for spelling than for reading, it was possible to use words that differed in the frequency of their phoneme-to-grapheme correspondences (feedback mapping) to investigate spelling. Half of the items were classified as typical, and half were classified as atypical. This distinction was based on the frequency of the Greek letters and bigrams provided by Ktori, van Heuven, and Pitchford (2008). Words that contained only the most frequent phoneme-grapheme correspondences were considered to be typical. Words that contained at least one example of a less frequent correspondence were deemed atypical. For instance, the letter ‘ι’, which represents the phoneme /e/, is seen in the Greek language more frequently than the letter ‘η’ or any of the other letters that can represent this phoneme. Therefore words that contained “ι” were considered typical whereas words containing “η” were considered atypical.

The list contained an equal number of words of low word frequency (0 to 13.89 appearances per million), medium frequency (13.89 to 53.89 appearances per million) and high frequency (above 53.89 appearances per million). Lemma frequency of the words was taken from the Hellenic National Corpus (available at hnc.ilsp.gr/). This is a corpus of modern Greek texts drawn from several media sources such as books, periodicals, and newspapers containing approximately 47 million written words. There was an equal number of short words (4, 5, 6 and 7 letters), words of medium length (8, 9, 10 letters) and long words (11 letters and above). Mean letter-length was 9 letters. The typical and atypical words were of similar mean frequency, length, imageability and age of acquisition (AoA). Because no database for AoA and imageability in Greek is available, AoA ratings were obtained from 100 highly literate Greek adults. There were no significant differences (all F's < 1), between typical and atypical words in terms of lemma frequency letter length, AoA and imageability.

The nonword list included 72 items (see appendix 2). Twenty-four were short (4, 5, 6 and 7 letters), 24 were of medium length (8, 9 and 10 letters) and 24 were long (11 letters and above). The mean length of the list was 9 letters. The same set of nonwords was used to test reading and spelling. Words and nonwords were tested separately.

Procedure

Participants were tested individually in a quiet room. The assessment in Greek was carried out in two or more sessions with reading and spelling being tested on different occasions with a time interval of at least one month between sessions.

Both word and nonword reading tasks were presented on a computer screen. Responses were recorded and measures of accuracy and latency were taken. All of the latency data used in the analysis was based on correct responses. An Apple Mac PowerBook G3 computer running Microsoft Office PowerPoint software was used for the presentation of the stimuli. Tasks were presented in fixed pre-randomized order with the word reading task first, and in font size 44 in lower case. The experimenter controlled the presentation. Participants were required to verbalise the words quickly and accurately. When testing spelling, the experimenter dictated the words and the participants had to write them down.

The *Audacity* software program (available at http://audacityteam.org/) was used to extract reading latencies in milliseconds. Presentation of each word was accompanied by an auditory tone that was visible in Audacity. The latency reflected the time in milliseconds from the onset of the tone to the onset of the first soundwave that was detected on the audacity recording of the speech signal corresponding to the response. Trials with pre-response articulation were discarded. All of the latency data used in the analyses was based on correct responses that were within 3 sds of a participant's mean for that condition. The outcomes of the analyses were the same regardless of whether more stringent trimming or no trimming at all was applied to the data.

Results

T-tests that were modified for use with single case designs (see Crawford and Howell, 1998) were used to compare the individual scores of the participants with dyslexia with the mean scores of the controls.

Phonological Dyslexia in Greek

The performance of two cases (AR and VP) with impaired nonword reading and spelling despite normal real word reading latencies and accurate spelling of words with atypical sound-spelling correspondences can be seen in Table 1. Responses that were consistent with any of the ways in which a particular phoneme is written in Greek were scored as correct on the nonword spelling test. AR showed significant impairments at both nonword reading accuracy ($t = -7.32$, $p < .001$) and nonword spelling accuracy ($t = -2.61$, $p < .001$) whereas she showed normal word reading latency and normal atypical word spelling accuracy. Similarly, VP was impaired at both nonword reading accuracy ($t = -4.56$, $p < .001$) and nonword spelling accuracy ($t = -3.95$, $p < .001$), but he was unimpaired at both word reading latency and atypical word spelling accuracy. Neither VP nor AR showed a typicality effect in spelling accuracy. The overall reading/ spelling profile of these two cases therefore corresponded to phonological dyslexia in Greek. In addition, both AR and VP exhibited normal nonword reading latencies, as was the case with the Greek phonological dyslexics reported by Douklias et al. (2009) and Niolaki et al. (2014).

Table 1. Performance of the phonological dyslexics and 25 controls at reading and spelling Greek words and nonwords.

	Controls (sd)	**AR (sd)**	**VP (sd)**
Word reading accuracy (max=54)	52.6 (1.61)	52	53
Nonword reading accuracy (max=72)	68.9 (2.13)	53*	59*
Word reading latency (ms)	471 (89)	549 (98)	515 (92)
Nonword reading latency (ms)	731 (134)	782 (219)	679 (188)
Typical word spelling accuracy (max=27)	25.7 (1.28)	27	27
Atypical word spelling accuracy (max=27)	24.8 (0.96)	26	25
Nonword spelling accuracy (max=72)	66.8 (2.93)	59*	55*

p<.05 * (significance test: Crawford & Howell, 1998)

Surface dyslexia in Greek

The performance of seven cases with a lexical impairment for reading and spelling despite normal accuracy when reading and spelling nonwords is shown in Table 2. The word reading latencies of all seven were significantly longer than those of controls (for MB, $t = 4.40$, $p < .001$; for AH, $t = 3.32$, $p<.001$; for MR, $t = 3.31$, $p<.01$; for TT, $t = 3.07$, $p < .01$; for GM, $t = 2.95$, $p < .01$; for NT, $t = 2.23$, $p < .05$; for NS, $t = 2.27$, $p < .05$). All seven individuals spelt words with atypical sound-spelling correspondences significantly less accurately than controls (for MB, $t = -4.90$, $p<.001$;

for AH, t = 7.97, p<.001; for MR, t = 2.86, p = .003; for TT, t = 25.33, p<.001; for GM, t = 2.86, p < .05; for NT, t = 15.12, p<.001; for NS, t = 1.84, p < .05).

Table 2

Performance at reading and spelling Greek words and nonwords by seven surface dyslexics in comparison with 25 normal readers/spellers

	Controls (sd)	MR	TT	GM	MB	AH	NT	NS
Word reading accuracy (max=54).	52.6 (1.61)	51	52	53	53	54	54	54
Nonword reading accuracy (max=72).	68.9 (2.13)	67	69	66	68	66	67	65
Word reading latency (ms)	471 (89)	771* (169)	750* (158)	739* (113)	870* (295)	772* (189)	673* (104)	677* (148)
Nonword reading latency (ms)	731 (134)	795 (190)	1132* (263)	833 (198)	1268* (368)	1010* (220)	786 (156)	891 (203)
Typical word spelling accuracy (max=27)	25.7 (1.28)	26	27	27	27	26	26	24
Atypical word spelling accuracy (max=27)	24.8 (0.96)	22*	0**	22*	20*	17*	10*	23*
Nonword spelling accuracy (max=72)	66.8 (2.93)	69	70	66	68	68	70	70

p<.05* (significance test: Crawford & Howell, 1998)

The accuracy of all of these individuals when spelling words with typical sound-spelling correspondences and when reading and spelling nonwords was within the normal range. The performance of all seven was therefore consistent with Douklias et al.'s criteria for developmental surface dyslexia in Greek.

Spelling errors

The errors made by the surface dyslexics when spelling real words were classified as being either phonologically appropriate or phonologically inappropriate (the two cases of phonological dyslexia made insufficient errors for meaningful analysis). Phonologically appropriate errors included substitutions of a correct grapheme by another grapheme that can represent the same phoneme. For example the letter 'ω' (omega) might be used instead of o (omicron) for the phoneme /o/, (e.g. 'οθόνη' = *screen* > 'οθώνη'), a double letter might be used instead of a single letter (e.g., 'γρίπη' = *flu* > 'γρίππη'), or a single letter might be used instead of a double letter (e.g., 'καλλιτέχνης' = *artist* > 'καλιτέχνης'). Phonologically inappropriate errors were spellings that altered the phonological identity of the word (e.g., αρχιτέκτονας / arhitektonas/ = *architect* > αρκιτέκτονας /arkitektonas/). We also noted whether any of the phonologically appropriate errors contained alternative spellings of inflectional suffixes (e.g., 'ασθενοφόρο' = *ambulance* > 'ασθενοφόρω' where the letter omicron rather than omega is appropriate for singular neutral nouns). Errors of this kind were deemed grammatical errors. Because grammatical errors can be prevented if an individual is aware of the relevant grammatical rule, errors of this kind are consistent with impaired grammatical knowledge rather than impaired orthographic knowledge (Protopapas et al., 2013).

Table 3 presents the error analysis for each individual case. The majority of errors (96.6%) made by the control group were phonologically appropriate. This figure was similar to the proportion of phonologically appropriate errors made by every one of the surface dyslexics. Phonologically inappropriate errors in Greek have been taken to reflect difficulties in nonlexical rather than lexical processing (Protopapas et al., 2013). Consistent with this classification, the surface dyslexics exhibited hardly any errors of this kind. Conversely, a large number of phonologically appropriate errors signifies inadequate registration of word-specific (or root-specific) knowledge, reflecting a poorly developed orthographic lexicon (Protopapas et al., 2013). The prevalence of errors of this kind is consistent with an impairment in learning orthographic information that is specific to particular items. For both controls and surface dyslexics, few of the phonologically appropriate errors were grammatical errors. The phonological errors that the surface dyslexic individuals made therefore appear to reflect an impaired ability to retain the orthographic form of Greek words rather than an impairment of grammatical knowledge.

Table 3.
The number and type of spelling errors on Greek real words that were made by the seven surface dyslexics and controls

	Number of errors	Phonologically inappropriate errors (%)	Phonologically appropriate orthographic errors (%)	Phonologically appropriate grammatical errors (%)
Control mean (n=25)	3.5	3.4	94.3	2.3
MR	6	0	100	0
TT	27	0	100	0
GM	5	0	100	0
MB	7	0	100	0
AH	21	4.7	95.3	0
NT	18	0	94.4	5.6
NS	7	0	100	0

Nonword reading latency

Four of the surface dyslexics read nonwords at a similar speed as controls (see Table 2). However three of them had significantly longer nonword reading latencies than controls (TT: t=2.93, p<.01; MB: t=3.93, p<.001; AH: t=2.04, p<.05). Slow reading of nonwords by Greek surface dyslexics was also observed by Douklias et al. (2009) and Niolaki et al. (2014). Table 2 makes it clear that this is not the case for all surface dyslexics. Precisely why these differences were observed in nonword spelling speed in individuals with surface dyslexia is unclear at the present time. Conversely, the two phonological dyslexics showed no evidence of slow nonword reading relative to controls (see Table 1) despite having significantly impaired nonword reading accuracy. As in previous studies of Greek dyslexia, it therefore appears that normal nonword reading speed can be associated with an impaired nonlexical/ phonological reading route, and impaired nonword reading speed can be associated with an otherwise unimpaired nonlexical/phonological reading route. It must be acknowledged that this outcome is counter-intuitive, and that it would be reasonable to expect that accuracy and speed impairments in Greek nonword reading would co-occur (Zabell & Everatt, 2002). Nevertheless, it is important to point out that fast but inaccurate reading of nonwords in developmental phonological dyslexia and slow but accurate reading of nonwords in developmental surface dyslexia has also been reported in English (Rowse and Wilshire, 2007). The relationship between nonword reading speed and nonword reading accuracy clearly requires further investigation in future studies of dyslexia in both opaque and transparent orthographies.

Surface and Phonological Dyslexia in English

The reading and spelling performance of these nine individual cases was consistent with Douklias et al.'s (2009) criteria for either surface or developmental phonological dyslexia in Greek. Seven of them fitted the profile of surface dyslexia because, compared to controls, they were accurate at reading and spelling Greek nonwords but slow at reading real Greek words. They were also impaired at spelling Greek words with atypical sound-spelling correspondences and, in most of their spelling errors, a low frequency phoneme-grapheme correspondence was replaced by a more typical correspondence. The performance of two individuals, whose accuracy was impaired when reading and spelling nonwords despite unimpaired reading and spelling of real words, was consistent with Douklias et al.'s (2009) criteria for developmental phonological dyslexia in Greek. The next step was to investigate whether these nine individuals would show a corresponding pattern of impaired performance when asked to read and spell lists of English words and nonwords.

English word lists

The list of words used for reading and spelling (see appendix 3) contained 20 regular (for both reading and spelling) and 20 irregular English words (for both reading and spelling). Regular and irregular words were matched on a one to one basis as far as possible for word frequency, imageability, grammatical class and number of letters, syllables, phonemes and morphemes. All English regular words contained grapheme-phoneme correspondences that would also be considered regular according to Greek grapheme-phoneme correspondences. That is, the equivalent grapheme in Greek is always associated with the same phoneme as its counterpart in English.

Rates of word frequency per million (including both spoken and written) were taken from The Corpus of Contemporary American English (COCA; available at http://corpus.byu.edu/coca/). The corpus contains approximately 520 million words of text (collected from 1990 to 2015 with the last update) and is equally divided among spoken, fiction, popular magazines, newspapers, and academic texts. The “frequency per million" rate used in the present study represents the sum of spoken, fiction, popular magazines, newspapers, and academic raw frequencies (appears in the COCA database as "ALL" frequency) divided by 520. Rates of imageability were obtained from 100 highly literate Greek adults who had English as a second language.

Between items analyses of variance indicated that there were no significant differences between regular and irregular words in frequency (F <1), imageability (F <1), number of letters (F(1,38) =3.848, p>.05), number of syllables (F <1), number of phonemes (F(1,38) =2.943, p=.>.05) and number of morphemes (F(1,38) =1.086, p>.05).

A list of 30 nonwords used by Hanley and Gard, (1995) was employed for nonword reading and spelling. All of the words were monosyllabic and contained either four or five letters (e.g. *homb, prull, dight jeach*). Tasks were performed in a fixed pre-randomized order with the word-reading task first. Presentation procedure was the same as for the Greek lists.

Results and Discussion

Modified t-tests (Crawford and Howell (1998) were again used to compare the individual scores of the phonological and surface dyslexics with the mean scores of controls. Eighteen of the normal readers/spellers who served as controls in the Greek language tests were available for further testing, and served as controls in the English language tests.

Table 4.

Reading and spelling performance in English of the 2 cases who had shown a phonological dyslexic profile in Greek.

	Controls (sd) N=18	**AR**	**VP**
Regular words reading accuracy (max=20).	19.3 (0.77)	19	19
Regular words reading latency (msec)	554 (66)	527 (46)	614 (85)
Irrgular words reading accuracy (max=20).	17.1 (1.89)	17	16
Irregular words reading latency (msecs)	603 (98)	614 (101)	732 (116)
Nonwords reading accuracy (max=30)	24.6 (1.88)	15*	17*
Regular words spelling accuracy (max=20)	19.3 (0.75)	19	20
Irregular words spelling accuracy (max=20)	18.5 (1.10)	17	17
Nonwords spelling accuracy (max=30)	24.7 (2.05)	18**	17**
Nonwords reading latency (msec)	737 (142)	770 (182)	791 (198)

p<.05 one-tailed*

Phonological Dyslexia in English

Table 4 displays the reading and spelling performance in English of the two cases with phonological dyslexia in Greek (AR and VP). AR's nonword reading accuracy (t= -4.97, p<.001) and nonword spelling accuracy (t= -3.18, p<.01) in English was impaired. Her regular word reading and irregular word spelling accuracy was preserved. VP's nonword reading accuracy (t=-3.94, p<.01) and nonword spelling accuracy (t=-3.66, p<.01) were impaired. His accuracy in reading and spelling irregular English words was normal. None of the errors that VP and AR made when spelling irregular words were phonologically appropriate. As in Greek, the speed with which AR and VP read typical words, atypical and nonwords was within the normal range.

AR and VP were also given two phonological awareness tests in English. These were a phoneme counting task in which they were asked to indicate the number of phonemes in 48 spoken English words and a spoonerising task in which they were asked to exchange the first phonemes in 20 pairs of spoken English words. Controls scored 31.1/48 correct (sd= 6.3) at phoneme counting and 16.8/20 (sd = 1.0) correct on the spoonerisms. AR and VP were significantly impaired at both tasks. AR scored 11 (t=-3.09, p<.001) and VP scored 19 (t= -1.86, p<.05) on the phoneme counting task. AR scored 7 (t=-9.64, p<.001) and VP scored 14 (t=-2.75, p<.01) on the spoonerisms task.

Both of the cases who showed poor reading and spelling accuracy of nonwords in Greek therefore showed exactly the same pattern of impairment when reading and spelling nonwords in English. Consistent with their Greek testing, the reading and spelling profile in English of both AR and VP is consistent with a phonological impairment that disrupts the development of the nonlexical/phonological reading route. It is therefore clear that these two individuals have developmental phonological dyslexia in both English and Greek.

Surface Dyslexia in English

Table 5 displays the reading and spelling performance in English of the seven cases who had been classified as surface dyslexic in Greek. TT showed impaired regular word reading (t=-4.70, p<.001) and impaired irregular word spelling (t=- 12.83, p<.001). AH showed impaired irregular word reading (t = -3.14, p<.01), and impaired irregular word spelling (t = -6.64, p<.001). NT showed impaired irregular word reading (t = -3.14, p<.01), and impaired irregular word spelling (t=-6.64, p<.001). GM showed impaired irregular word reading accuracy (t = -3.14, p<.01) and impaired irregular word spelling (t = -3.98, p<.001). MB showed impaired irregular word reading accuracy (t = 2.63, p<.01) and impaired irregular word spelling (t = -6.64, p<.001). MR showed impaired irregular word reading accuracy (t = 2.11, p<.05) and impaired irregular word spelling (t =-3.10, p<.001). NS showed impaired irregular word reading accuracy (t = 2.11, p<.05) and impaired irregular word spelling (t =-2.21, p<.05).

Table 5

Performance at reading and spelling English words and nonwords by the seven cases who had shown a surface dyslexic profile in Greek.

	Controls (sd)	MR	TT	GM	MB	AH	NT	NS
Regular word reading accuracy (max=20).	19.3 (0.77)	20	20	19	19	20	20	20
Regular word reading latency (msec)	554 (66)	703* (119)	769* (140)	686* (98)	718* (177)	742* (145)	741* (132)	701* (112)
Irregular word reading accuracy (max=20).	17.1 (1.89)	13*	8*	11*	12*	11*	11*	13*
Irregular word reading latency (msec)	603 (98)	787* (178)	828* (186)	809* (159)	838* (167)	956* (195)	753 (144)	723 (138)
Nonword reading accuracy (max=30).	24.6 (1.88)	22	25	23	24	24	24	23
Regular word spelling accuracy (max=20)	19.3 (0.75)	18	20	20	19	20	20	19
Irregular word spelling accuracy (max=20)	18.5 (1.10)	15*	4*	14*	11*	11*	11*	16*
Nonword spelling accuracy (max=30)	24.7 (2.05)	23	27	23	23	26	24	23
Nonword reading latency (msec)	758 (143)	988	1103*	1011	1312*	1098*	971	837

p<.05* (significance test: Crawford & Howell, 1998)

As in Greek, the proportion of spelling errors that were phonologically appropriate was over 90%. All seven cases also showed accuracy levels at nonword reading and spelling that was within the normal range. They also read regular words significantly more slowly than the controls (TT: $t=3.17$, $p<.01$; AH: $t=2.77$, $p<.01$; NT: $t=2.76$, $p<.01$; GM: $t=1.95$, $p<.05$; MB: $t=2.42$, $p<.05$; MR: $t=2.20$, $p<.05$; NS: $t=2.17$, $p<.015$). This is consistent with the idea that impaired development of the lexical route means that words with typical spelling-sound correspondences are read by the slower nonlexical/phonological route. Two of the surface dyslexics read irregular words at a similar speed as controls (see Table 5), but the majority had significantly longer irregular word reading latencies than those of controls (AH: $t=3.51$, $p<.01$; MB: $t=2.33$, $p<.05$; TT: $t=2.24$ $p<.05$; GM: $t=2.05$, $p<.05$; MR: $t=1.83$, $p<.05$).

Nonword reading latencies showed a similar pattern in English as in Greek. The same three surface dyslexics who had been slower than controls at reading nonwords in Greek were also slower than controls at reading nonwords in English (MB: $t=3.77$, $p<.01$; TT: $t=2.35$, $p<.05$; AH: $t=2.31$, $p<.05$). MR, GM, NT and NS read nonwords at a similar speed as controls.

The performance of all seven of the cases whose reading and spelling was consistent with developmental surface dyslexia in Greek (slow reading and inaccurate spelling of atypical words) showed clear evidence of a selective deficit in their accuracy of reading and spelling irregular words in English and a significant speed deficit in reading regular words. It appears that these seven individuals have found it difficult to learn the lexical representations of English words and instead rely predominantly upon the nonlexical/phonological reading route. Finally, all of these cases performed within 1sd of the control mean on both of the tests of phonological awareness on which the two phonological dyslexics were significantly impaired. It is therefore clear that these seven individuals were surface dyslexic in both English and Greek.

Nevertheless it is important to investigate an alternative explanation of why these individuals might have performed poorly with irregular English words. It is possible that they did not know the correct pronunciation of these words and believed the regularized pronunciation to be correct. There is evidence from Spanish (Pitts & Hanley, 2010) that speakers of a transparent orthography sometimes regularize the pronunciation of irregular English words because they originally learnt these words from their written form without exposure to the correct pronunciation. Not unreasonably, these readers appear to have assumed that the word should be pronounced the way that it is written. In such circumstances, the regularization of these words during reading is clearly not the result of an impaired ability to learn the lexical form of written words.

Further investigation of English irregular word reading in surface dyslexia.

The seven individuals with surface dyslexia were therefore asked to perform two additional tasks to examine further the nature of their difficulties when reading irregular English words. In the first task, each individual was presented with 20 pairs of words in a two-item forced choice test. One of the items was always a phonetically accurate transcription of the correct pronunciation of an irregular English word that was written with Greek letters. The other item was either the regularized pronunciation of the same word written in Greek or else it was a participant's own pronunciation of the word if it differed from both the correct and the regularized pronunciation. The participant's task was to decide which of the two words written in Greek sounded like an English word. If the participant selected their own error, then this would suggest that they believed the regularization to be the correct pronunciation of the word in English. The regularized pronunciations were presented in Greek rather than in English for two reasons. First, it ensured that participants were using phonology rather than the lexical representation of the word in English to perform the task. Second, it was considered likely that the participants would be more skilled in the use of Greek than English spelling-sound correspondences and would therefore be slightly less likely to make a decoding error when reading the stimuli.

When this task was administered to the controls, they achieved a score of 18.8/20 correct (sd = 1.56). None of their individual scores was significantly impaired relative to the controls. TT scored 20/20, MB and MR scored 19/20, AH NT, and NS scored 18/20, and GM scored 17/20. It therefore appears that these seven individuals were aware of the correct pronunciations of the irregular English words even when they read them incorrectly.

The second task investigated whether these seven individuals would pronounce irregular words correctly during a picture-naming task that did not involve presentation of a word's written form. If not, then a failure to read an irregular word correctly would represent ignorance of a word's pronunciation rather than any impaired ability to learn the written form of irregular words. Twenty irregular items for reading were taken from PALPA, no 53 (Kay, Lesser & Coltheart, 1992) and were presented twice to each participant, once as a picture and once as a written word during separate testing sessions. There was a gap of at least one month between testing sessions. An accuracy measure was used that comprised the number of items read correctly as a percentage of the items that were named correctly from pictures. For instance, if a participant named 10 items correctly in the picture-naming task but was able to read only 5 of these items accurately in the reading task, a score of 50% would be given. The same task was also given to the controls whose mean score was 96.6% (sd = 5.68). All of the surface dyslexics performed significantly below the level of the controls on this task (TT scored 61% (18 pictures named correctly, 14 words read correctly); $t= -6.10$, $p<.001$, NT scored 78% (18 pictures named correctly, 11 words read correctly); t= -3.19, p<.01, AH scored 78% (9 pictures named correctly, 7 words read correctly); t= -3.19, p<.01, MR scored 82% (17 pictures named correctly, 14 words read correctly); t= -2.50, p<.05, MB scored 85% (13 pictures named correctly, 11 words read correctly); t= -1.99, p<.05, GM scored 86% (7 pictures named correctly, 6 words read correctly); t = -1.82, p<.05, NS scored 80% (15 pictures named correctly, 12 words read correctly); t=2.85, p<.01). For example, when shown a picture of a "thumb" some of these individuals named it correctly as /θʌm/. However, several of them made a regularization error when reading this word, pronouncing it as /θʌmb/.

Performance on these two tasks reveals impaired English irregular word reading accuracy by these seven individuals even when they know the correct meaning and pronunciation. The possibility that these seven individuals are unable to read irregular words aloud because they are unfamiliar with them or because they believe the regularised pronunciation to be correct can therefore be discounted.

It is interesting to note that the performance of the surface dyslexics differed on the picture-naming task. Five of them (TT, NT, MR, NS, MB) performed above the control mean (15/20, sd = 2.2) or within one standard deviation of the mean. Intact spoken picture naming suggests that the semantic and phonological systems and the connections between them are intact in these individuals. Such an outcome is consistent with the view that the reading and spelling impairments of these five individuals affects development of the orthographic units themselves or perhaps the connections between the orthographic units and the semantic system. However, the picture naming accuracy of both AH (9/20, t = 2.88, p <.01) and GM (7/20, t = 3.75, p <.01) was significantly below that of the controls.

Picture naming deficits are generally associated with an impaired semantic system or with weak connections between the semantic and phonological systems.

Impairments of this kind have been proposed as the cause of acquired surface dyslexia in some individuals (e.g. Behrmann & Bubb, 1992; Watt, Jokel, & Behrmann, 1997). This is because a semantic system impairment, or a failure to access the phonological system from the semantic system, might require an individual to rely disproportionately on the non-lexical/phonological route when reading words aloud. It has recently been suggested that different subtypes of developmental surface dyslexia exist in Hebrew (Friedmann and Lukov, 2008) and that some cases experience problems in accessing phonology from semantics (Gvion and Friedmann, 2016). Additional research with AH and GM is currently investigating whether their overall reading and spelling profile is consistent with a developmental impairment of this kind.

General Discussion

These findings provide important information about the relationship between developmental dyslexia in opaque and transparent orthographies. The hallmark of surface dyslexia in English is inaccurate reading of words with typical spelling-sound correspondences and inaccurate spelling of words with atypical sound-spelling correspondences. Douklias et al. (2009) claimed that surface dyslexia can also be observed in Greek (an orthography that does not contain any words with atypical spelling-sound correspondences) and that its hallmarks are slow reading of real words and inaccurate spelling of words with low frequency phoneme-grapheme correspondences. In the present study, we extended Douklias et al.'s findings by reporting the cases of seven adults whose reading and spelling performance satisfied these criteria for surface dyslexia in Greek. Critically, a co-occurrence was observed in all seven of these individuals between slow reading times for real words in Greek and inaccurate reading of words with atypical grapheme-phoneme correspondences in English. A co-occurrence was also observed between inaccurate spelling of words with atypical phoneme-grapheme correspondences in both languages. These co-occurrences provide strong evidence that surface dyslexia genuinely exists in Greek and that slow reading of familiar words in Greek reflects the same underlying impairment as that which leads to inaccurate reading of words with atypical spelling-sound correspondences in English. Furthermore, two individuals were identified with phonological dyslexia in both Greek and English. These two individuals were impaired at reading and spelling nonwords in both languages consistent with the idea that the same kind of impairment leads to phonological dyslexia in both Greek and English. Unlike surface dyslexia, which seems to manifest differently as a function of the depth of the orthography, it appears that a phonological impairment leads to similar problems (poor reading and spelling of nonwords) in alphabetic orthographies regardless of their transparency.

This study also provides information about the nature of dyslexia in transparent orthographies. The two cases of phonological dyslexia in Greek that we have observed show that a selective impairment to the nonlexical/phonological route can impair literacy development in transparent orthographies. However, these two individuals both read words and nonwords as quickly as controls. It does not appear, therefore, that slow reading by dyslexics in transparent orthographies is necessarily caused by impaired development of the phonological/nonlexical reading route. We suggest instead that slow reading by individuals with dyslexia in Greek is the hallmark of a developmental impairment to the lexical route in the DRC (Coltheart et al., 2001) and CDP++ models (Perry et al., 2010) or to the semantic route in the triangle model (Plaut et al., 1996; Wollams, 2014), and that longer reading times reflect an over-reliance by these individuals on the slower nonlexical/phonological reading route.

In summary, we have shown that the underlying deficits that impair development of the two reading routes seem to be the same in Greek surface and phonological dyslexia as in English surface and phonological dyslexia respectively.

This finding indicates that the foundation skills that allow children to learn to read and spell familiar words are the same in Greek as in English, and that the foundation skills that allow children to read and spell unfamiliar words are the same in Greek as in English. Such an outcome provides evidence that the neurophysiological substrate(s) that support the lexical/semantic and the phonological pathways that are involved in reading and spelling are the same in both Greek and English. Moreover, the parallels that were observed in both Greek and English between the nature of the impairments observed in reading and spelling suggests that the neurophysiological substrate(s) that are involved in reading are the same as those that are involved in spelling.

Such an outcome is not inconsistent with the DRC approach (Coltheart et al., 2001) even though the underlying mechanisms that support reading in the DRC model are both language-specific and reading-specific. On the other hand, these conclusions appear to follow directly from the primary systems approach that has been advocated by supporters of the triangle model (Patterson & Lambon Ralph, 1999; Woollams, 2014). Because reading is an ability that is late acquired both phylogenetically and ontogenetically, the systems that subserve the acquisition of literacy must rely upon connections between more basic underlying knowledge systems. The primary systems approach therefore claims that the visual, phonological and semantic structures supporting literacy are general types of information that are not specific to either the reading system or to the English language. Consequently, our findings support the predictions of the triangle model (Plaut et al., 1996) that a developmental weakness in part of the underlying substrate will inevitably lead to an impairment that affects development of literacy in different orthographies in an analogous way.

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Appendices

Appendix A

Raw data associated with the article can be found in the online version, at http…

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Appendix 1

Greek typical words (for spelling) list accompanied by rates of frequency, length (number of letters), AoA (age of acquisition) and imageability

	Frequency	Length	AoA	Imageability
γρίπη = *flu*	3.4	5	376	204
σέλινο = *celery*	0.4	6	413	460
αδαής = *clumsy, inexperienced*	2.4	5	698	132
ζεστασιά = *warmth*	3.0	8	308	325
ασθενοφόρο = *ambulance*	8.9	10	418	593
αναστενάζω = *I sigh, suspire*	3.4	10	451	398
πονοκέφαλος = *headache*	9.8	11	341	313
κεφαλογραβιέρα = *kind of Greek cheese*	0.1	14	557	411
μιλιταριστικός = *militaristic*	0.6	14	694	247
γιορτή = *celebration, festival, name day*	36.9	6	204	342
τροχός = *wheel*	18	6	470	435
μέριμνα = *provision*	20.7	7	648	238
δεκαπέντε = *fifteen*	40.2	9	318	324
μονοπάτι = *footpath, trail*	21	8	402	449
απρόοπτο = *unforeseen*	14.2	8	515	264
προσεκτικός = *careful*	48.2	11	262	381
αρχιτέκτονας = *architect*	25.1	12	661	477
ανταπόκριση = *response, connection*	24.4	11	632	214
διπλός = *double*	68.3	6	310	383
οθόνη = *screen, monitor, display*	59	5	441	504
εκτιμώ= *I appreciate, estimate, reckon, rate*	242	6	589	233
προσπαθώ = *I try (verb)*	323.8	8	282	304
περιοδικό = *magazine*	86.7	9	402	620
αρμόδιος = *apposite*	267.3	8	621	259
θερμοκρασία = *temperature*	58.2	11	388	367
παρακολουθώ = *I attend, observe, watch, spy*	173	11	403	442
προσδιορίζουμε= *we determine, define*	97.9	14	625	259
Mean (SD)	**61.3 (87.7)**	**8.85 (2.82)**	**460 (144)**	**355 (119)**

Greek atypical words (for spelling) list accompanied by rates of frequency, length (number of letters), AoA (age of acquisition) and imageability

	Frequency	Length	AoA	Imageability
ζήτω = *hooray, hurrah*	4.1	4	333	227
κηρήθρα = *honeycomb*	0.3	7	667	427
ευόδωση = *fruitfulness, effectiveness*	0.9	7	697	169
εξυπνάδα = *cleverness*	2.9	8	348	309
δύσπνοια = *dyspnea*	0.8	8	600	496
επιείκεια = *lenience*	3.9	9	675	241
ενοχλητικός = *annoying*	9.1	11	374	323
γραμματόσημα = *stamps*	4.6	12	426	515
αντιπροσωπευτικότητα = *representativeness*	1	20	613	256
τυχαία = *accidently, randomly*	28	6	384	277
άγγελος = *angel*	39.4	7	456	489
έγκυρος = *valid*	32.4	7	557	248
υπόσχεση = *promise*	39.1	8	352	294
ναυπηγείο = *shipyard*	17.1	9	511	504
μεταβλητός= *variable, alterable*	33.6	10	698	214
ευτυχισμένος = *happy*	15	12	372	353
χειρόγραφος = *handwritten*	15.4	11	555	456
εμπειρογνώμονας= *connoisseur, appraiser*	32.7	15	657	176
αλήθεια = *truth*	171.8	7	246	382
άγκυρα = *anchor*	96.8	6	457	645
καθήκον = *duty, obligation*	72.3	7	574	264
ευχαριστώ = *thank (you)*	187	9	199	389
πετρέλαιο = *petrol*	77.8	9	409	557
ποιότητα = *quality*	160.4	8	576	277
καλλιτέχνης= *artist*	98.7	11	389	354
πανεπιστήμιο = *university*	214.9	12	486	534
επιχειρηματικός = *enterprising*	79.7	14	608	230
Mean (SD)	**53.3 (63.4)**	**9.41 (3.33)**	**490 (141)**	**356 (130)**

Appendix 2

Non-word reading/spelling list in Greek and rates of length (number of letters)

σότα	4	Τιμαλόνι	8	σιταρομένος	11
άρος	4	Παλαμάρο	8	περιοδικλές	11
αρμί	4	Αντιβάζω	8	κρησιμοποιώ	11
γόας	4	Οπολογία	8	πρωτοφουλία	11
τίτα	4	Πεμακοτό	8	τραμπαπολίνο	12
βριν	4	Ουσάδικο	8	ποροτεχνικός	12
ράτσο	5	Καμπρώνω	8	δαμποτικολάς	12
λάντο	5	συνφέτης	8	μιστοπορεκός	12
λίμπο	5	Καλαντίνο	9	μπουκαπορτώνω	13
σίτιο	5	Ρινιματιά	9	κανερικλάμινο	13
πάτσα	5	Ποτραλάμι	9	γαλαχτοπωλείο	13
λούξι	5	Ντισκοδία	9	καλιβινεριζός	13
κέμπες	6	Τιμπαλόνι	9	απονευρικατίζω	14
άμπολα	6	Κοντραλιά	9	καλαπετράβακας	14
τάμπος	6	Δασπαλίκι	9	βομφαρθιστικός	14
τσάπος	6	εντόλεμος	9	κραπματικότητα	14
κέμπες	6	τραβαλιάζω	10	βραστηριοποίηση	15
ητορία	6	κονφελάριο	10	εκδιομηχανισμός	15
κράντας	7	Σεπενέντιο	10	κατριμιτσούλιας	15
πανοδία	7	φιλάτροπος	10	καμικαβικλώντας	15
λίνταρο	7	ανταρομένη	10	πυσικοτεραπεφτής	16
γάλασσα	7	λιτασομένα	10	αντεγωναστικότετα	16
νταμάζι	7	σαποκαρόζι	10	βακονεριασιμπάκι	16
πάντεμο	7	αποτραδίζω	10	αντελοκαλιέργκια	16

Appendix 3

List of matched English typical and atypical words (for both reading and spelling) accompanied by rates of frequency (per million), imageability, number of letters, number of syllables, number of phonemes and number of morphemes.

Regular							Atypical						
Word	Fr.	Im.	Let.	Syl.	Phon.	Mor.	**Word**	Fr.	Im.	Let.	Syl.	Phon.	Mor.
cat	39.2	687	3	1	3	1	aunt	31.1	583	4	1	3	1
jam	10.2	662	3	1	3	1	lamb	12.2	680	4	1	3	1
nest	13.6	580	4	1	4	1	ghost	16.9	605	5	1	4	1
hold	155.3	478	4	1	4	1	move	212.0	467	4	1	3	1
tent	19.4	626	4	1	4	1	sledge	0.8	603	6	1	4	1
frog	6.7	676	4	1	4	1	yacht	4.8	637	5	1	3	1
banana	8.6	689	6	3	6	1	aeroplane	0.2	679	9	3	7	2
robin	22.6	617	5	2	5	1	giraffe	1.3	623	7	2	5	1
sister	93.6	614	6	2	5	1	soldier	28.5	620	7	2	5	1
wind	87.1	546	4	1	4	1	watch	146.3	573	5	1	4	1
canal	13.6	611	5	2	5	1	castle	16.1	627	6	2	4	1
spring	101.0	556	6	1	5	1	heart	192.6	625	5	1	3	1
market	207.7	604	6	2	5	1	island	96.2	638	6	2	5	2
plant	89.3	623	5	1	5	1	blood	143.4	652	5	1	4	1
context	65.0	244	7	2	8	2	routine	29.7	211	7	2	5	2
smog	2.5	422	4	1	4	1	quay	0.6	501	4	1	2	1
leg	47.2	662	3	1	3	1	goat	9.7	628	4	1	3	1
pen	17.7	673	3	1	3	1	thumb	15.6	630	5	1	3	1
drop	63.2	420	4	1	4	1	lose	85.9	382	4	1	3	1
mist	8.9	609	4	1	4	1	shoe	16.7	657	4	1	2	1
Mean SD	53.6 (55.3)	580 (112)	4.50 (1.19)	1.35 (0.59)	4.40 (1.19)	1.05 (0.22)	Mean (SD)	53.0 (68.2)	581 (114)	5.30 (1.38)	1.35 (0.59)	3.75 (1.21)	1.15 (0.30)

Fr.= Frequency, Im.= Imageability, Let.= Number of letters, Syl.= Number of syllables, Phon.= Number of phonemes, Mor.= Number of morphemes