Developmental surface dysgraphia without surface dyslexia.

In Press, Cognitive Neuropsychology

Accepted 4/4/18

J Richard Hanley

&

Andreas Sotiropoulos

University of Essex, UK

Address for correspondence

Prof. J. Richard Hanley

Department of Psychology

University of Essex

Colchester CO4 3SQ

UK

EMAIL rhanley@essex.ac.uk

Telephone 0044 1206-874331

Fax 0044 1206-873598

Abstract

The case is reported of an individual (NK) with a developmental spelling impairment (dysgraphia) who has no apparent problems in reading. His performance is therefore similar to a case of dysgraphia without dyslexia (PJT) reported by Hepner, McCloskey & Rapp (2017), and provides further evidence of a classical dissociation between impaired spelling and preserved reading in individuals with developmental literacy problems. The dissociation is observed when NK is asked to read and spell in either his first (Greek) or his second language (English). An investigation of his spelling performance revealed that his impairment was more selective than that of PJT. Although his spelling of regular words and nonwords was normal, NK had a problem in spelling words with atypical sound-letter associations despite having no problems in reading aloud or understanding the meaning of words of this kind. It is argued that NK's pattern of performance can be best explained in terms of normal development of an orthographic system that allows access to the meaning and pronunciation of written words during reading. In terms of a dual route model of spelling, his poor spelling appears to be the result of a developmental impairment that impedes access to the orthographic system from phonology and semantics. In terms of the triangle model, his poor spelling appears to be the result of a developmental impairment that affects activation of orthography from semantics.

Introduction

In English, problems in learning to spell (developmental dysgraphia) usually co-occur with problems in learning to read (developmental dyslexia). For example, individuals with developmental phonological deficits (e.g. Campbell & Butterworth, 1985; Funnell & Davidson, 1989; Howard & Best, 1996; Snowling & Hulme, 1989; Temple & Marshall, 1983; Wang, Nickels & Castles, 2015) appear to be impaired at reading and at spelling unfamiliar words and nonwords. Individuals with developmental surface dysgraphia (e.g. Brunsdon, Coltheart & Nickels, 2005; Castles & Coltheart, 1996; Goulandris & Snowling, 1991; Hanley, Hastie & Kay, 1992; Hanley & Gard, 1995; Romani, Ward & Olson, 1999; Temple, 1984) appear to be impaired at reading and at spelling irregular words (words that contain at least one atypical spelling-sound correspondence). A straight-forward explanation of this co-occurrence is that the same processing systems that are used to spell words are also used to read them (e.g. Rapp & Lipka, 2011; Sotiropoulos & Hanley, 2017a).

Recently, however, a case of developmental dysgraphia (PJT) was reported by Hepner, McCloskey and Rapp (2017) in whom reading appeared to be entirely preserved. Although PJT's spelling of both words and nonwords was severely impaired, he could read aloud regular words, irregular words, and nonwords at above average levels. He also performed well at orthographic lexical decision and at defining written homophones. These results show that PJT had preserved access to the orthographic system during reading and could access both the semantic system and the phonological system from the orthographic system.

One possible explanation of this dissociation is that separate orthographic systems are involved in reading and spelling, and that PJT suffered from impaired development of the spelling lexicon despite normal development of the reading lexicon. Hepner et al. (2017) instead argued that this pattern of performance could be explained in terms of a unitary orthographic system if it is assumed that spelling requires different associative connections from those that are involved in reading (for further discussion of this issue see McCloskey & Rapp, 2017). Hepner et al. suggested that PJT might be poor at spelling irregular words because of problems in accessing the orthographic system from the semantic system and from the phonological system. He was good at reading words, they claimed, because the connections from the orthographic lexicon to the phonological and semantic systems had developed normally. They also argued that PJT had a separate impairment to the development of the non-lexical sound-spelling conversion system that produced impaired spelling of regular words and nonwords.

The literature contains very few case reports of individuals with developmental dysgraphia who demonstrate such a clear dissociation between impaired spelling and preserved reading. Kohnen, Nickels, Coltheart and Brunsdon (2008) reported the case of a child (KM) with surface dysgraphia without dyslexia. KM had, however, suffered a brain injury prior to learning to read and so does not represent a straightforward example of a developmental spelling impairment (for discussion of the relationship between reading and spelling in acquired dysgraphia, see Hillis & Rapp, 2004; Tainturier & Rapp, 2001). Below, therefore, we describe another case of developmental dysgraphia (NK) who shows an equally striking dissociation between his spelling and

reading performance in both Greek and English. We compare NK's spelling ability with that of PJT, and discuss how the impaired spelling of both of these individuals can be explained in terms of a unitary orthographic system that is used for both reading and spelling.

Case Report

Case details. NK is a Greek national whose first language is Greek and whose second language is English. He was recruited as a participant in a doctoral study (Sotiropoulos, 2015) that examined the reading and spelling performance of 30 Greek students who had experienced developmental literacy difficulties in childhood. The impaired reading and spelling performance of nine of these 30 individuals was described by Sotiropoulos and Hanley (2017a, 2017b). NK's first exposure to English was at school in Greece where he was taught English as a foreign language from the age of eight years onwards. He was studying for a university degree in the UK when he took part in this investigation. At that point, he had spent five years in the UK and his total exposure time to English was 17 years.

Twenty-five Greek-English bilinguals, who were studying for a degree in the UK, acted as controls. Like NK, their first language was Greek and they had all learnt English at school as a foreign language. They were matched to NK on time of exposure to English. Their mean first exposure to English was at 8.6 years (sd = 2.1), and their mean total exposure time was 15.8 years (sd = 3.4). They had spent an average of 4.2 years (sd = 1.8) in the UK at time of testing. The controls had normal reading and spelling ability (as reported to the second author). Their literacy skills were not formally tested before they participated in the study.

None of the participants, including NK, reported any head injury or illness that might have affected their performance.

Production and comprehension of spoken words. In contrast to some surface dyslexics (Gvion & Friedmann, 2016) and surface dysgraphics (Sotiropoulos and Hanley, 2017b), NK showed no evidence of word finding difficulties. He was asked to name 71 pictures of objects in Greek and in English on separate testing sessions. Accuracy was good in both Greek (69/71 names correct; control mean = 67.4, sd = 2.1) and English (65/71 names correct; control mean = 64.0, sd = 2.8). NK's picture-naming latency was also normal in Greek (956 msecs) and in English (1087 msecs). The mean picture-naming latencies for the controls were 1001 msecs (sd = 131) in Greek and 1112 msecs (sd = 156) in English.

Accuracy was unimpaired on a test of spoken word comprehension in which participants were asked to provide definitions of 68 spoken words. The same set of words was used in both languages. His score was 54/68 correct in Greek (control mean = 55.0 words, sd = 7.5) and 48/68 correct in English (control mean = 48.0 words, sd = 6.1).

Phonological awareness. NK was given some Greek phonological awareness tests that were taken from Douklias et al. (2009). Tests of segmentation required him to listen to 24 spoken words and indicate either the number of phonemes or syllables that it contained. Deletion tests required him to listen to 24 spoken words and respond by removing the first or last syllable or phoneme. For the spoonerisms task, 12 pairs of two- and three-syllable words were presented and he was asked to exchange the first phonemes between the 2 words. NK performed without error on all of these tasks.

NK also performed well on two phonological awareness tests in English that were taken from Perin (1983). A phoneme counting task required participants to indicate the number of phonemes in 32 spoken words and 16 nonwords. On a spoonerisms task, participants heard the name of a popular musician and were asked to exchange the first phonemes in the given name and surname (e.g., 'Bob Dylan' > 'Dob Bylan'). NK scored 35/48 correct at phoneme counting (control mean = 31.1/48, sd = 6.3) and 17/18 correct on the spoonerisms task (control mean =16.8/18, sd = 1.0).

Rapid naming (RAN) for digits and objects was assessed using the subtests of the Phonological Assessment Battery (Frederickson, Frith & Reason, 1997). NK's rapid automatized naming times in both Greek and English were within the normal range for objects and for digits (rapid object naming in Greek: NK= 39 secs, controls mean = 31.9 secs, sd= 5.4 sec; rapid digit naming in Greek: NK= 14 secs, controls mean = 15.9 secs, sd= 2.8 sec; rapid object naming in English: NK= 35 secs, controls mean = 31.4 secs, sd= 4.7 sec; rapid digit naming in English: NK= 15 secs, controls mean = 18.4 secs, sd= 3.0 secs).

Spelling. Unlike English, Greek is a transparent orthography in which there are no irregular words for the purposes of reading. There are, however, some Greek vowels that can be spelled in more than one way. We refer to Greek words that are written with the most common sound > spelling correspondence as *regular* words. Words that are spelled with a less common sound > spelling correspondence are referred to as *irregular* words.

Spelling to dictation was tested in both Greek and English. The Greek and English lists contained unrelated words. Sotiropoulos and Hanley (2017a) provide full details of the characteristics of the words that were used. NK's

performance is summarized in Table 1. It can be seen that NK's spelling accuracy is significantly lower than that of controls when spelling irregular words in Greek ($t = 13.28$, $p < .001$) and in English ($t = 3.98$, $p < .001$). By contrast, his spelling of regular words and nonwords was unimpaired in both languages. This pattern of performance is consistent with developmental surface dysgraphia.

NK's spelling errors were also typical of those seen in surface dysgraphia. A list of his errors can be found in the Appendix. All of the errors in English were phonologically appropriate. In Greek, 15/17 (88.2%) of his spelling errors were phonologically appropriate. This figure was similar to the proportion of phonologically appropriate errors (96.6%) made by the control group. Phonologically appropriate errors in Greek have been taken to reflect difficulties in lexical processing (Protopapas et al., 2013). According to Protopapas et al., such errors suggest inadequate word-specific (or root-specific) knowledge, reflecting a poorly developed orthographic lexicon.

We also noted whether any 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 are considered to reflect impaired grammatical knowledge rather than impaired orthographic knowledge because they can be prevented if an individual is aware of the relevant grammatical rule (Protopapas et al., 2013). Both NK and the controls made only a tiny minority of grammatical errors (one out of the NK's seventeen spelling errors was grammatical). The phonological errors that NK made therefore appear to reflect an impaired ability to remember the orthographic form of irregular Greek words rather than impaired grammatical knowledge.

In a further spelling test, NK's ability to write the names of pictures was compared with his ability to spell the same words to dictation. This test was administered in English only. Twenty-two pictures whose names were irregular English words were presented for written naming. Several months later, the same words were presented orally. NK spelled correctly the same 12 words on both versions of the test. He was significantly impaired at both spelling picture names ($t=-3.81$, $p<.01$) and at spelling to dictation ($t=-3.89$, $p<.01$). Controls scored 19.6/22 (sd = 1.9) at written picture naming and 20/22 (sd = 1.6) at spelling to dictation. Unlike two of the surface dysgraphic cases reported by Sotiropoulos and Hanley (2017b), therefore, NK was equally impaired at spelling the names of pictures and at spelling to dictation.

Reading. The speed and accuracy with which NK read Greek words and nonwords is shown in Table 2. Because all Greek words are regular for the purposes of reading, the results for regular and irregular word reading were collapsed. There was no significant difference between NK and controls for either real word reading accuracy or speed (both $t < 1$) in Greek. NK's nonword reading accuracy ($t = 1.36$ $p > .05$) and speed ($t < 1$) were also unimpaired. Douklias et al. (2009) showed that in Greek, surface dyslexia is associated with accurate but slow reading of familiar words, and that phonological dyslexia is associated with inaccurate nonword reading and poor phonological awareness. NK therefore does not show the hallmarks of either surface or phonological dyslexia in Greek.

Table 2 also shows the speed and accuracy with which NK read English words and nonwords. Both regular words and irregular words were read as accurately and as quickly as controls. There was therefore no evidence of surface

dyslexia in English. Normal accuracy and speed of nonword reading revealed no evidence of phonological dyslexia in English.

NK was also given a test of orthographic lexical decision in both Greek and English. Different words were used in the two languages (for details of the materials, see Sotiropoulos & Hanley, 2017b). Twenty-four English words along with their corresponding pseudohomophones (e.g. *feel* and *feal*) were used for the English lexical decision test. Thirty-four Greek words (e.g. "παγκόσμιος"= global) along with their corresponding pseudohomophones (e.g. "παγγόσμειος") were used for the Greek lexical decision test. NK scored 21/24 correct on the test in English (control mean = 21.2, sd = 1.6), and 27/34 on the test in Greek (control mean = 27.8, sd = 3.0). NK's decision latencies were also within the normal range (for English, NK's mean = 936 msecs; control mean = 907 msecs, sd = 233; for Greek, NK's mean = 1128 msecs; control mean = 1066 msecs, sd = 321).

NK also performed well on a reading test that required access to the meaning of English written words. This test was administered in English only. On some trials (see Sotiropoulos & Hanley, 2017b, for further details), he was shown a target word (e.g. *fruit*) followed by two homophones (e.g. *pear, pair*). He was asked to decide which of the homophones was semantically related to the target word. On other trials, he was shown a target word (e.g. *drink*) and had to decide which of two words (*bear, beer*) was closer in meaning. One member of each pair of words (*bear* in the example above) was a word that sounds the same as the other word in the pair (*beer* in the example above) when read via grapheme-phoneme rules. Friedmann and Lukov (2008) referred to pairs of words of this kind as *potentiophones*. NK was correct on 29/34 trials (control mean = 28.4, sd

= 1.8). NK's decision latencies were also within the normal range (NK's mean = 2015 msecs; control mean = 1934 msecs, sd = 339).

Discussion

The results have shown that the speed and accuracy with which NK read aloud words and nonwords in Greek and English was unimpaired. Crucially, he was fast and accurate at reading irregular English words. He also performed well at orthographic lexical decision and was able to access the meaning of written words. He therefore showed no evidence of surface or phonological dyslexia in either English or Greek.

Despite unimpaired reading, NK had difficulties spelling irregular words in both Greek and English. Furthermore, his spelling errors were almost always phonologically correct, and his spelling of regular words and nonwords was accurate. His spelling therefore shows all of the hallmarks of developmental surface dysgraphia. NK's reading performance is quite different from that of seven surface dysgraphics reported by Sotiropoulos and Hanley (2017b) who were all impaired at reading aloud the same set of irregular English words that NK read without difficulty. Four of them were poor at lexical decision, consistent with an impairment to the orthographic lexicon itself. Friedmann and Lukov (2008) refer to this disorder as *input* surface dyslexia. A fifth case performed well at lexical decision but was impaired at accessing the meaning of written words. Friedmann and Lukov refer to this disorder *output* surface dyslexia. Like NK, the remaining two cases could access the meaning of written words. Nevertheless, they were both poor at reading aloud and at spoken picture naming, consistent with a difficulty in accessing the phonological lexicon from

the semantic system. NK had no difficulty of this kind in spoken word production. His reading performance therefore resembles that of PJT (Hepner et al., 2017) who also showed no signs of a reading impairment in the context of a developmental spelling disorder.

Because it was confined to words with atypical letter-sound associations, NK's spelling impairment is more selective than that of PJT (Hepner et al., 2017). PJT was impaired at spelling nonwords and regular words as well as irregular words. Whereas NK showed no signs of phonological dysgraphia, PJT clearly experienced a mixed form of dysgraphia with problems in spelling words of all kinds. One possibility that can easily be discounted is that NK and PJT were suffering from developmental graphemic buffer dysgraphia (Kohnen and Nickels, 2017). NK's preserved spelling of nonwords is inconsistent with a graphemic buffer problem. PJT's (Hepner et al., 2017) problems with both oral and written spelling, and his problems in both real word and nonword spelling make a graphemic buffer disorder more plausible. In graphemic buffer dysgraphia, however, spelling errors mostly comprise letter substitution errors, transposition errors, deletions and additions. PJT made virtually no errors of this kind when spelling nonwords. When spelling real words, approximately 50% of his errors were phonologically correct. The remainder appeared to involve errors of partial lexical knowledge and the application of incorrect phoneme-grapheme correspondences. Consequently PJT's error profile differed markedly from the case of graphemic buffer disorder reported by Barisic et al. (2017).

His poor spelling of both words and nonwords therefore suggests that PJT had separate developmental impairments to the lexical and non-lexical spelling routes. The impairment to the non-lexical route disrupted nonword spelling, and

the impairment to the lexical route disrupted irregular word spelling. Because Hepner et al.'s (2017) explanation of PJT's spelling problems involves two separate impairments, it should be possible to see a developmental case with good reading performance who experiences just one of these two types of spelling impairment. The finding that NK shows surface dysgraphia without dyslexia is therefore consistent with Hepner et al.'s account of PJT's impaired spelling.

Insert Figure 1 and 2 about here

What is the precise nature of NK's lexical spelling impairment? Purcell, Shea and Rapp (2014) put forward a version of the DRC model (Coltheart, Rastle, Perry, Langdon & Ziegler, 2001) in which there is just one orthographic lexicon (orthographic LTM) for reading and spelling. In this model (see Figure 1), orthographic LTM receives input from both semantics and the phonological lexicon (phonological LTM) during spelling. NK's difficulty in spelling irregular words to dictation and in spelling the names of pictures that are irregular words is consistent with a developmental impairment to both of these connections. NK appears to have access to orthographic LTM from abstract letter identities when reading words, and can access both the semantic system and phonological LTM from orthographic LTM. The results therefore strongly support the existence of separate input and output connections between orthographic LTM and the semantic system, and separate input and output connections between orthographic LTM and phonological LTM (see Figure 1). In the case of NK, the direct connections from the orthographic units to the semantic system and from

the orthographic units to the phonological system appear to have developed normally. It is the connections from the semantic system and from the phonological system to orthographic LTM that are impaired. In the case of PJT (Hepner et al., 2017), these two connections are also impaired, and there is a third impairment to the phonology > orthography conversion system.

The *triangle* model of reading (Harm & Seidenberg, 1999; Plaut, McClelland, Seidenberg & Patterson, 1996; Woollams, 2014) can provide a different account of NK's impaired spelling (see Figure 2). Advocates of the triangle model argue that, for most people, the phonological reading pathway is mainly used to process nonwords and regular words (Woollams, Madrid, & Patterson, 2016). This pathway will only be used to read a relatively small number of irregular words that are highly familiar to an individual. Because the phonological pathway processes only a few irregular words, the correct pronunciations of most irregular words are generated by first activating their meaning from the orthographic units. Let us assume that the same processing units that are responsible for reading in this model are also responsible for spelling (for discussion, see Sotiropoulos and Hanley, 2017b). NK's poor spelling of irregular words indicates a developmental impairment to the semantics > orthography pathway in Figure 2. NK's preserved access to the meaning of written words despite his poor spelling of picture names is consistent with the existence of a separate orthography > semantics pathway that has developed normally (see Figure 2).

Is it also necessary to assume an impairment to the phonology > orthography pathway in Figure 2 to explain NK's impaired spelling to dictation? Even in a system that has developed normally, the phonology > orthography

pathway would not be expected to spell accurately more than a relatively small number of irregular words. Because NK can spell a few irregular words in both English and Greek (see Table 1), his impaired spelling to dictation of irregular words would not require an additional developmental impairment to this pathway. Conversely, PJT's (Hepner et al., 2017) impaired spelling of both irregular words and nonwords is consistent with developmental impairments to both the semantic and phonological spelling pathways in Figure 2. The triangle model can therefore provide a parsimonious explanation of the different types of developmental dysgraphia shown by NK and PJT. (For further discussion of the relative merits of the DRC and the triangle model in explaining developmental surface dyslexia and dysgraphia, see Sotiropoulos & Hanley, 2017b).

In conclusion, the case of NK extends the findings of Hepner et al. (2017). An additional case of developmental spelling impairment with preserved reading provides further evidence of a classical dissociation between reading and spelling performance in individuals with developmental literacy problems. It is also interesting that NK's spelling problems are more selective than those of PJT and appear to be confined to irregular words. The case of NK therefore shows that it is possible to experience developmental surface dysgraphia without developmental surface dyslexia. The findings with NK are also consistent with Hepner et al.'s conclusion that a dissociation between impaired spelling and preserved reading can be explained without the need to postulate the existence of separate orthographic lexicons for reading and spelling. It is clearly possible to accommodate the spelling problems experienced by NK and PJT in terms of developmental impairments to the connections from the semantic and phonological systems to the orthographic units or lexicon. It is not necessary to

assume that, in either of these two cases, the impairment has prevented development of the orthographic representations themselves.

Finally, it is important to note that NK shows exactly the same dissociation between impaired spelling and preserved reading of familiar words in Greek and English. This finding is consistent with the strong parallels that have previously been observed in the nature of the literacy impairments that are experienced by dyslexic individuals in their first and second language (e.g. Morfidi, Van Der Leij, De Jong, Scheltinga & Bekebrede, 2007; Sotiropoulos and Hanley, 2017a, b). Such an outcome provides further support for Sotiropoulos and Hanley's (2017a) claim that the neurophysiological substrate(s) that support the pathways that are involved in reading and spelling words in alphabetic writing systems are the same regardless of whether the orthography is transparent (Greek) or opaque (English).

References

Barisic, K., Kohnen, S., & Nickels, L. (2017). Developmental graphemic buffer dysgraphia in English: A single case study. *Cognitive Neuropsychology*, **34**, 94-118.

Brunsdon, R., Coltheart, M., & Nickels, L. (2005). Treatment of irregular word spelling in developmental surface dysgraphia. *Cognitive Neuropsychology*, 22(2), 213-251.

Campbell, R., & Butterworth, B. (1985). Phonological dyslexia and dysgraphia in a highly literate subject: A developmental case with associated deficits of phonemic processing and awareness. *Quarterly Journal of Experimental Psychology,* **37A***,* 435-475.

Castles, A., & Coltheart, M. (1996). Cognitive correlates of developmental surface dyslexia: A single case study. *Cognitive Neuropsychology,* **13***,* 25-50.

Coltheart, M., Rastle, K., Perry, C., Langdon, R., & Zeigler, J. (2001). DRC: A dual route cascaded model of visual word recognition and reading aloud. *Psychological Review,* **108***,* 204 -256*.*

Crawford, J.R., & Howell, D.C. (1998). Comparing an individual's test score against norms derived from small samples. *The Clinical Neuropsychologist,* **12(4),** 482- 486.

Douklias, S., Masterson, J., & Hanley, J.R (2009). Surface and phonological developmental dyslexia in Greek. *Cognitive Neuropsychology*, **26** (8), 705-723.

Frederickson, N. Frith, U. & Reason, R. (1997). *Phonological Assessment Battery*. Windsor: NFER-Nelson.

Friedmann, N., & Lukov, L. (2008). Developmental surface dyslexias. *Cortex,* **44,** 1146-1160.

Goulandris, N. K., & Snowling, M. (1991). Visual memory deficits: A plausible cause of developmental dyslexia? Evidence from a single case study. *Cognitive Neuropsychology,* **8,** 127-154.

Gvion, A., & Friedmann, N. (2016). A principled relation between reading and naming in acquired and developmental anomia: Surface dyslexia following impairment in the phonological output lexicon. *Frontiers in Psychology: Language Sciences*, **7(340)**, 1-16.

Hanley, J.R. & Gard, F. (1995). A dissociation between developmental surface and phonological dyslexia in 2 undergraduate students. *Neuropsychologia*, **33,** 909-914.

Hanley, J.R., Hastie, K. & Kay, J. (1992). Developmental surface dyslexia and dysgraphia: an orthographic processing impairment. *Quarterly Journal of Experimental Psychology*, **44A**, 285-319.

Harm, M.W. & Seidenberg M.S. (1999). Phonology, reading acquisition, and dyslexia: insights from connectionist models. *Psychological Review,* **106**, 491–528.

Hepner, C., McCloskey, M., & Rapp, B. Do reading and spelling share orthographic representations? Evidence from developmental dysgraphia. *Cognitive Neuropsychology*, **34**, 119-143.

Hillis, A., & Rapp, B. (2004). Cognitive and neural substrates of written language comprehension and production. In M. Gazzaniga (Ed.), *The New Cognitive Neurosciences* (3rd ed., pp. 775–788). Cambridge, MA: MIT Press.

Kohnen, S., Nickels, L., Coltheart, M., & Brunsdon, R. (2008). Predicting generalization in the training of irregular-word spelling: Treating lexical spelling deficits in a child. *Cognitive Neuropsychology*, **25(3),** 343-375.

McCloskey, M. & Rapp, B. (2017). Developmental dysgraphia: An overview and framework for research. *Cognitive Neuropsychology*, **34 (3-4)**, 65-82.

Morfidi, E., Van Der Leij, A., De Jong, P. F., Scheltinga, F., & Bekebrede, J. (2007). Reading in two orthographies: A cross-linguistic study of Dutch average and poor readers who learn English as a second language. *Reading and Writing*, **20(8),** 753-784.

Perin, D. (1986). Phonemic segmentation and spelling. *British Journal of Psychology*, **74**, 129-144.

Plaut, D.C., McClelland, J.L., Seidenberg, M.S., & Patterson, K. (1996). Understanding normal and impaired word reading: Computational principles in quasi-regular domains. *Psychological Review,* **103**, 56-115.

Protopapas, A., Fakou, A., Drakopoulou, S., Skaloumbakas, C., & Mouzaki, A. (2013). What do spelling errors tell us? Classification and analysis of errors made by Greek schoolchildren with and without dyslexia. *Reading and Writing,* **26**, 615-646.

Purcell, J.J., Shea, J., & Rapp, B. (2014). Beyond the VWFA: The orthography-semantics interface in spelling and reading. *Cognitive Neuropsychology,* **31,** 482-510.

Rapp, B. & Lipka, K. (2011). The literate brain: The relationship between spelling and reading. *Journal of Cognitive Neuroscience*, **23**, 65-82. 1180-1197.

Romani C**.,** Ward J., & Olson A. (1999). Developmental surface dysgraphia: What is the underlying cognitive impairment? *Quarterly Journal of Experimental Psychology*. **52A** (1), 97-128.

Snowling, M., & Hulme, C. (1989). A longitudinal case study of developmental phonological dyslexia. *Cognitive Neuropsychology, 6,* 379-401.

Sotiropoulos, A. (2015). Surface and phonological developmental dyslexia among Greek University students in both Greek and English. *A thesis submitted for the degree of Doctor of Philosophy.* University of Essex, UK.

Sotiropoulos, A., & Hanley, J.R. (2017a). Surface and phonological developmental dyslexia in both Greek and English. *Cognition*, **168**, 205-216.

Sotiropoulos, A., & Hanley, J.R. (2017b). Lexical decision performance in developmental surface dysgraphia: Evidence for a unitary orthographic system that is used in both reading and spelling. *Cognitive Neuropsychology*, **34**, 144-162

Tainturier, M. J., & Rapp, B. (2001). The spelling process. In B. Rapp (Ed.), *What Deficits Reveal about the Human Mind/Brain: A handbook of Cognitive Neuropsychology* (pp 263-289). Philadelphia: Psychology Press.

Temple, C.M. (1985). Developmental surface dyslexia: A case report. *Applied Psycholinguistics,* **6**, 391-406.

Temple, C.M. & Marshall, J.C. (1983) A case study of developmental phonological dyslexia. *British Journal of Psychology, 74*, 517-533.

Wang, H-C, Nickels, L., & Castles, A. (2015). Orthographic learning in developmental surface and phonological dyslexia. *Cognitive Neuropsychology, 32* (1), 58-79.

Woollams, A. (2014). Connectionist neuropsychology: Uncovering ultimate

causes of acquired dyslexia. *Philosophical Transactions of the Royal Society B*, **369**, 1634.

Woollams, A., Lambon Ralph, M., Madrid, G. & Patterson, K. E. (2016). Do you read how I read? Systematic individual differences in semantic reliance amongst normal readers. *Frontiers in Psychology*. **7**, 1757. https://doi.org/10.3389/ fpsyg.2016.01757

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.

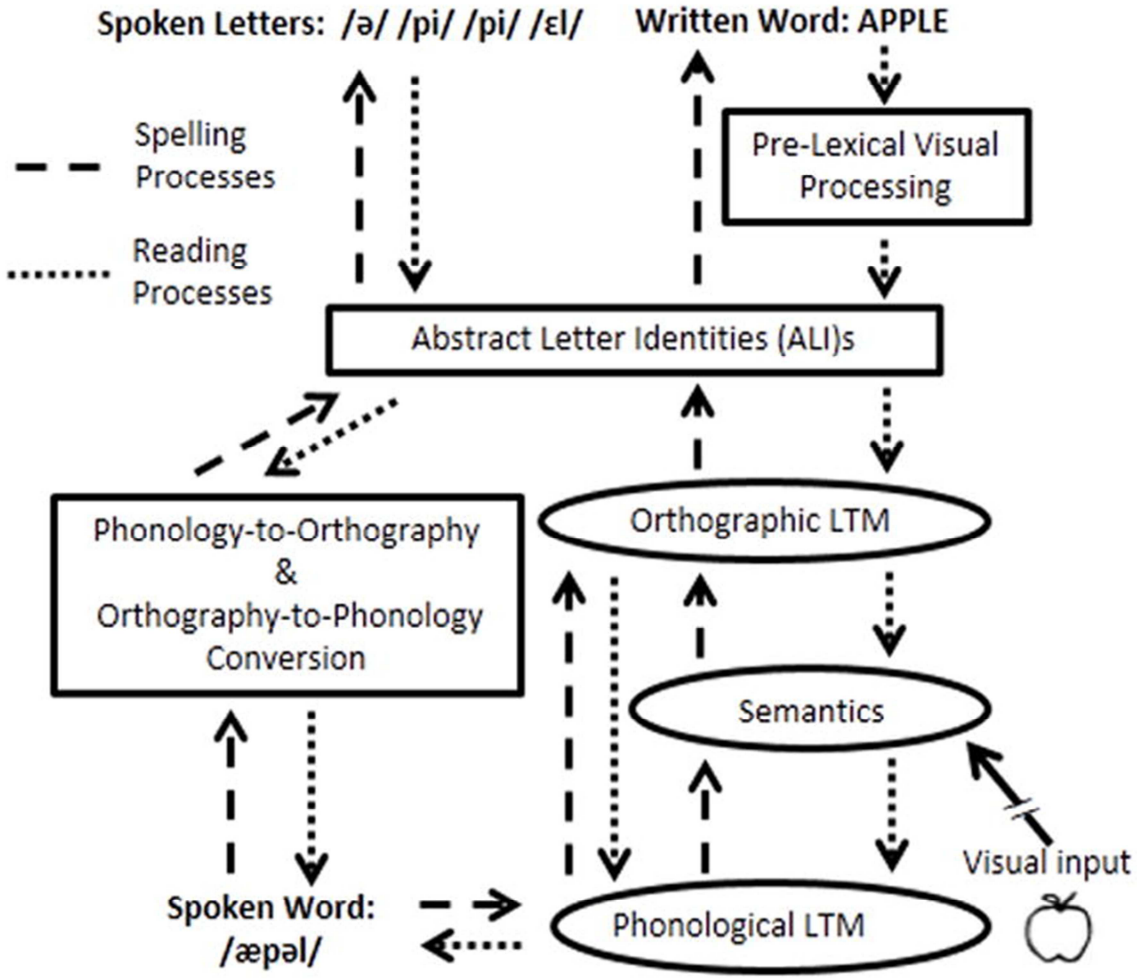

Figure 2

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

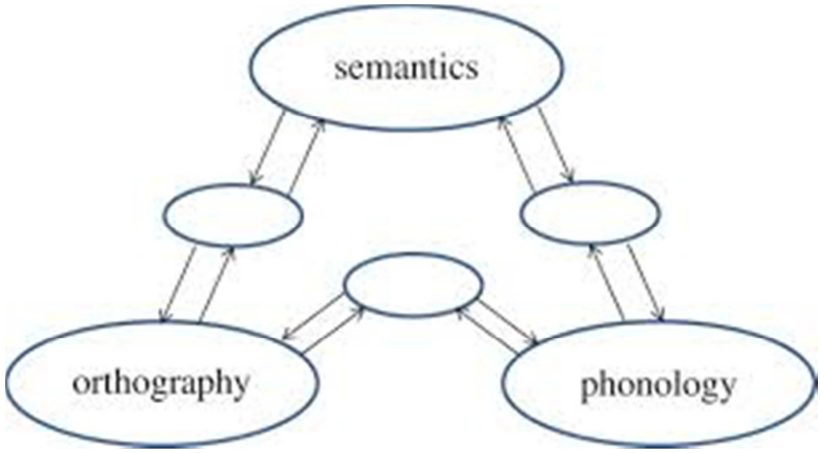

Table 1

NK's spelling accuracy for words and nonwords in comparison with 25 normal controls.

	Greek Words		
	Regular words (max=27)	Irregular words (max=27)	Nonwords (max=72)
NK	25	12*	64
Controls (sd)	25.7 (1.3)	24.8 (1.0)	66.8 (2.9)
	English Words		
	Regular words (max=20)	Irregular words (max=20)	Nonwords (max=30)
NK	18	14*	24
Controls (sd)	19.3 (0.8)	18.5 (1.1)	24.7 (2.1)

p<.05* (modified t-test: Crawford & Howell, 1998)

Table 2

NK's reading speed and accuracy for Greek and English words and nonwords in comparison with 25 normal controls.

Greek Words

	Accuracy		*Speed (msecs)*	
	Familiar words (n=54)	Nonwords (n = 72)	Familiar words	Nonwords
NK	52	66	495	745
(sd)			(69)	(155)
Controls	52.6	68.9	471	731
(sd)	(1.6)	(2.1)	(89)	(134)

English Words

	Accuracy			*Speed (msecs)*		
	Regular words	Irregular words	Nonwords	Regular words	Irregular words	Nonwords
NK	19	16	25	600	642	766
(sd)				(74)	(119)	(161)
Controls	19.3	17.1	24.6	554	603	758
(sd)	(0.8)	(1.9)	(1.9)	(66)	(98)	(143)

Appendix

NK's spelling errors in Greek

Regular words:

1) μέριμνα (provision) → "μέρυμνα" (phonologically appropriate – orthographic error)
2) κεφαλογραβιέρα (kind of Greek cheese) → "κεφαλογραφιέρα" (phonologically inappropriate error)

Irregular words:

1. έγκυρος (valid) → "έγκυρως" (phonologically appropriate – grammatical error)
2. κηρήθρα (honeycomb) → "κιρήθρα" (phonologically appropriate – orthographic error)
3. ευόδωση (fruitfulness) → "ευόδοση" (phonologically appropriate – orthographic error)
4. ευτυχισμένος (happy) → "ευτιχισμένος" (phonologically appropriate – orthographic error)
5. αντιπροσωπευτικότητα (representativeness) → "αντιπροσοπευτικότητα" (phonologically appropriate – orthographic error)
6. *επιχειρηματικός (enterprising) → "επιχιριματικός" (phonologically appropriate – orthographic errors)
7. άγκυρα (anchor) → "άγκιρα" (Phonologically appropriate – orthographic errors)
8. *εμπειρογνώμονας = (connoisseur) → "εμπιρογνόμονας" (phonologically appropriate – orthographic errors)
9. επιείκεια (lenience) → "επιείκια" (phonologically appropriate – orthographic error)
10. *δύσπνοια (dyspnea) → "δίσπνια" (phonologically appropriate – orthographic errors)
11. εξυπνάδα (cleverness) → "εξιπνάδα" (phonologically appropriate – orthographic error)
12. καλλιτέχνης (artist) → "καλιτέχνης" (phonologically appropriate – orthographic error)
13. καθήκον (duty) → "καθίκον" (phonologically appropriate – orthographic error)
14. πανεπιστήμιο (university) → "πανεπιστίμιο" (phonologically appropriate – orthographic error)
15. χειρόγραφος (handwritten) → "χιρόγραφος" (phonologically appropriate – orthographic error)

* (NK's spelling of these two words contained more than one error).

NK's spelling errors in English

<u>Spelling to dictation errors:</u>

Regular words: canal → "kanal", cat → "kat"

Irregular words: axe → "ax", blood → "blud", bread → "bred", door → "dor", flute → "floot", goat → "gote", heart → "hart", island → "iland", knife → "nife", lamb → "lam", shirt → "shert", skirt → "skert", thumb → "thum", tie → "ty", yacht → "yot",

<u>Spelling from pictures</u>

Irregular words: axe → "ax", bread → "bred", door → "dore", flute → "floot", goat → "gote", knife → "nife", shirt → "shert", skirt → "skurt", thumb → "thum", tie → "ty".