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Lexical decision performance in developmental surface dysgraphia: Evidence for a unitary orthographic system that is used in both reading and spelling.

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Abstract

The relationship between spelling, written word recognition and picture naming is investigated in a study of seven bilingual adults who have developmental surface dysgraphia in both Greek (their first language) and English (their second language). Four of the cases also performed poorly at orthographic lexical decision in both languages. This finding is consistent with similar results in Italian that have been taken as evidence of a developmental impairment to a single orthographic system that is used for both reading and spelling (e.g. Angelelli, Marinelli, & Zoccolotti, 2010). The remaining three participants performed well at orthographic lexical decision. At first sight, preserved lexical decision in surface dysgraphia is less easy to explain in terms of a shared orthographic system. However, the results of subsequent experiments showed clear parallels between the nature of the reading and spelling difficulties that these three individuals experienced, consistent with the existence of a single orthographic system. The different patterns that were observed were consistent with the claims of Friedmann and Lukov (2008) and Gvion and Friedmann (2016) that several distinct sub-types of developmental surface dyslexia exist. We show that individual differences in spelling in surface dysgraphia are also consistent with these sub-types; there are different developmental deficits that can give rise, in an individual, to a combination of surface dyslexia and dysgraphia. Finally, we compare the theoretical framework used by Friedmann and her colleagues that is based upon the architecture of the DRC model (Coltheart, Rastle, Perry, Langdon, & Zeigler, 2001) with an account that relies instead upon the Triangl*e* model of reading (Plaut, McClelland, Seidenberg & Patterson, 1996).

Introduction

Developmental surface dysgraphia in the English writing system is an impairment that allows individuals to spell nonwords and regular words accurately but disrupts their ability to learn the spellings of irregular words. Irregular words (e.g. *pint)* have atypical correspondences between one or more of the phonemes and the graphemes that they contain. In case studies of individuals with surface dysgraphia, disorders of reading and spelling tend to co-occur, with individuals having problems in learning to read as well as to spell irregular words (e.g. Castles & Coltheart, 1996; Goulandris & Snowling, 1991; Hanley, Hastie & Kay, 1992; Hanley & Gard, 1995; Romani, Ward & Olson, 1999; Temple, 1984).

A co-occurrence of reading and spelling impairments has also been observed in studies of developmental surface dyslexia and dysgraphia in more transparent alphabetic writing systems such as German, Greek, and Italian. Although these orthographies contain very few words that are irregular for the purposes of reading, they are less transparent for the purposes of writing and contain many words with atypical spelling to sound correspondences. Douklias, Masterson and Hanley (2009) showed that Greek surface dysgraphics experience selective problems in spelling words of this kind and also tend to read familiar Greek words relatively slowly. Douklias et al. argued that slow reading and inaccurate spelling are both the consequence of the same developmental impairment. Bergmann and Wimmer (2008) found that German-speaking dyslexics had particular problems in spelling irregular German words. They showed that such individuals also found it difficult to distinguish correctly spelled words from pseudohomophones on a written lexical decision task even though they could successfully distinguish pseudohomophones from phonologically incorrect spellings. Angelelli, Marinelli, & Zoccolotti (2010) found that Italian surface dysgraphic children who were impaired at spelling irregular words were also impaired on written lexical decision tasks where they had to distinguish correct spellings from their own phonologically plausible misspellings. Normally developing Italian children in this study also found it difficult to distinguish a correct spelling from their own misspellings. In English, consistent findings have been obtained in developmental surface dyslexia/dysgraphia (e.g. Hanley et al. 1992), in acquired surface dyslexia/dysgraphia (e.g. Behrmann & Bub, 1992), and in skilled adult readers/spellers (e.g. Holmes & Carruthers, 1998). Such findings suggest that the same orthographic units (or lexicon) support spelling, reading aloud and lexical decision. They are therefore consistent with the results of Rapp and Lika's (2011) fMRI investigation in which the same area in the left mid-fusiform appeared to be involved in both recognizing and spelling written words.

In this paper, we describe the performance of three cases of developmental surface dysgraphia who perform well at lexical decision (Experiment 1). A key issue that we will investigate is whether the performance of these three individuals is nonetheless consistent with the single lexicon account. We also examine the assumption that the fundamental impairment in developmental surface dyslexia/dysgraphia is to the development of the orthographic lexicon itself (rather than to its input or output pathways). We will provide evidence that this assumption is only true in some cases of surface dyslexia/dysgraphia, and that there are important individual differences in the core deficit that leads to impaired reading and spelling of irregular words.

The claim that qualitatively different impairments can be observed in individuals with an irregular word reading deficit has been advanced on several occasions with regard to acquired surface dyslexia (e.g. Ellis & Young, 1988; Ellis, Lambon Ralph, Morris & Hunter, 2000). More recently, Friedmann and Lukov, (2008) and Gvion and Friedmann (2016) have suggested that different types of underlying impairment can also be observed in developmental surface dyslexia in Hebrew, a semitic language with a relatively opaque alphabetic orthography. Some of the developmental surface dyslexics studied by Friedmann and Lukov performed badly at written lexical decision, consistent with an impairment to the development of the orthographic lexicon itself. Friedmann and Lukov referred to this condition as *input* surface dyslexia. However, other surface dyslexics performed well at lexical decision but showed poor performance on a test that required access from written words to the semantic system. Friedmann and Lukov argued that in these cases the orthographic lexicon had developed normally, and referred to this condition as *orthographic output* surface dyslexia.

Friedmann and Lukov (2008) attempted to explain these differences in terms of the architecture of the DRC model of reading aloud (Coltheart, Rastle, Perry, Langdon & Ziegler, 2001). Advocates of the DRC model (e.g. Coltheart & Funnell, 1987) have long argued that the same lexicon is used for both reading and spelling. Figure 1 therefore presents Purcell, Shea and Rapp (2014)'s version of the DRC model in which there is just one orthographic lexicon (orthographic LTM). We will refer to it as the DRC-single lexicon account (DRC-SLA). In this model, familiar words can be read aloud by both the semantic pathway (orthography > semantics > phonology) and by the direct lexical route from the orthographic lexicon to the phonological lexicon.

Insert Figure 1 about here

Friedmann and Lukov (2008) argued that although the orthographic lexicon itself is impaired in input surface dyslexia, the problems in reading familiar words in orthographic output surface dyslexia are instead caused by an impairment that impedes access from the orthographic lexicon to both the semantic system and the phonological lexicon. In other surface dyslexics, however, Friedmann and Lukov observed good lexical decision performance and preserved access to semantics. These individuals also performed well at picture naming. Friedmann and Lukov suggested there might be a third type of developmental surface dyslexia that they termed *interlexical* surface dyslexia. Individuals with interlexical surface dyslexia, they claimed, have an intact orthography-semantic reading route that allows good performance on lexical decision and semantic decision tasks. Their poor reading of irregular words is instead caused by impaired development of the direct connection from the orthographic lexicon to the phonological lexicon (although, if so, it is surprising that these individuals could not read irregular words aloud via the semantic system). Finally, Gvion and Friedmann (2016) also observed impaired reading aloud of irregular words in Hebrew in eight developmental cases with preserved access to the meaning of written words but poor picture naming. Consequently, Gvion and Friedmann claimed that a problem at the level of the phonological lexicon can also make it necessary for individuals to read via the non-lexical route and show a pattern that is consistent with surface dyslexia.

The present study investigates individual differences in seven bilingual adults with surface dyslexia and dysgraphia. In a previous report (Sotiropoulos and Hanley, 2017), we have shown that all seven perform accurately when reading and spelling nonwords and regular words in both Greek (their first language) and English (their second language). However, consistent with developmental surface dysgraphia in both Greek and English, all seven made a disproportionately large number of spelling errors on English and Greek words with atypical spelling-sound correspondences. They were also inaccurate at reading irregular English words and slow at reading familiar Greek words consistent with impaired development of the orthographic lexicon in both Greek (Douklias et al. 2009; Niolaki, Terzopoulos, & Masterson, 2014) and English. The present study investigates their performance on tests of orthographic lexical decision (Experiment 1), on a test of semantic access from written words (Experiment 2), and on written (Experiment 3) and spoken picture-naming tests (Experiment 4). In so doing, we attempt to accommodate their reading and spelling performance in English and Greek within the theoretical framework that Friedmann and Lukov (2008) and Gvion and Friedmann (2016) devised in order to explain surface dyslexia in Hebrew. In particular, we examine whether, consistent with the DRC-SLA model that is presented in Figure 1, the performance of all seven can be explained without the need to postulate the existence of separate orthographic lexicons for reading and spelling.

Experiment 1 Orthographic Lexical Decision

Participants

All of the participants were Greek nationals who were students at British Universities at the time of testing. They were aged between 20 and 38 years-old. Their first language was Greek and their second language was English. They were recruited as part of a doctoral study (Sotiropoulos, 2015) that examined the reading and spelling performance of 30 Greek students who had experienced developmental literacy difficulties in childhood. Approval for the study was obtained from the Ethics Committee of the University of Essex. Seven of the thirty dyslexics fit the criteria for surface dyslexia/dysgraphia in Greek and English and were therefore included in the present study. All seven had been classified as dyslexic by educational psychologists in Greece during their school years. Eighteen participants who had normal reading and spelling ability (as reported to the first author) acted as controls. The time that the dyslexics and had spent in the UK, the age at which they leant English and the length of their exposure to English were all fairly similar to that of the controls (see Table 1).

The reading and spelling performance of these seven cases in Greek and English has previously been reported by Sotiropoulos and Hanley (2017). Their performance when reading and spelling in English is summarized in Table 2. Sotiropoulos and Hanley demonstrated that all seven were significantly less accurate than controls at spelling English and Greek words that contained atypical spelling-sound correspondences. Over 90% of the spelling errors that they made in both English and Greek were phonologically appropriate. They also performed slowly, though accurately, at reading familiar Greek and English words and made regularisation errors when reading aloud irregular English words. They performed at normal levels of accuracy relative to controls when reading and spelling both Greek and English nonwords. All seven therefore suffered from surface dyslexia/ dysgraphia in both languages.

Insert Table 1 and 2 about here

Materials

Twenty-four English words along with their corresponding pseudohomophones (e.g. *feel* and *feal*) were used (48 letter strings in total; see appendix B) for the English lexical decision test. Thirty-four Greek words (e.g. "παγκόσμιος"= global) along with their corresponding pseudohomophones (e.g. "παγγόσμειος") were used (68 letter strings in total; see appendix A) for the Greek lexical decision test. The pseudohomophones were derived from the words by changing one or two vowels or consonants. Pseudohomophones and words were identical in pronunciation.

Procedure

In each language, the items were presented in one pseudorandomized list. This procedure allowed counterbalancing of the order with which the two items of a word–

pseudohomophone pair was presented. The sequence was word before pseudohomophone for half of the pairs and the opposite for the other half. Moreover, close proximity of a word and its pseudohomophone was avoided. The Greek lexical decision test was administered approximately six months before the English version of the test.

The experimental materials were presented on the screen of an Apple Mac PowerBook G3 computer. Microsoft Office Powerpoint software was used for the presentation of the stimuli. Words were presented in font size 44 in lower case. 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.

The experimenter controlled the presentation. Participants were presented with one item at a time and had to decide whether the presented word was correctly written. They were required to give a "yes" or "no" response orally to each item. Only when participants gave a "yes" answer for the word and a "no" answer for its corresponding pseudohomophone, was performance for the pair considered to be correct. Scores could potentially vary from 0 (reflecting zero correct decisions) to 24 (reflecting 24 correct decisions), and from 0-34 in Greek.

Results and Discussion

Results are presented in Table 3. T-tests that were modified for use in single case studies (Crawford & Howell, 1998) were used to compare the performance of the dysgraphics with the mean score of the controls. The accuracy of four of the participants was significantly impaired on the English lexical decision task (TT $t= -10.73$, $p<.001$; NT $t= -4.42$, $p< .001$; MB $t= -4.49$, $p<.001$; NS $t= -3.20$, $p<.001$). These response times for these four individuals were also significantly slower than the controls for both words (TT t=4.57; p<.001; NT t=2.42, p<.05; MB t=2.757, p<.01; NS t=2.07, p<.05) and pseudohomophones (TT; t=8.94, p<.001, NT; t=3.03, p<.01, MB; t=3.79, p<.01, NS; t=, p<.05). However the accuracy and speed of the other three cases (MR, AH, GM) was normal and did not differ significantly from that of the controls.

Insert Table 3 about here

The four participants whose scores were impaired at English lexical decision in Experiment 1 also performed significantly less accurately than controls at lexical decision in Greek (TT t=-6.47, p<.001; NT t=-4.84, p<.001; MB t=-3.20, p< .001; NS t=-3.20, p< .001). Their responses were also significantly slower than controls on both words (TT t=4.39, p<.001; NT t=2.34,; p=.016, MB t=2.859, p=.005; NS; t=2.19, p p<.05) and pseudohomophones (TT t=6.83, p<.001, NT t=2.26, p<.05; MB; t=3.18, p<.01; NS; t=2.17, p<.05). The speed and accuracy of the three participants who performed well at lexical decision in English (MR, AH, GM) did not differ significantly from the controls in Greek.

The results show a consistent pattern. Four of the cases were impaired at lexical decision in both languages and three were unimpaired. As the participants who were impaired at English lexical decision were also impaired at Greek lexical decision, it seems unlikely that their poor English lexical decision performance is associated with any of the variables reported in Table 1. In addition, a comparison of the scores in Tables 2 and 3 provides no evidence that the four individuals with poor lexical decision were more impaired at reading and spelling irregular English words than the three individuals with good lexical decision performance. It does not appear, therefore, that the overall severity of the dyslexic impairment is responsible for the observed differences in lexical decision performance.

Instead, the results suggest that the literacy problems that these individuals experience have distinct causes. It appears that TT, NT, NS and MB are suffering from what Friedmann and Lukov (2008) have categorized as *input* surface dyslexia in which the impairment is considered to be at the level of the orthographic lexicon itself. Input surface dyslexia cannot, however, be reasonably attributed to MR, AH and GM for whom preserved lexical decision performance in Experiment 1 suggests that the orthographic lexicon in both Greek and English is working relatively well.

One possible explanation for a dissociation between lexical decision and spelling performance is that there are separate orthographic systems for reading and spelling and that surface dyslexics with impaired lexical decision have impairments to both systems (e.g. TT, NT and MB) while those with preserved lexical decision (e.g. MR, AH and GM) have impairments to just the spelling system. But if MR, AH and GM have no impairment to the orthographic units that are used for reading, why do they read familiar Greek words slowly and irregular English words inaccurately (Sotiropoulos & Hanley, 2017)? Instead we investigate the possibility that this dissociation can be explained in terms of a single orthographic lexicon for reading and spelling, as in Figure 1. It appears that TT, NT and MB have an impairment to the orthographic lexicon itself (input surface dyslexia). In Experiment 2, we investigate whether the performance of MR, AH and GM is consistent with an impairment to the development of connections from the orthographic lexicon to the semantic system (orthographic output surface dyslexia).

Experiment 2 English Semantic Decision task

Friedmann and Lukov (2008) showed that when there is good performance at lexical decision, surface dyslexia is sometimes associated with poor performance on a semantic decision test for written words. Experiment 2 investigated whether MR, AH and GM would perform in an analogous manner. In Experiment 2, the task required that the appropriate meaning of a written word be accessed. If MR, AH and GM have a problem that affects reading immediately after processing by an intact orthographic lexicon, then these three individuals should perform poorly on a task that requires access to the semantic system for written words. The target words were irregular English words in an attempt to ensure that the task could not be accomplished by using a nonlexical reading route.

Materials

Table 4 presents the materials that were used in Experiment 2. Following Friedmann and Lukov (2008), a target phrase or word that was always regular was presented on the screen. A pair of homophones (e.g. *sun/son*), or potentiophones (e.g. *now/know*) was presented to its immediate right (e.g. *family: sun/son; be informed: now/know*). One member of each pair was semantically related to the target word or phrase, the other word was either a homophone or a potentiophone of the target word or phrase. Potentiophones are words that, when read via grapheme-to-phoneme conversion, could potentially be read as other words (e.g., ‘‘now’’, which can be sounded out as the word ‘‘know’’). Participants had to choose whether the word on the right or the left of each pair was semantically associated with the target word. Eighteen pairs of homophones contained an irregular word and a regular one. The irregular word was always the word that was semantically related to the target word, and so participants should choose it as the correct response. In half of those pairs the correct word (irregular) appeared first (e.g. *fruit:* ***pear****/pair*) and in half of the pairs the incorrect word (regular) appeared second (e.g. *part of: sum/**some***). Fourteen pairs of potentiophones were presented. In half of those pairs the correct word appeared first (e.g. *miss:* ***lose*** *loose*) and in half of the pairs the incorrect word appeared second (e.g. *drink: bear/**beer***). Among the 14 word-potentiophone pairs that were used in the semantic decision task, there were 2 pairs of words in which both items were potentiophones of each other ("now" and "know", "whose" and "hose"). Scores could potentially vary from 0 reflecting zero correct pairs to 32 reflecting 32 correct pairs.

Procedure

The task was presented on a computer screen in font size 44 in lower case. SuperLab for Mac software was used for the presentation of the decision tasks. Participants indicated an answer by pressing a key on the keyboard according to whether the correct answer was on the left or right of the pair of words. Measures of both accuracy and speed were taken.

Results and Discussion

Insert Table 4 and 5 about here

Results are presented in Table 5. As would be expected if they had a problem at the level of the orthographic lexicon, all four of the individuals who performed badly at lexical decision in Experiment 1 also showed poor semantic decision accuracy relative to controls (TT $t= -2.99$, $p< .01$; NT; $t= -2.43$, $p= .01$,; MB; $t= -1.88$, $p< .05$; NS $t= -2.99$, $p< .01$). Accuracy problems in the semantic decision task were accompanied by significantly slowed latencies (TT; $t=6.14$, $p<.001$; NT $t=3.85$, $p<.01$; MB $t=3.77$, $p<.01$; NS; $t=3.53$, $p<.01$.)

Importantly, one of the remaining surface dysgraphic individuals (MR) also performed significantly less accurately ($t= -3.55$, $p< .01$) and more slowly than controls $t=2.77$, $p<.01$) on the semantic task despite unimpaired lexical decision in Experiment 1. MR's pattern of performance is therefore consistent with Friedmann & Lukov's (2008) definition of orthographic output surface dyslexia, a problem in accessing semantic representations from otherwise intact orthographic representations. The possibility that

MR has an additional problem in accessing the phonological lexicon will be investigated in Experiment 4, which examines spoken picture naming.

AH and GM, however, were unimpaired at making semantic decisions in terms of either speed or accuracy. This outcome suggests that their orthographic system has developed normally and that there is good access from the orthographic lexicon to the semantic system. The cause of their impaired ability to read irregular words aloud will be further investigated in Experiment 4. Experiment 3, however provides a comparison of spelling to dictation with written spelling of picture names.

Experiment 3 Spelling the names of pictures.

In this experiment, we further investigate irregular word spelling. AH and GM's good lexical decision performance (Experiment 1) suggested that their orthographic lexicon is intact. If the same lexicon is used for spelling as for reading, then it might be possible for AH and GM to access the orthographic lexicon from the semantic system despite their problems in spelling to dictation. According to the model outlined in Figure 1, such an outcome would also require that the link from the semantic system to the orthographic lexicon is preserved. This seems quite possible in light of AH and GM's ability to access the meanings of irregular English words during reading (Experiment 2). Experiment 3, therefore, compares AH and GM's spelling of picture names that are irregular English words with their spelling of the same words to dictation.

MR also performed well at lexical decision (Experiment 1) but could not access the semantic representations of irregular written words (Experiment 2), consistent with an impairment to the pathway from the orthographic lexicon to the semantic system. It seems quite possible that MR would have a corresponding impairment to the connections from the semantic system to the orthographic lexicon (see Figure 1). If so, despite his preserved orthographic lexicon, it would follow that he would not perform any better at spelling picture names that at spelling to dictation.

The results of Experiment 1 suggested that TT, NT, NS and MB have a problem at the level of the orthographic lexicon. Consequently they should also be as impaired at spelling picture names as they are at spelling to dictation.

Materials and Procedure

Twenty-two objects were selected from Snodgrass and Vanderwart's (1980) set of pictures. They all had one-syllable names in English: *axe, ball, bow, bowl, bread, coat, comb, book, door, eye, flute, fly, glove, key, knife, shirt, shoe, skirt, swan, thumb, tie, watch.* They comprised words with a phoneme that has a low-contingency spelling. Three had low-contingency spellings of their consonants (*comb*, *thumb* and *knife*) and the remainder had low-contingency spellings of their vowels. Spelling contingency was determined on the basis of the analysis of phoneme-to-spelling correspondences provided by Barry and Seymour (1988). Low-contingency words contained neither the first nor the second most common spelling of phonemes. For example, the most common spelling of the long vowel /u:/ is OO, as in *moon*, which occurs in 47.9% of words with this vowel, and the second most common spelling is EW, as in *shrewd* and *brew*, which occurs in 10.1% of words; the low-contingency spelling in *flute* is the third most common and occurs in only 9.6% of words. Although these words have low-contingency spellings, they are not necessarily irregular for reading. For example, for both the high-contingency spelling *OO* (as in *moon* and *boot*) and the low-contingency spelling *U-E* (as in *flute* and *dune*), the major spelling-to-sound correspondence is /u:/. The word *flute* therefore has a low-contingency spelling of its vowel, but it is regular for reading.

Each item was presented twice during separate testing sessions to each participant, once as a picture and once as a spoken word. Participants were asked to write down the word. There was a gap of at least one month between testing sessions. Half of the participants (TT, NS, GM, AH and nine controls) received the written picture-naming test first and half received the spelling to dictation test first (MB, NT, MR, and nine controls). A percentage score was also calculated that comprised the number of items spelt correctly to dictation as a percentage of the items that were spelt correctly from pictures. For instance, if a participant spelt only 5 items correctly in the spelling to dictation task but was able to spell 10 of these items accurately from pictures, a score of 50% would be given.

Results and Discussion

Consistent with the surface dysgraphic profile of the participants, over 97% of the errors that were made in the spelling to dictation test were phonologically appropriate responses. The corresponding figure for written picture naming errors was 77%. However, the remaining errors on written picture naming were not spelling errors; 17% were omissions and 7% were superordinate errors.

Insert Table 6 about here

Mean accuracy and latency scores are shown in Table 6. The most important finding is that, consistent with the single orthographic lexicon account, the performance of AH and GM showed no evidence of any impairment relative to controls when spelling picture names. Nevertheless, the spelling of both AH ($t = 3.89$, $p<.01$) and GM ($t = 4.38$, $p<.01$) remained severely impaired when they were asked to write the same items to dictation. By contrast all of the remaining participants were impaired on both versions of the test. TT was impaired at spelling to dictation ($t=-7.30$, $p<.01$) and written spelling ($t=-6.83$, $p<.01$). NT was impaired at spelling to dictation ($t=-3.89$, $p<.01$) and written spelling ($t=-3.81$, $p<.01$). MB was impaired at spelling to dictation ($t=-4.38$, $p<.01$) and written spelling (t=-

3.81, $p<.01$). MR was impaired at spelling to dictation ($t=-2.43$, $p<.05$) and written spelling ($t=-2.81$, $p<.01$). NS was impaired at spelling to dictation ($t=-1.95$, $p<.05$) and written spelling ($t=-2.36$, $p<.05$).

The Revised Standardised Difference Test (RSDT; Crawford and Garthwaite, 2005) was used to investigate the dissociation between written spelling and spelling to dictation. A significant dissociation was found for both AH and GM, who performed well at written picture naming but badly at spelling to dictation of the same items (AH RSDT $t = 5.89$, $df = 17$, $p < .001$; GM RSDT $t = 8.85$, $df = 17$, $p < .001$). The remaining surface dysgraphics showed no significant dissociation between the two modalities consistent with equal impairments on both tasks. The third row in Table 7 shows that, apart from AH and GM, the participants did not spell correctly in written picture naming any items that they had been unable to spell to dictation. Performance in the two different output modalities was highly correlated in controls ($r=.92$, $p <.01$).

The results of Experiment 3 show that there are strong parallels between the way in which all seven of these surface dysgraphic individuals read and spell familiar English words. TT, NT, NS and MB appear to have a problem at the level of the orthographic lexicon that impairs irregular word reading and the spelling of irregular words from pictures and to dictation. The two participants (AH and GM) who could access the meanings of written words from print in Experiment 2 appeared able to access the representations of words in the orthographic lexicon from their semantic representations and so spell correctly the names of pictures that they could not spell to dictation. MR, conversely, who was impaired at accessing the meaning of written words from print in Experiment 2 seemed unable to use the semantic pathway to spell words. These findings provide strong support for the view that the same orthographic lexicon is involved in reading and spelling.

The parallels between AH and GM's ability to spell picture names and to access the meaning of written words and between MR's inability to spell picture names and access the meaning of written words are also striking. They are consistent with the view that, contrary to the model presented in Figure 1, the same orthography > semantics pathway that is used in the reading of irregular English words can be used in reverse to support the spelling of these words. We return to this issue in General Discussion.

Experiment 4 Spoken Picture naming

In Experiment 4, we investigate further the reason why AH and GM are poor at reading and spelling irregular words to dictation given their preserved ability to make lexical decisions and semantic decisions about written words (Experiments 1 and 2). One possibility is that these two individuals have an anomic impairment of the kind that was described by Gvion and Friedmann (2016). Although they appear to have an intact orthography-semantic reading route that allows good performance on lexical decision tasks and on semantic decision tasks, they may have a developmental impairment that prevents them from activating the representations of familiar words in the phonological output lexcion. Alternatively, AH and GM may have what Friedmann and Lukov (2008) refer to as interlexical surface dyslexia in which there is an impairment to the connection from the orthographic lexicon to the phonological lexicon.

The obvious way to test these alternatives is to examine spoken picture naming. Interlexical surface dyslexia is associated with preserved spoken picture naming (Friedmann & Lukov, 2008). Conversely, if AH and GM suffer from an impairment to the speech output system, their picture naming should be significantly worse than controls. The other five surface dyslexics should perform relatively well because their impairment is to the orthographic system (TT, NT, MB, NS), or to the connections between the orthographic system and the semantic system (MR). Because the orthographic system is not involved in picture naming (visual input > semantics > phonology in Figure 1), the semantic representations and, subsequently, the names of the pictures should be readily available to these five individuals.

Materials and Procedure

The picture naming task comprised 71 pictures (see appendix D) taken from Snodgrass and Vanderwart (1980). An Apple Mac PowerBook G3 computer using Microsoft Office Powerpoint software was used for the presentation of the stimuli. Responses were recorded using the Audacity software programme and measures of both accuracy and latency were taken. The experimenter controlled the presentation. Participants were asked to give the name of each picture orally in Greek, as quickly and accurately as possible. They were also able to correct their answers as only the final answers were taken into account for the accuracy measure. Between four and six months later, the same pictures were again presented and the participants were asked to respond in English.

Insert Table 7 about here

Results and Discussion

The results are presented in Table 7. As was expected, neither TT, NT, NS, MB nor MR experienced any difficulties with spoken picture naming. There appears to be no impairment that is associated with the retrieval of words from the phonological lexicon in any of these five cases. This finding confirms that the overall performance of TT, NT, NS, MB is consistent with Friedmann and Lukov's (2008) definition of input surface dyslexia and that MR's overall performance is consistent with their definition of output surface dyslexia.

The picture naming performance in English of AH and GH was significantly impaired on measures of both accuracy (AH; t= -3.48, p<.01; GM; t= -3.82, p<.01) and speed (AH; t= -3.52, p<.01, GM; t= -6.23, p<.001). Fourteen of the 17 English picture-naming errors made by AH were classified as semantic and the remaining three were omissions (e.g. *bow* -"I don't know"). Semantic errors included superordinate categories and circumlocutions (e.g., *ant*-"bee", *pig*-"animal", *anchor* -"this thing in the ships, I can't remember the name of it). Twelve of the 18 errors made by GM were semantic errors (e.g., *pig*- "sheep", *goat*-"animal", *anchor* -"an instrument, I can't remember the name of it") and four were omissions (e.g., rabbit-"I don't know") There was one visual error (*flute*-"pen") and one phonological error (*thumb*-"/θʌmb/").

A similar pattern was observed when these participants were asked to respond in Greek. Both AH and GM made significantly more errors than controls (AH; t= -4.91, p< .001, GM; t= -4.91, p< .001) 4 (n = 18, sd = 2.1). AH (t=4.47, p<.001) and GM (t=7.39, p<.001) also named the pictures significantly more slowly than controls. Once again, neither TT, NT, MB, MR nor NS experienced any speed or accuracy problems.

These results clearly show that AH and GM were impaired at spoken picture naming. Their impaired accuracy and speed, and the type of errors that they made are similar to the developmental surface dyslexic participants reported by Gvion and Friedmann (2016). It therefore appears that AH and GM make regularisation errors when reading aloud irregular words because the lexical route is disrupted by a problem that is associated with the phonological output lexicon. This impairment resembles that observed not only in Gvion and Friedmann's developmental surface dyslexics but also in Watt, Jokel, and Behrmann's (1997) case of acquired surface dyslexia.

In light of their impaired ability to access phonology from semantics, we also investigated whether AH and GM would have difficulties in accessing the meaning of spoken words. Importantly, their auditory comprehension ability revealed no evidence of any impairment. First, following their attempt to name the pictures aloud in English, AH and GH were shown the items that they had previously failed to name correctly. They were then asked to match each picture with one of two orally presented words: a false name and the correct name (e.g., *is this an ant or bee*?). In the case of an omission or a superordinate error, a semantically related word was given instead. AH corrected all his false answers (17/17), and GM gave 15 out of 18 correct responses in the picture identification task, correcting all the semantic errors that he previously made. Both individuals, therefore, appeared able to access the meaning of auditorily presented words that they had been unable to produce during spoken picture naming.

Second, AH (39/40) and GM (37/40) both performed within the normal range when given a test of spoken word-picture matching that was taken from the PALPA battery (Test 47:Kay, Lesser & Coltheart, 1992). Controls, however, performed at ceiling on this task (38.6/40, sd = 1.20) so these data do not represent a robust examination of AH and GM's ability to understand spoken words.

Third, we administered an auditory comprehension test that was based on the vocabulary sub-test of the WASI (Wechsler, 1999). It was first given in Greek and 6 months later it was given in English. Participants heard 34 words and were asked to provide a definition. A score of two was awarded on each trial where an accurate definition was given (e.g., *improvise > ad-lib*). A score of one was awarded when a less precise definition was provided (e.g., *improvise > to adjust to new conditions and demands*). A score of zero was given for an incorrect answer (e.g., *improvise > compromise*). The 34 English words with their 34 Greek translations are presented in Appendix E. Mean scores are shown in Table 8. It can be seen that control performance was not at ceiling and that all of the dysgraphic participants, including AH and GM performed within the normal range on both English and Greek versions of the test.

Insert Table 8 about here

There is therefore no evidence that either AH or GM have a problem in understanding spoken words. Such an outcome is consistent with the existence of separate pathways between semantics and phonology that support speech comprehension and production (see Figure 1). In AH and GM, the link from phonology to semantics appears to be unimpaired even though the link from semantics to phonology has not developed normally.

Since AH and GM could spell accurately irregular English words from pictures (Experiment 3), it appeared that AH and GM could make use of the semantic system when spelling irregular words from pictures but not when spelling irregular words to dictation. Because they can access the meaning of spoken words (Experiment 4) and because the connections between semantics and orthography are intact (Experiment 2 and 3), it is surprising that AH and GM cannot use the semantic route to activate the orthographic representations of irregular words when spelling to dictation. It appears as if the non-lexical route in some way captures the spelling process when target words are spoken aloud, impeding the semantics > orthography pathway from generating the correct spelling of words with atypical sound-spelling correspondences.

General Discussion

Previous research has shown that individuals with developmental surface dysgraphia in orthographies such as English (e.g. Hanley et al. 1992), German (Bergmann & Wimmer, 2008) and Italian (Angelelli et al., 2010) frequently perform badly on tests of lexical decision. Such a pattern of performance has been taken as support for the view that the same orthographic lexicon is used in reading and spelling and that a developmental impairment to this lexicon affects both spelling and lexical decision. In the present study, consistent with such findings, we have reported the performance of four individuals with surface dysgraphia (TT, NT, NS, MB) who were impaired at orthographic lexical decision in both English and Greek. However, contrary to those earlier reports, the present study has provided evidence of three individuals (MR, AH, GM) with developmental surface dysgraphia who performed well at orthographic lexical decision tasks in both English and Greek. Preserved lexical decision performance raises the possibility that separate orthographic lexicons exist for reading and spelling. Any suggestion that these three individuals might have an impaired spelling lexicon but an unimpaired reading lexicon was discounted, however. This is because all three of these individuals read familiar words in Greek and English more slowly than controls and their oral reading of irregular English words was inaccurate (Sotiropoulos & Hanley, 2017).

Three types of developmental surface dyslexia and dysgraphia

Instead, we have claimed that this pattern of performance can be readily explained in terms of a single orthographic lexicon. In so doing, we have employed the framework used by Friedmann and Lukov (2008) and by Gvion and Friedmann (2016) to explain the existence of different types of developmental surface dyslexia in Hebrew. Friedmann and her colleagues observed these differences in a semitic language (Hebrew) in which the cues to phonology from orthography are relatively limited. Our results suggest that these distinctions can be applied equally effectively to surface dyslexia in less opaque orthographies than Hebrew such as English. Most importantly, we have extended Friedmann's framework to also accommodate developmental spelling impairments in surface dysgraphia in terms of the DRC-SLA (see Figure 1).

The four cases (TT, NT, NS and MB) who were impaired at orthographic lexical decision appeared unable to read and spell irregular words because of a problem at the level of an orthographic lexicon that encodes the identity and the order of the graphemes that familiar written words contain (input surface dyslexia and dysgraphia). The three individuals (MR, AH, GM) who performed well at lexical decision had an intact orthographic lexicon but appeared to have suffered damage to other components of the reading and writing system. In the case of MR who performed poorly when making semantic decisions about written words, it appeared that his orthographic lexicon was intact but that there was a developmental impairment to the connections between the orthographic lexicon and the semantic system (orthographic output surface dyslexia and dysgraphia). As a consequence, he found it difficult to access the meaning of written words in Experiment 2 and to access the orthographic representations of words from semantics when spelling the names of pictures (Experiment 3).

The good lexical decision performance of AH and GM in Experiment 1 was again consistent with an intact orthographic lexicon. Their unimpaired ability to access the meaning of written words (Experiment 2 is consistent with a preserved pathway from orthography to semantics. As with the developmental surface dyslexics reported by Gvion and Friedmann (2016), it appears that AH and GM's impaired ability to read irregular words aloud is the consequence of a difficulty in accessing the phonological system from the semantic system during spoken word production (Experiment 4). Experiment 3 revealed a striking dissociation between their impaired spelling to dictation and preserved spelling of picture names. It appears that AH and GM had preserved access to the orthographic lexicon from semantics when spelling the names of pictures despite their inability to spell the same words to dictation.

Our results have therefore shown that a single lexicon account can provide a plausible explanation of the finding that a developmental spelling impairment that is selective to irregular words (developmental surface dysgraphia) can co-occur with both impaired (TT, NT, NS and MB), and preserved (MR, AH, GM) lexical decision performance for words of this kind. The core impairment in those with impaired lexical decision appears to be to the development of the orthographic lexicon itself. The core developmental impairment in those with unimpaired lexical decision appears to be to the connections between the orthographic lexicon and the semantic system (MR) or to the connections from the semantic system to the phonological system (AH and GM). Therefore, there are at least three distinct developmental deficits that can give rise, in an individual, to a combination of surface dyslexia and dysgraphia. All three are consistent with the claim that the same orthographic lexicon is used for both reading and spelling. Such an outcome provides further evidence that the same neurophysiological substrate(s) supports learning to read and learning to spell familiar words (Rapp & Lipka, 2011).

It is also important to note that in Experiments 1 and 4, the nature of the processing impairment that these seven individuals experienced in English was identical to the processing impairment that they experienced in Greek. This outcome strengthens the claims of Sotriopoulos and Hanley (2017) that the foundation skills that are important for learning to read and spell in English are the same as those that are required for learning to read and spell in Greek. The results of these two experiments provide further evidence that the neurophysiological substrate that supports the connections between orthography and semantic that are involved in learning to read and spell is the same in both Greek and English. Consequently, a developmental weakness in part of this underlying substrate will inevitably lead to an impairment that affects development of literacy in different orthographies in an analogous way.

The DRC versus the Triangle model

To maintain consistency with the approach taken by Friedmann and her colleagues, we have so far explained the findings in terms a version of the DRC model (Coltheart et al., 2001). In order to accommodate both reading and spelling, the expanded DRC-single lexicon account (DRC-SLA) that is represented in Figure 1 has been used. In this section, we further scrutinise the effectiveness of the DRC-SLA and contrast it with an account that relies instead upon the *triangle* model of reading (Harm & Seidenberg, 1999; Plaut, McClelland, Seidenberg & Patterson, 1996; Woollams, 2014). We will discuss whether the architecture of the triangle model (see Figure 2) can provide a more or less satisfactory account than the DRC-SLA model of the individual differences in reading and spelling that have been observed in Experiments 1-4.

According to the triangle model, there are separate pathways from orthography to semantics (the semantic route) and from orthography to phonology (the phonological route). The orthographic units do not contain information about the way in which individual words are spelled. Instead this information is instantiated in the connections between orthography and phonology and in the connections between orthography and semantics. Early versions of the model (Seidenberg & McClelland, 1996) demonstrated that both regular and irregular words could be read reasonably accurately by a single orthography > phonology pathway. When, however, an orthography > semantics pathway was incorporated into the model in subsequent simulations (Plaut et al., 1996), the semantic pathway assumed primary responsibility for reading all but the most frequent irregular words. Proponents of the triangle model therefore assume that, for the majority of readers, the correct pronunciations of both regular and irregular English words are generated by first activating their meaning from the orthographic units (see Figure 2). This claim has been criticized because a small number of acquired dyslexics with semantic impairments can read irregular words despite being unable to define them (e.g. Blazely, Coltheart & Casey, 2005). In response, adherents of the triangle model claim that there exist a minority of readers of English who rely more heavily on the orthography > phonology than on the orthography > semantics pathway when reading words with atypical spelling-sound correspondences (Plaut, 1997; Woollams, Lambon Ralph, Madrid & Patterson, 2016).

Because the semantic pathway is so important for the accurate reading of irregular English words, its impaired development is assumed to cause surface dyslexia (Woollams, 2014). Nonwords, regular words and irregular words of high familiarity can be read on the basis of direct mappings between orthographic units and phonological units (the phonological route). It is assumed that this pathway develops relatively normally in surface dyslexia. Poor nonword reading in phonological dyslexia is explained in terms of a developmental impairment to the phonological units themselves (Harm & Seidenberg, 1999).

Insert Figure 2 about here

Whether or not exactly the same units and connections are used in spelling and reading has not been made explicit by supporters of the triangle model. Nevertheless, such a proposal is certainly consistent with the *primary systems* approach that is frequently advocated by supporters of the triangle model model (Patterson & Lambon Ralph, 1999; Woollams, 2014) in which the systems that subserve the acquisition of literacy rely upon connections with more basic underlying knowledge systems. Furthermore, although the triangle model has rarely been used to investigate spelling performance, Loosemore, Brown & Watson (1991) reported a successful simulation of the phonological spelling route. They used a similar architecture to that which the triangle model employs during simulations of the phonological route in reading. In this model, the spellings of regular English words were more easily acquired than the spellings of irregular words, and some of the symptoms of surface dysgraphia were simulated.

The cases of TT, NT, NS and MB: Input surface dyslexia and dysgraphia. As we have seen, the DRC-SLA can parsimoniously explain the poor reading, spelling and lexical decision performance of TT, NT, NS and MB in terms of a single impairment to the development of the orthographic lexicon. In the triangle model, the orthography > semantics pathway is involved in making lexical decisions (e.g. Plaut and Booth, 2006). TT, NT, NS and MB's impaired lexical decision and poor reading performance would be the result of very weak connections between the orthographic units and the semantic system. If the same pathway between orthography and semantics is also involved in written word production then this impairment would explain TT, NT, NS and MB's impaired spelling of irregular words. Otherwise an additional semantics > orthography impairment would be necessary to explain their spelling deficit.

The case of MR: Orthographic output surface dyslexia and dysgraphia. Can the triangle model explain MR's inability to access meaning from print despite preserved lexical decision as the consequence of an impairment to the connections between the orthographic and semantic systems? If the orthography > semantics pathway is involved in making orthographic lexical decisions, then an orthography > semantics impairment might be expected to produce poor lexical decision performance. However, a simulation by Plaut and Booth (2006, p 198) showed that it was possible to lesion the orthography > semantics pathway such that lexical decision was "relatively unaffected over a range of lesion severities that produced substantial semantic impairment". The dissociation between TT, NT, NS and MB's impaired and MR's preserved lexical decision performance could therefore be explained by the triangle model in terms of differences in the severity of the orthography

> semantic impairment. MR's poor spelling of picture names could be seen as reflecting the impaired development of the same pathway between orthography and semantics or the impaired development of a separate spelling route from semantics to orthography.

According to the DRC-SLA, MR has developmental impairments to the connections from the orthographic lexicon to the semantic system (poor access to the meaning of irregular English words when reading), and to the connections from the orthographic lexicon to the semantic system (poor spelling of picture names that are irregular English words). In the DRC-SLA, however, there is also a direct-lexical reading route that can read familiar words aloud via a connection between the orthographic lexicon and the phonological lexicon without the need for semantic mediation. In order to explain MR's poor reading of irregular words, it would therefore be necessary to assume that there is an additional phonology > orthography deficit that has inhibited the development of the direct-lexical reading route (see Figure 1). Poor spelling of irregular words would indicate an additional impairment to the development of the orthography > phonology spelling route in Figure 1.

According to the triangle model, the direct connection from the orthographic system to the phonological system is primarily used to process regular words and nonwords. MR, is relatively proficient at reading and spelling regular words and nonwords (Table 1). Unlike the DRC-SLA, therefore, it would not be necessary to assume that MR has any additional developmental impairment to the connections between orthography and phonology unless he is one of the small number of readers who rely on the phonological pathway to process irregular words (Woollams et al., 2016).

The cases of AH and GM: Phonological output surface dyslexia. The triangle model can explain AH and GM's reading and picture naming problems as the consequence of a single developmental impairment to the pathway from the semantic system to the phonological system (Figure 2). AH and GM's preserved ability to comprehend the meanings of spoken words despite their impaired spoken word output is consistent with the existence of separate pathways between semantics and phonology that are involved in speech production and comprehension (see Figure 1 and 2). As with MR, there is no need to assume a developmental impairment to the pathway between orthography and phonology because, according to the triangle model, this route is not primarily responsible for the way in which most individuals read irregular words. AH and GM could not have a developmental impairment at the level of the phonological units themselves because, according to the triangle model, the outcome would be developmental phonological dyslexia (Harm & Seidenberg, 1999).

In terms of the DRC-SLA, AH and GM's impaired picture naming and reading aloud of irregular words could be seen as the consequence of developmental impairments to the connections from the semantic system to the phonological lexicon. If so, as with the case of MR, it would be necessary to assume a second developmental impairment to the pathway from the orthographic lexicon to the phonological lexicon in order to explain their poor irregular word reading. Alternatively, if as Gvion and Friedmann (2016) suggest, the impairment was at the level of the phonological output lexicon itself, then this would prevent both the lexical-semantic and direct-lexical reading routes from producing the correct pronunciations of irregular words. Nonword reading ability would not be affected in this scenario (see Figure 1). If, however, AH and GM have a problem at the level of the phonological output lexicon itself, it becomes difficult to explain their unimpaired ability to comprehend the meaning of spoken words without the assumption that separate phonological lexicons are used in auditory comprehension and production. This assumption is not implausible but it requires a more elaborate model than that presented in Figure 1. In summary, in order to explain AH and GM's impaired reading of irregular words, the DRC-

SLA model requires separate impairments to the lexical-semantic and direct lexical routes or else it requires separate input and output phonological lexicons.

What about AH and GM's spelling of words with atypical phoneme>grapheme correspondences? Both the DRC-SLA and the triangle model can explain AH and GM's accurate spelling of the names of pictures that are irregular English words (Experiment 3) in terms of an unimpaired pathway from semantics to orthography. AH and GM's poor spelling to dictation of words with atypical sound-spelling correspondences is less easy to explain, however. In the DRC-SLA, there must be a developmental impairment to the connection from the phonological lexicon to the orthographic lexicon. An orthography-phonology impairment is not required by the triangle model as this pathway would not be considered responsible for the way in which most people spell irregular words. But neither model can explain why AH and GM's spelling to dictation of irregular words cannot proceed via the intact semantics > orthography pathway.

Conclusion. In summary, both the DRC-SLA (Figure 1) and the triangle model can accommodate most of the main findings reported in this study. However, both models have relative strengths and weaknesses and neither model can readily accommodate all of them.

The DRC-SLA provides the most straightforward explanation of lexical decision impairments. TT, NT, NS, MB's impaired lexical decision, reading and spelling (Tables 2 & 3) can be explained in terms of a single lesion to the orthographic representations themselves. MR's preserved lexical decision but impaired semantic access is consistent with a developmental impairment to the pathway from orthography to semantics. The triangle model assumes instead that a severe developmental impairment to the orthography > semantics pathway disrupts lexical decision (TT, NT, NS, MB), and that a weaker impairment to this pathway can impair semantic access but not lexical decision (MR). Unless the same orthography-semantics pathway is used for both reading and spelling, the triangle model would also require an additional impairment in order to explain TT, NT, NS, MB's irregular word spelling deficits. Both models would require an additional impairment to this pathway to explain MR's spelling deficit. Nonetheless, the existence of a single pathway between orthography and semantics would explain the parallels between the way in which MR, AH and GM access the meaning of written words and spell the names of pictures (Experiments 2 and 3). Figures 1 and 2 both contain two separate orthography-semantics pathways, but both models could be easily modified to include just one.

In the DRC-SLA, there must be developmental impairments to both the lexical - semantic route and the direct lexical route between orthography and phonology to explain why an individual such as MR is unable to read irregular words aloud. The absence of a reading (and spelling) route of this kind in the triangle model means that it can provide a more parsimonious account than the DRC-SLA of the developmental impairments that are needed to explain the irregular word reading (and spelling) deficits that MR experiences.

Finally, neither model can fully explain the nature of AH and GM's spelling impairment. Because they appear to have preserved links from phonology to semantics and from semantics to orthography, the reason why they are unable to spell to dictation words with atypical sound-spelling correspondences remains obscure.

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Figure 1

A dual route model of reading, spelling and picture naming that is taken from Purcell, Shea and Rapp (2014) in which the same lexicon (Orthographic LTM) is used for reading and spelling. Ovals indicate lexical processing for orthography, phonology or semantics. The short dotted lines and the dashed lines between the ovals indicate reading processes and spelling processes respectively.

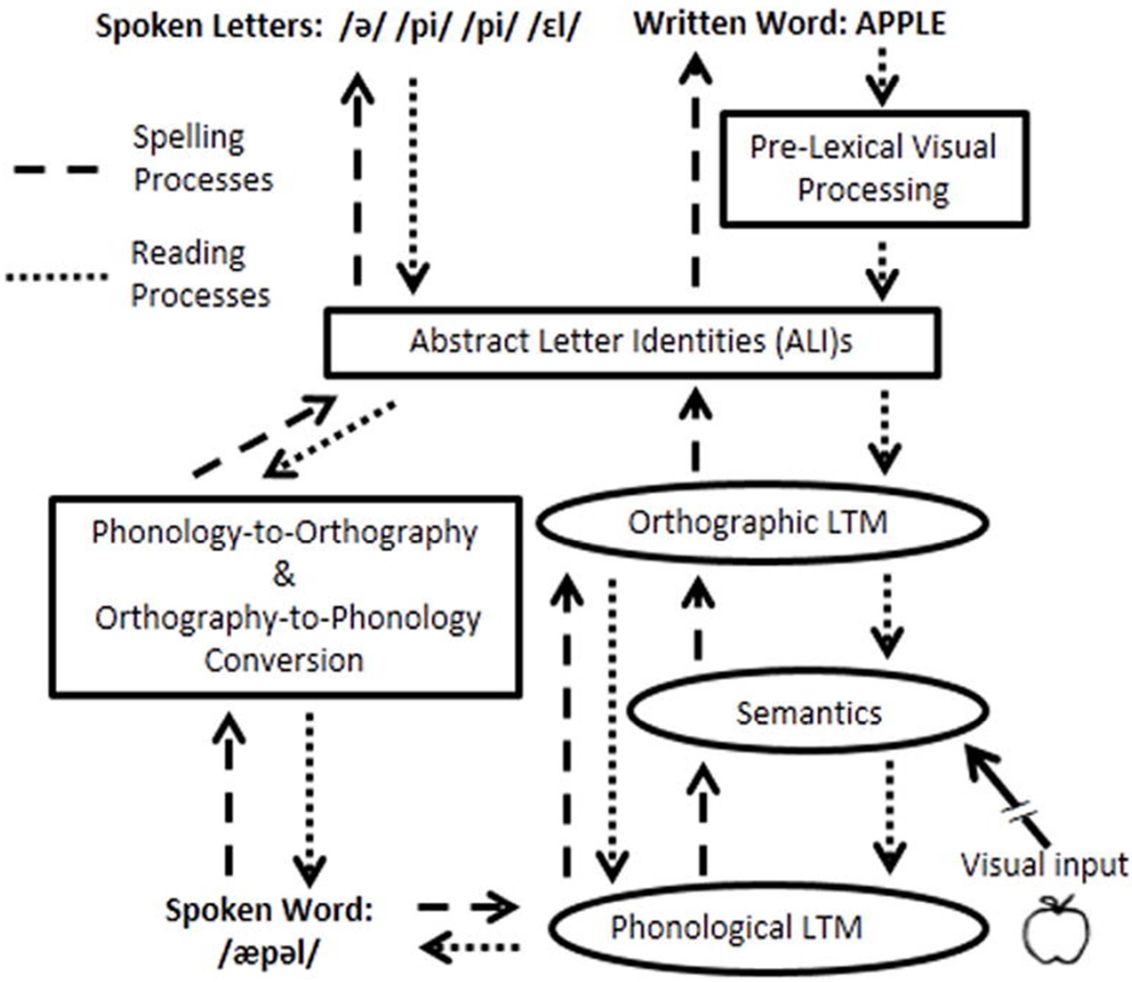

Figure 2

The basic architecture of the triangle model of reading in which the connections between orthography, phonology and semantics are bidirectional.

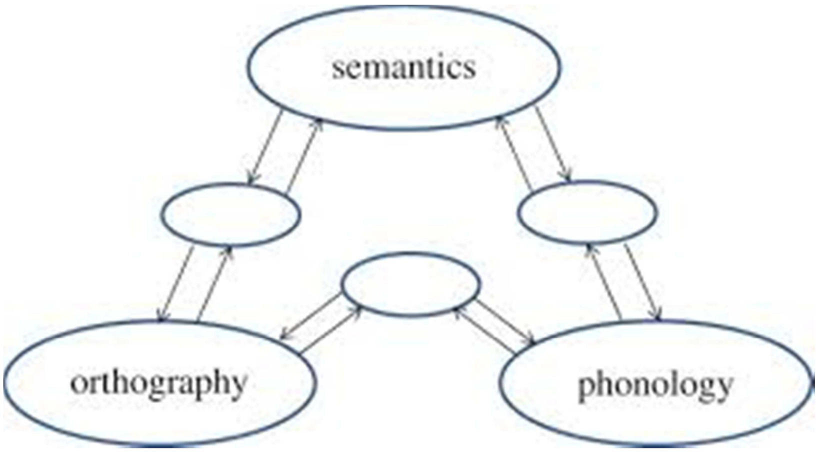

Table 1

The amount of time spent in the UK and the amount of exposure to the English language of the seven dysgraphics/dyslexics and eighteen control participants

	Controls (sd)	TT	NT	MB	MR	NS	AH	GM
Time spent in UK (years)	4.22 (1.8)	10	4	3	7	2	8	6
First exposure to English (years)	8,6 (2.1)	8	9	9	8	10	8	8
Total time of exposure (years)	15.8 (3.4)	21	15	14	19	12	20	17

Table 2

Performance at reading and spelling English words and nonwords by 7 surface dyslexics in comparison with 18 normal readers/spellers (data are taken from Sotiropoulos & Hanley, 2017)

	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*	769*	686*	718*	742*	741*	701*
Irregular word reading accuracy (max=20).	17.1 (1.89)	13*	8*	11*	12*	11*	11*	13*
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

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

Table 3

The English and Greek lexical decision accuracy and latency for real words ("yes responses") and pseudohomophones ("no responses") of 7 dysgraphic individuals in comparison with 18 controls.

English Lexical Decision (max = 24)

	Controls (sd)	TT	NT	MB	NS	MR	AH	GM
Accuracy	21.2 (1.6)	4*	14*	14*	15*	23	22	20
RT (*Yes* responses)	907 (233)	2001*	1485*	1567*	1403*	1058	1130	859
RT (*No* responses)	1008 (255)	3349*	1803*	2000*	1615*	1332	1236	1074

Greek Lexical Decision (max=34)

	Controls (sd)	TT	NT	MB	NS	MR	AH	GM
Accuracy	27.8 (3.0)	8*	13*	18*	18*	24	25	28
RT (*Yes* responses)	1066 (321)	2515*	1836*	2009*	1788*	1104	1192	977
RT (*No* responses)	1202 (341)	3603*	1995*	2317*	1963*	1358	1381	1186

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

Table 4.

Pairs of potentiophones used in the English semantic task.

Triad (target meaning: pair of homophones)	
drink: bear / **beer**	*"bear"* could be read as *"beer"* if read like *"clear"*
which person owns: **whose** / hose	*"hose"* could be read as *"whose"* if read like *"lose"*
water pipe: **hose** / whose	*"whose"* could be read as *"hose"* if read like *"chose"*
be informed: now / **know**	*"now"* could be read as *"know"* if read like *"snow"*
at the moment: **now** / know	*" know"* could be read as *"now"* if read like *"how"*
miss: **lose** / loose	*"loose"* could be read as *"lose"* if read like *"choose"*
look carefully: pear/ **peer**	*"pear"* could be read as *"peer"* if read like *"dear"*
hair brush: **comb** / come	*"come"* could be read as *"comb"* if read like *"dome"*
TV: shoe / **show**	*"shoe"* could be read as "show" if read like *"toe"*
clothes: **stain** / stein	*"stein"* could be read as "stain" if read like *"vein"*
dog: bread / **breed**	*"bread"* could be read as *"breed"* if read like *"read"*
oxygen: **air** / ear	*"ear"* could be read as "air" if read like *"wear"*
dislike: height / **hate**	*"height"* could be read as *"hate"* if read like *"weight"*
all: **whole** / howl	*"howl"* could be read as "whole" if read like *"bowl"*

**Correct item in bold*

Table 5

Semantic Decision performance in English of 7 dysgraphic individuals in comparison with controls.

	Controls (n = 18) (sd)	TT	NT	MB	NS	MR	AH	GM
Accuracy (max=34).	28.4 (1.8)	23**	24**	25*	23*	22**	29	27
Latency (ms)	1934 (339)	4072*	3276*	3247*	3164*	2897*	2303	1896

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

Table 6

A comparison of spelling to dictation with the spelling of picture names together with the proportion correct on spelling to dictation conditionalized on correct written picture naming

	Controls (n = 18) (sd)	TT	NT	MB	NS	MR	AH	GM
Spelling to dictation	20.0 (1.6)	5*	12*	11*	16*	15*	12*	11*
Spelling picture names	19.6 (1.9)	6*	12*	12*	15*	14*	17	19
Spelling to dictation/ Picture name spelling	1.0 (.02)	1.0	1.0	1.0	1.0	1.0	.71	.58

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

Table 7

Naming performance of 71 pictures in English and in Greek by 7 dysgraphic individuals in comparison with 18 controls.

	Controls (sd)	TT	NT	MB	MR	NS	AH	GM
English Pictures								
Accuracy	64.0 (2.8)	69	63	66	68	64	54*	53*
Naming Latency (ms)	1112 (156)	912	1123	1201	1053	1295	1676*	2111*
Greek Pictures								
Accuracy	67.4 (2.1)	70	67	69	70	69	57*	57*
Naming Latency (ms)	1001 (131)	850	1014	1112	1045	1234	1603*	1995*

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

Table 8

Mean accuracy (SD) on the auditory comprehension test (max = 68) in both Greek and English.

	Controls (n = 14)	TT	NT	MB	NS	MR	AH	GM
English	48.0 (6.1)	59	51	51	46	48	45	47
	Controls (n = 9)	TT	NT	MB	NS	MR	AH	GM
Greek	55.0 (7.5)	64	59	58	54	56	48	50

Appendices

Appendix A

Words and pseudohomophones used in the Greek orthographic lexical decision task in Experiment 1.

Words	Pseudohomophones
αυτοκίνητο	αφτοκίνητο
αυτοθαυμάζομαι	αφτοθαυμάζομαι
τρέχω	τραίχω
ξιφασκία	ξυφασκία
στρατόπεδο	στρατόπαιδο
ουτοπιστής	ουτωπιστής
εξαιρώ	εξερώ
ωφέλιμος	οφέλιμος
τσουρέκι	τσουραίκι
άφραγκος	αφραγγος
αγγλομαθής	αγκλομαθής
αγκάθι	αγγάθι
μέλισσα	μέλισα
αγιογραφώ	αγιογραφφώ
αυτοσεβασμός	αφτοσευασμός
αβασίλευτος	αυασίλεφτος
εύσωμος	έφσομος
καύσωνας	κάφσονας
κεραυνός	καιραβνός
περισσεύω	περισέβω
αυτεπάγγελτος	αφτεπάγκελτος
αυτοσυγκράτηση	αφτοσυγγράτηση
ήσυχος	ύσηχος
στρογγυλός	στρογκιλός
ήττα	ίτα
μοιραίος	μυρραίος
οπωροκηπευτικά	οπορωκηπευτικά
τυποποίηση	τιποποίυση
παγκόσμιος	παγγόσμειος
πρίγκιπας	πρύγγιπας
αλληλεγγύη	αληλεγκύη
μαραγκός	μαρραγγός
θάλασσα	θάλλασα
εκκλησία	εκλλησία

Appendix B

Words and pseudohomophones used in the English orthographic lexical decision task in Experiment 1.

Words	**Pseudohomophones**
speed	spead
learn	lern
need	nead
dream	dreem
yacht	yot
answer	anser
debt	det
year	yeer
cough	coff
muscle	mussle
girl	gerl
group	groop
green	grean
ceiling	cealing
mortgage	morgage
feed	fead
soup	soop
nurse	nerse
scream	skream
leaf	leef
cream	creem
keep	keap
mean	meen
fear	feer

Appendix C

Pairs of homophones used in the English semantic decision task in Experiment 2

Triad (target meaning: pair of homophones)
be informed: no / **know**
fruit: **pear** / pair
destroy: brake / **break**
death: **bury** / berry
room: sweet / **suite**
family: **son** / sun
God: praise / **prays**
construct: **build** / billed
part of: sum / **some**
meat: **steak** / stake
large: grate / **great**
animal: **bear** / bare
nothing: nun / **none**
lost: **waste** / waist
all: hole / **whole**
bus: **route** / root
food: eight / **ate**
number: too / **two**

**Correct item in bold*

Appendix D

The Greek picture names from Experiment 4.

τσεκούρι *(axe)*	**άλογο** *(horse)*	**καράβι** *(yacht/sailboat)*
μπάλα *(ball)*	**φεγγάρι** *(moon)*	**πατούσα** *(foot)*
φιόγκος *(bow*	**πάπια** *(duck)*	**λεμονί** *(lemon)*
μπολ *(bowl)*	**βιβλίο** *(book)*	**κρεμμύδι** *(onion)*
ψωμί *(bread)*	**ήλιος** *(sun)*	**βουνό** *(mountain)*
παλτό *(coat)*	**ροδάκινο** *(peach)*	**βίδα** *(screw)*
χτένα *(comb)*	**γουρούνι** *(pig)*	**αγελάδα** *(cow)*
πόρτα *(door)*	**σκαμνί** *(stool)*	**βέλος** *(arrow)*
μάτι *(eye)*	**πιρούνι** *(fork)*	**καρέκλα** *(chair)*
φλογέρα *(flute)*	**πόδι** *(leg)*	**ποτήρι** *(glass)*
μύγα *(fly)*	**ρόδα** *(wheel)*	**ελέφαντας** *(elephant)*
γάντι *(glove)*	**ρολόι (τοίχου)** *(clock)*	**πουλί** *(bird)*
κατσικά *(goat)*	**τούρτα** *(cake)*	**σκάλα** *(ladder)*
κλειδί *(key)*	**στέμμα** *(crown)*	**κουνέλι** *(rabbit)*
μαχαίρι *(knife)*	**τύμπανο** *(drum)*	**αστέρι** *(star)*
πουκάμισο *(shirt)*	**πρόβατο** *(sheep)*	**βούρτσα** *(brush)*
παπούτσι *(shoe)*	**στυλό** *(pen)*	**φρυγανιέρα** *(toaster)*
φούστα *(skirt)*	**σύννεφο** *(cloud)*	**φώκια** *(seal)*
κύκνος *(swan)*	**μύτη** *(nose)*	**σκύλος** *(dog)*
αντίχειρας *(thumb)*	**αρκούδα** *(bear)*	**κούνια** *(swing)*
γραβάτα *(tie)*	**άγκυρα** *(anchor)*	**ψάρι** *(fish)*
ρολόι *(watch)*	**σίδερο** *(iron)*	**ζώνη** *(belt)*
μυρμήγκι *(ant)*	**καρδιά** *(heart)*	**ψαλίδι** *(scissors)*
μέλισσα *(bee)*	**μαϊμού** *(monkey)*	

Appendix E

Words used in the auditory comprehension test used in Experiment 4.

bird, calendar, number, bell, lunch, police, vacation, pet, balloon, transform, alligator, cart, blame, dance, purpose, entertain, famous, reveal, decade, tradition, rejoice, enthusiastic, improvise, impulse, haste, trend, intermittent, devout, impertinent, niche, presumptuous, formidable, ruminate, panacea.

πούλι, ημερολόγιο, νούμερο, κουδούνι, γεύμα, αστύνομια, διακοπές, κατοικίδιο, μπαλόνι, μεταμορφώνω, αλιγάτορας, καρότσι, κατηγορία, χορός, σκοπός, διασκεδάζω, διάσημος, αποκαλύπτω, δεκαέτια, παράδοση, ευφραίνομαι, ενθουσιώδης, αυτοσχεδιάζω, παρόρμηση, βιασύνη, τάση, διαλείπων, ένθερμος, άξεστος, εσοχή, ξιπασμένος, ανυπέρβλητος, αναμασώ, πανάκεια