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Varieties of developmental dyslexia in Greek children

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Abstract

The current study aimed to investigate in a group of nine Greek children with dyslexia (mean age 9;9 years) whether the surface and phonological dyslexia subtypes found by Douklias et al. (2009) could be identified. A simple regression was conducted using printed word naming latencies and nonword reading accuracy for 33 typically developing readers. 90% confidence intervals were established and dyslexic children with datapoints lying outside the confidence intervals were identified. Using this regression based method three children with the characteristic of phonological dyslexia (poor nonword reading), two with surface dyslexia (slow word naming latencies), and four with a mixed profile (poor nonword reading accuracy and slow word naming latencies) were identified. The children were also assessed in spelling to dictation, phonological ability, rapid naming, visual memory and multi-character processing (letter report). Results revealed that the phonological dyslexia subtype children had difficulties in tasks of phonological ability, and the surface subtype children had difficulties in tasks of multi-character simultaneous processing ability. Dyslexic children with a mixed profile showed deficits in both phonological abilities and multi-character processing. In addition, one child with a mixed profile showed a rapid naming deficit and another showed a difficulty in visual memory for abstract designs. Overall the results confirm that the surface and phonological subtypes of developmental dyslexia can be found in Greek speaking children. They also indicate that different subtypes are associated with different underlying disorders.

Key words: Greek dyslexic children; subtypes; phonological ability; multi-character simultaneous processing.

Introduction

Research looking into reading and spelling disabilities has been carried out mainly with English speaking participants. Harris and Hatano (1999) argued that caveats should be borne in mind before attempting to generalize findings from the English writing system to other systems. However, research on diverse writing systems (Pae, Senvcik, & Morris, 2010; Cholewa et al., 2010; Deacon, Wade-Woolley, & Kirby, 2009) shows that stumbling blocks faced by English-speaking children appear to be similar to those encountered by children learning other languages. The severity of the difficulties has been found to depend on the characteristics of writing systems as they are described by the statistical properties of each language. Share (2008) argued that "it remains to be seen to what extent the classic dual-route distinction between phonological and surface dyslexia... relates in cases of more conventional orthographies" (p. 592). We aimed to see whether further evidence for the distinction could be found for Greek, a transparent orthography in a case series design. The importance of the case series design according to Schwartz and Dell (2010) derives from the fact that data can be simultaneously treated and presented at both individual and group level and data from individual cases can complement data from group studies.

Greek lies on a continuum of spelling-sound consistency, having almost 1:1 mappings from orthography to phonology but being inconsistent for spelling. For Greek, spelling development seems to be a life-long experience. This may be explained by its orthographic complexity, as written Greek has many words which contain different graphemes representing the phonemes /o/, /i/ and /e/, since certain phonemic distinctions (e.g., between the vowels represented by <η, ι, υ, οι, ει, υι> and those represented by <ο, ω> or by <ε, αι>) are no longer present in the language. Importantly though, Nunes, Aidinis and Bryant (2006) note that inconsistencies in Greek lie in the context of a system that is otherwise highly consistent, as inflectional spelling is quite regular.

Turning to research carried out with English children with reading and spelling difficulties, this has indicated that some children have a selective phonological decoding deficit (e.g., Campbell & Butterworth, 1985; Snowling & Hulme, 1989; Hulme & Snowling, 1992) while others have difficulty with irregular word reading and spelling (e.g., Brunsdon, Coltheart, & Nickels, 2005; Castles & Coltheart, 1996; Goulandris & Snowling, 1991; Dubois et al., 2007; Valdois et al., 2003). This dissociation was first identified in adults with acquired dyslexia (Newcombe & Marshall, 1973; Holmes, 1973; Shallice, 1981). It formed a cornerstone of evidence for dual route models of reading (e.g., Coltheart, 1987) and spelling (e.g., Barry, 1994), but has since been simulated in single route models of reading, such as the connectionist triangle model of Seidenberg & McClelland (1989) and the multi-trace memory model of Ans et al. (1998).

Castles and Coltheart (1993) provided evidence that surface and phonological dyslexia were relatively common amongst English speaking dyslexic children. They assessed 106 children (53 with dyslexia age range 7 to 14 years, and 53 typically developing (TD) readers matched with the dyslexics on age, mean age: 11;2) using irregular words and nonwords. The researchers carried out simple regression analyses with predictor variables the age of the control group and outcome the irregular word reading score on one occasion and the non-word reading score on the other. The progression in reading (of both irregular words and non-words) of children with typical reading development was used as the basis for the classification of the dyslexic children into subtypes: being poor in reading irregular words or non-words or both. The researchers used the criterion of 90% confidence interval (CI). Eighteen dyslexics (34%) fell below the CI for nonword or irregular word reading but were within the TD range for the other task. Ten dyslexic children exhibited the pattern of surface dyslexia (unimpaired nonword reading but impaired irregular word reading) and 8 dyslexic children showed the pattern of phonological dyslexia (unimpaired irregular word reading but impaired non-word reading). The rest of the children (N=32 cases) were impaired in both processes but still they were more impaired in one of the two.

Manis et al. (1996) carried out a similar study to that of Castles and Coltheart with 51 dyslexics, as did Stanovich, Siegel, and Gottardo (1997). In both these studies when reading age control children were considered the number of surface dyslexic children was reduced in contrast to the phonological dyslexics. The researchers concluded that surface dyslexia was a delay in reading development. There was also critique regarding whether the same theoretical model can (or should) be used for both acquired dyslexics, who had developed reading and spelling abilities and lost them after brain injury, and developmental dyslexics, who had never been able to acquire literacy skills (Ellis, 1985). A number of authors have argued that the evidence for the discrete subtypes is contentious, or else can be explained in terms of individual differences in terms of instruction or intervention (see for example, Bryant & Impey, 1986; Wilding, 1990; Thomson, 1999; Sprenger-Charolles & Serniclaes, 2003; Stanovich et al., 1997; Sprenger-Charolles et al., 2011).

Douklias, Masterson and Hanley (2009) reported cases of phonological and surface developmental dyslexia in Greek. They assessed 84 Greek-speaking children aged 9-12 years and identified four cases of poor readers showing selective reading difficulties. The researchers employed the regression methodology from Castles and Coltheart (1993). They used nonword reading accuracy in order to identify children with a deficit only in phonological processes for reading, and single word reading speed to identify a selective deficit in whole word or lexical processes. They justified the use of real word reading speed, instead of accuracy, due to the absence of irregular words for reading in Greek. The suggestion was that reading speed should be slow in surface dyslexic children due to the fact that they have impaired lexical processes and need to rely on time-consuming phonological decoding (or sublexical) processes. In summary, according to their classification, children with a selective disorder of sublexical reading processes in Greek will have difficulties in nonword reading accuracy but their reading speed might be within the normal range, whereas children with surface dyslexia would have a selective deficit in reading speed but their nonword reading accuracy might be within the normal range. Two of the children in the Douklias et al. study exhibited poor nonword reading accuracy, and two exhibited slow familiar word reading but unimpaired nonword reading. The authors made a series of predictions about the performance in spelling and in phonological awareness tasks of the four children, on the basis of the characteristics of surface and phonological dyslexia in English speaking cases, and the fact that in Greek irregular words do not exist for reading although they do for spelling. Douklias et al. found that the children with the profile of surface dyslexia showed significant difficulty spelling irregular words but not nonwords, while the profile of phonological dyslexia was associated with the opposite pattern. In addition, the two children with the profile of phonological dyslexia exhibited worse performance in phonological awareness tasks (blending and deleting syllable and phonemes, spoonerisms) than age matched control children. One of the two children with the profile of surface dyslexia did not show impaired performance in the phonological awareness tasks; however, the other child with this profile was worse than controls in phoneme and syllable deletion, indicating a mild phonological deficit. Finally, both children with the profile of surface dyslexia showed worse performance in rapid naming tasks than the control children, while the phonological dyslexics were unimpaired in these tasks. Douklias et al. speculated, in line with previous suggestions of Manis et al. (1999), that rapid naming deficits and surface dyslexia may reflect the same underlying difficulty – one that involves a difficulty in forming arbitrary associations, such as those that must be learnt between irregular words and their pronunciations.

The present study aimed to see whether further evidence could be found for the existence of subtypes of developmental surface and phonological dyslexia in a group of Greek speaking dyslexic children, and to extend the scope of the Douklias et al. study. Also, in the latter study poor readers were included and not children diagnosed with dyslexia. Children diagnosed with dyslexia by educational authorities in Greece participated in the clinical group in the present study. The developmental dyslexic children were matched in terms of non-verbal ability and receptive vocabulary with same age controls. We aimed to investigate not only phonological awareness and rapid automatized naming, as in the Douklias et al. study, but also multi-character processing ability (with letter report tasks) and visual memory. Multi-character processing ability, assessed in tasks involving the simultaneous presentation of letters, has been found to be associated with surface dyslexia in English and French dyslexic children (Valdois, Bosse, & Tainturier, 2004). Also, Niolaki and Masterson (2013) recently presented a case of a Greek-speaking child, RF, with surface dyslexia who exhibited a selective difficulty with letter report from arrays, and no evidence of a phonological deficit.

The association of reading ability and multi-character simultaneous processing was outlined using the *multiple-trace memory model* of reading by Ans, Carbonnel, and Valdois (1998). According to this, skilled reading involves global and serial analytic processing. A letter report deficit affects global processing and leads to especial difficulty with irregular words, since acquisition of orthographic recognition units for irregular words is particularly dependent on simultaneous processing of all the letters in the word. Alternatively, a phonological deficit will affect analytic processing and consequently nonword reading. Accordingly, studies have reported that surface dyslexic participants showed a letter report difficulty (c.f., Valdois et al., 2003; Dubois et al., 2010; Peyrin et al., 2012).

Another factor that has been associated with surface dyslexia and that was investigated in the current study is visual memory. Goulandris and Snowling (1991) presented the case of JAS, a developmental dyslexic who had poor performance in reading irregular low frequency words and a spelling impairment. She exhibited a deficiency in sequential visual memory span. This was assessed by presenting JAS with a sequence of unfamiliar symbols. She was asked on each trial to select the target symbols from a set that included the targets and some foils and to arrange them in the correct order. Goulandris and Snowling suggested that JAS had not been able to build up a whole word lexicon due to her visual memory problem. In similar vein, Romani et al. (1999) reported the case of AW, a 22-year-old student with developmental surface dysgraphia. AW showed good performance in tasks tapping phonological short-term memory and phonological abilities such as spoonerisms and blending, He showed a very similar profile to the 22-year-old surface dysgraphic, Allan, who had been reported earlier by Hanley et al. (1992). Like Allan, AW performed well in visual memory tasks where recall of a single visual shape was required. He also performed well when recall was required from arrays where symbols were presented simultaneously. However, AW exhibited poor performance in a task involving reproducing arrays of unfamiliar symbols when these were presented sequentially. Romani et al. suggested that AW had poorly specified lexical representations leading to poor spelling performance as a result of his difficulty encoding serial order.

The present study had the following aims. Firstly, we wanted to investigate whether the profiles identified in Greek dyslexics by Douklias et al. could be replicated. That is, whether we would find children with impaired non-word reading but word naming latencies in the range of TD readers (the profile of phonological dyslexia), and others with slow naming latencies for words but accurate nonword reading (the profile of surface dyslexia). The second aim was to investigate whether the phonological dyslexia profile would be associated with a selective deficit of phonological abilities, and whether surface dyslexia would be associated instead with a deficit of rapid naming, as observed by Douklias et al. (2009) or visual memory (e.g. Goulandris & Snowling, 1991) or multi-character simultaneous processing (e.g., Valdois et al., 2003), since these have been observed to occur in developmental surface dyslexia in previous studies. We also examined whether dyslexic children who showed a mixed profile of reading difficulties would show a combination of associated deficits. The unique contribution of the present study is that it uses a wide range of assessments with a group of formally diagnosed dyslexic children who are speakers of Greek.

Method

Participants

Participants were nine children diagnosed with developmental dyslexia by educational authorities in the province of Chania, Greece, and 33 (17 female) typically developing readers from the same region. Dyslexic children had a mean age of 9;09 years (*SD*=0;09, range 9;0-11;01). The typically developing readers (TDR) served as same age and non-verbal ability matched controls in analyses of the data from the experimental tasks. TDR children were recruited from a mainstream morning school in the city of Chania. Their mean age was 10;01

years (*SD*=0;07, range 9;0-11;06). The children with developmental dyslexia had all been assessed at the regional centre for Differential Diagnosis and SEN Support. The interdisciplinary diagnostic team at each regional centre comprises a child psychiatrist, an educational psychologist, a special educational needs teacher, a speech and language therapist and a social worker. A diagnosis of dyslexia is given when a significant discrepancy is observed between a child's cognitive ability and expected educational attainment. Part of the assessment procedure involves interviews with the child's teacher and parents.

Independent t-tests were used to look for group differences between the dyslexic and TDR groups in the background characteristics of age, nonverbal ability (assessed by the Matrix Analogy Test, Naglieri, 1985), receptive vocabulary (assessed by the Peabody Picture Vocabulary Test, adapted for Greek by Simos, Sideridis, Protopapas, & Mouzaki, 2009) and phonological short term memory (using a digit span task from the Athena Test (Paraskevopoulos, Kalatzi-Azizi, & Giannitsas, 1999)). There were no significant differences on any of these measures.

The children were also assessed in the standardised reading fluency subtest of Test A, developed by Panteliadou and Antoniou (2007), and in the single word spelling test developed by Mouzaki, Protopapas, Sideridis and Simos (2007). In the former, reading fluency is assessed using a text and involves recording the number of words read in one minute. The latter involves spelling to dictation of single words. The words in the test were chosen by Mouzaki et al. from primary school reading primers. It is an untimed test. T-tests revealed a significant difference in the scores of the TDR and dyslexic children for both reading fluency ($t(38)=7.5$, $p<.0001$, $r=0.77$) and spelling ($t(40)=8.5$, $p<.0001$, $r=0.80$). A summary of the scores of the two groups in all the background assessments is provided in Table 1. The significant differences between the groups are indicated in this table and in other tables throughout the paper by asterisks.

(Table 1 about here)

Tasks

Children were assessed for word and nonword reading and spelling, and for phonological ability, rapid automatized naming, visual memory and letter report with the following tasks.

Reading and spelling of words and nonwords

The set of items used by Loizidou-Ieridou, Masterson and Hanley (2009) was employed. This consists of 40 words and 40 nonwords, divided equally into short and long items. In addition, half of the words are high frequency and half low frequency. The nonwords provided a measure of sublexical reading processes. Since irregular words for reading do not exist for Greek, word reading latency was used in the analyses for the present paper, as in the study of Douklias et al., as a measure of the efficiency of lexical processes. Reading latency was assessed using computerized presentation[1]. Stimuli were presented centered on the screen of a Dell Inspiron portable lap-top computer with Windows 7. Font was Consolas size 14. Vocal reaction times were extracted from the sound files using the *Checkvocal* programme developed by Protopapas (2007). Latencies were calculated in milliseconds from the time the stimuli appeared until the child provided a verbal response (threshold was set at 60 dB). Only correct reading responses were included in calculating the mean word reading latency for each child.

For spelling, the same set of word and nonword items was employed. The 40 words consist of twenty irregularly spelled and twenty regularly spelled items. Each word was dictated to the child, followed by a sentence with the word embedded, and then the word was repeated once more by the tester (e.g., <εκκλησία>/eklisia/ (church), "Κάθε Κυριακή πηγαίνω στην εκκλησία" (Every Sunday I go to the church), <εκκλησία>).

Experimental tasks

Phonological awareness (PA)

The blending subtest from the Athena Test (Paraskevopoulos, Kalatzi-Azizi, & Giannitsas, 1999) was used to assess PA. The test consists of 32 trials. On each trial the child is presented with individual phonemes and asked to blend these to form a word. As the test proceeds the items become longer and contain more consonant clusters. The child's score consists of the number of correctly blended words (maximum = 32). A spoonerisms task was also used to assess PA. The task was developed based on the full spoonerisms subtest of the Phonological Assessment Battery (PhAB, Frederickson, Frith, & Reason, 1997). On each trial a pair of words is presented and the child is asked to transpose the initial phonemes of the words (for example, for the pair <γάτα>:/yata/ (cat)- <φίλος>:/filos/ (friend) the correct response would be <φάτα>:/fata/-<γίλος>:/yilos/). There were ten trials in total. Following the procedure for the spoonerisms task in the PhAB, a discontinue criterion was adopted of either 3 minutes total time taken or when three consecutive incorrect responses were recorded. The maximum correct score in the test was 20.

Rapid naming

The rapid naming of digits subtask from the PhAB (Frederickson et al., 1997) was used. The digits are presented on two cards, with ten groups of five digits on each card. Children are asked to name the digits as quickly as possible. Following the manual instructions for the test, the total time taken to name the digits was recorded. Errors were very rare in the task and are not reported. We also administered a rapid naming of letter sounds task, devised for this study[2]. Six lowercase high-frequency letters (α /a/, κ /k/, π /p/, λ /l/, ε /e/, σ /s/) were used for this task. The administration and scoring were the same as for the rapid naming of digits.

Visual memory

The Memory for Designs and Memory for Pictures subtests from the Athena Test (Paraskevopoulos et al., 1999) were used to assess visual memory. The tester uses a set of cards to create a test array on each trial, so that presentation of stimuli is simultaneous. The array is presented to the child for inspection for five seconds and then removed from view. After a five second retention interval the child is given the cards (no distractors) and is asked to reproduce the array in correct order. In the Memory for Pictures subtest stimuli consist of nine familiar pictures (a duck, a bicycle, a house, etc.), whereas in the Memory for Designs subtest stimuli are nine abstract designs. Each subtest begins with three cards in the array and the number increases (subject to performance) throughout the trials, to six cards. There are two trials at each array length with 16 trails in total in each subtest. The testee has two opportunities to provide a correct response on each trial, the first is scored with 2 points, the second with 1. If two incorrect responses are observed at a particular array length the test is discontinued. Correct responses are considered as those where the array items are reproduced in the correct order. The maximum correct score is 32.

Letter report

An adaptation of the task developed by Bosse et al. (2003) was employed. The task was presented on computer. At the start of each trial the screen was blank for 50 msecs then a fixation point appeared in the centre of the screen for 1000 msecs, and then the target array was presented for 200 msecs. Arrays consisted of five consonant letters, in Consolas 14 font, with .57cm spacing between letters. In the global report version of the task children were asked to report all the letters in the array on each trial. In the partial report version, children were asked to report a single letter from the array on each trial. In this version, the target letter was indicated by a cursor presented for 50 msecs, 1.1˚ below the target at the offset of the letter string. The tester noted children's responses at the time of testing and responses were also recorded for later verification.

The task was presented on a Dell Inspiron lap-top computer with Windows 7, the video mode was 1366x768 at 60Hz. Nine uppercase letters were employed (Γ, Δ, Θ, Λ, Ξ, Π, Σ, Φ, Ψ). As Greek letter names are not frequently used and they are two syllables and longer than English letter names, children were asked to respond with letter sounds in the task, rather than letter names, as in previous studies. The global and partial report versions of the task were presented as blocked sessions, with global report first. For global report there were 20 trials. Participants were asked to name as many letters as they could identify. The scores consisted of number of letters reported correctly (maximum = 100) and number of arrays reported correctly (maximum = 20), irrespective of whether letters were reported in the correct order or not. For the partial report version there were 45 trials and scores consisted of the number of single letters reported correctly (maximum = 45).

Procedure

The study began once Institute of Education, London, Ethical approval had been given and letters of parental consent for children's participation were received. The testing of the TD children took place between February and June 2012. Children were seen in a quiet room at their school by the first and second authors, first language speakers of Greek. Children were asked to read the passage for the reading fluency test and the 40 words and 40 nonwords as accurately as possible. The words and nonwords were presented in blocks, with fixed randomised presentation order and nonwords presented first. Children's responses were recorded for later verification. In a separate testing session one month later children were presented with the words and nonwords for spelling to dictation, and non-verbal reasoning, spelling and receptive vocabulary assessments. The latter tests were group administered. Testing lasted 30-40 minutes. Finally, the PA, rapid naming, letter report and visual memory tests were individually administered in further sessions lasting 15-25 minutes, in order to avoid participant fatigue.

Results

In order to look for the profiles of phonological and surface dyslexia we used the regression based technique employed by Castles and Coltheart (1993). We conducted a regression analysis plotting nonword reading accuracy against word reading latencies using the data for all the TDR children. 90% confidence intervals (CIs) were established and dyslexic children whose scores lay outside the CIs were identified. Modified t-tests (Crawford & Howell, 1998) were then used to look for differences in scores in the background and experimental tasks between these cases and age matched TDR children.

Before presenting these analyses we first report the overall group results in the reading, spelling and experimental tasks for the dyslexic and TDR children. Inspection of these results allowed us to see whether the dyslexic children as a group were exhibiting the characteristics previously reported for Greek-speaking children with literacy difficulties.

Results for dyslexic and TDR groups in reading, spelling and experimental tasks

A summary of the results in reading and spelling the Loizidou et al. words and nonwords, and in the PA, rapid naming, visual memory and letter report tasks for the dyslexic and TDR groups is given in Table 2. A significant difference in the scores of the dyslexic and TDR groups was found for word reading latency (t (8.2) = 3.3, p = .011, r = 0.75), but not reading accuracy. For nonword reading a significant difference was observed for accuracy (t (8.5) = 3.9, p=.004, r=0.80), while for latency, the difference approached significance (t (8.6) = 2.1, p=.06, r=0.58). Significant differences were found for regular word, irregular word and nonword spelling (t (9.4) =2.7, p=.024, r=0.66, t (21.1) = 10.8, p<.0001, r=0.92 and t (8.6) =2.7, p=.027, r=0.68, respectively). Significant differences were also observed for blending (t(39)=2.6, p=.013, r=0.38), spoonerisms (t(39)=4.8, p<.0001, r=0.61), rapid naming of digits (t(11.6)=2.8, p=.016, r=0.63), rapid naming of letter sounds (t(8.7)=2.4, p=.043, r=0.61), and for global letter report, both arrays correct (t(27)=3.8, p<.001, r=0.59) and letters correct (t(27)=4.5, p<.0001, r=0.65). There were no significant group differences for either of the visual memory tasks or for partial letter report.

(Table 2 about here)

Classification of dyslexic children into subgroups using the regression outlier technique

A simple regression analysis was carried out using scores of all the TDR children for nonword reading accuracy and word reading latency. The results revealed a significant relationship (r = -.51, P=.003) between the two (F (1,30) = 9.2, p=.005). Further analysis was conducted with chronological age as a covariate in order to see whether age accounted for this relationship. The association remained significant even when age was entered as a covariate (partial r=-.36, p=.047). 90% confidence intervals were established. Predicted values based on the relationship were used to identify those dyslexic children with scores markedly below expectation on one task based on their performance on the other task. The results for the dyslexic children were plotted and are presented in Figure 1.

(Figure 1 about here)

There were three dyslexic children with the characteristics of phonological dyslexia (relatively fast reading latencies for words but poor nonword reading accuracy), two with the characteristics of surface dyslexia (relatively good nonword reading accuracy but slow reading latencies for words) and four with a mixed profile (slow reading latencies and poor nonword reading).

Comparison of results for individual dyslexic children and TDR controls

Dyslexic children with the profile of phonological dyslexia were PD1, PD2 and PD3, those with the profile of surface dyslexia were SD1 and SD2, and those with a mixed profile were MD1, MD2, MD3 and MD4. Scores in the background and experimental tasks of the individual dyslexic children were compared to those of TDR children who were matched on the basis of chronological age. Controls for PD1, SD1, MD1, MD2 and MD3, were nine TDR children with mean age 9;02 (*SD*=0;03). Those for PD2 were eleven TDR children with mean age 9;09 (*SD*=0;04), and those for PD3, SD2 and MD4 were thirteen children with mean age 10;07 (*SD*=0;05).

1. *Background assessments (nonverbal reasoning, receptive vocabulary, digit span, reading fluency and spelling)*

Age, gender and scores in the background assessments for the individual dyslexic children are given in Table 3. There were no significant differences between the scores of individual dyslexic children and those of their respective controls for nonverbal ability or receptive vocabulary. For digit span, two children with the profile of phonological dyslexia and one with a mixed profile scored significantly lower than their respective controls (PD1: $t(9)=4.04$, $p=.002$, $r=0.80$, PD3: $t(13)=2.3$, $p=.019$, $r=0.54$ and MD3: $t(9)=4.04$, $p=.002$, $r=0.64$), however, two children with a mixed profile scored significantly higher than controls in this measure (MD1: $t(9)=3.44$, $p=.004$, $r=0.75$, MD2: $t(9)=1.94$, $p=.044$, $r=0.54$). Seven dyslexic children scored significantly lower than controls for reading fluency (PD3: $t(10)=3.7$, $p=.002$, $r=0.76$, SD1: $t(9)=2.1$, $p=.036$, $r=0.57$, SD2: $t(10)=2.8$, $p=.01$, $r=0.66$, MD1: $t(9)=2.25$, $p=.027$, $r=0.59$, MD2: $t(9)=2.02$, $p=.039$, $r=0.56$, MD3: $t(9)=2.43$, $p=.021$, $r=0.62$, MD4: $t(13)=2.9$, $p=.008$, $r=0.63$). For the Mouzaki et al. spelling test, the children with the profile of phonological dyslexia all scored significantly lower than controls (PD1: $t(9)=1.8$, $p=.05$, $r=0.51$, PD2: $t(9)=1.5$, $p=.044$, $r=0.45$, PD3: $t(13)=2.6$, $p=.012$, $r=0.58$) while two of the children with a mixed profile did so (MD3: $t(9)=1.86$, $p=.05$, $r=0.53$, MD4: $t(13)=1.99$, $p=.035$, $r=0.48$), and for the other two the difference approached significance (MD1: $t(9)=1.5$, $p=.08$, MD2: $t(9)=1.7$, $p=.06$).

(Table 3 about here)

2. Reading words and nonwords

A summary of accuracy and naming latency for reading the Loizidou et al. words and nonwords for the dyslexic children and controls is given in Table 4.

(Table 4 about here)

For word reading accuracy, PD3 and MD4 had scores that were significantly worse than those of controls ($t(13)=5.3$, $p<.001$, $r=0.83$, $t(13)=6.81$, $p<.0001$, $r=0.88$, respectively). The word reading latencies of the two children with a profile of surface dyslexia and all the children with a mixed profile were significantly slower than those of controls (SD1: $t(7)=3.6$, $p=.005$, $r=0.81$, SD2: $t(13)=4.8$, $p<.0001$, $r=0.80$, MD1: $t(9)=1.97$, $p=.04$, $r=0.55$, MD2: $t(9)=4.1$, $p=.003$, $r=0.81$, MD3: $t(9)=11.38$, $p<.0001$, $r=0.97$, MD4: $t(13)=7.024$, $p<.0001$, $r=0.89$). Word reading latency was close to being significantly slower than that of controls for PD3 ($t(13)=1.7$, $p=.054$, $r=0.18$).

For nonword reading accuracy all the children with a profile of phonological dyslexia had worse scores than controls (PD1: $t(7)=2.8$, $p=.015$, $r=0.73$, PD2: $t(11)=5.1$, $p<.0001$, $r=0.84$, PD3: $t(13)=16.5$, $p<.0001$, $r=0.98$). In addition, the scores of three of the children with a mixed profile were significantly worse than those of controls (MD2: $t(9)=2.06$, $p=.04$ $r=0.56$, MD3: $t(9)=8.69$, $p<.0001$, $r=0.95$, MD4: $t(13)=9.63$, $p<.0001$, $r=0.94$). For nonword reading latency the two children with a profile of surface dyslexia and two of the children with a mixed profile had longer latencies than controls (SD1: $t(7)=2.6$, $p=.02$. $r=0.70$, SD2: $t(13)=2.3$, $p=.019$, $r=0.54$, MD3: $t(9)=8.51$, $p<.0001$, $r=0.94$, MD4: $t(13)=2.04$, $p=.032$, $r=0.49$).

3. *Spelling words and nonwords*

Scores of the dyslexic children and controls in spelling the Loizidou et al. regular words, irregular words and nonwords are presented in Table 5.

(Table 5 about here)

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The dyslexics with the profile of phonological dyslexia were significantly less accurate in regular word spelling than controls (PD1: $t(9)=2.6$, $p=.015$, $r=0.65$, PD2: $t(11)=4.7$, $p<.0001$, $r=0.81$, PD3: $t(12)=4.4$, $p<.0001$, $r=0.79$). This was also the case for two of the children with a mixed profile (MD3: $t(9)=3.92$, $p=.002$, $r=0.79$, MD4: $t(12)=1.85$, $p=.045$, $r=0.47$). For irregular word spelling eight of the dyslexic children were significantly less accurate than controls (PD2: ($t(11)=3.5$, $p=.003$, $r=0.78$, PD3: $t(12)=2.6$, $p=.015$, $r=0.60$, SD1: $t(8)=2.1$, $p=.033$, $r=0.60$, SD2 ($t(12)=2.3$, $p=.025$, $r=0.55$, MD1: $t(9)=1.88$, $p=.05$, $r=0.53$, MD2: $t(9)=2.18$, $p=.03$, $r=0.59$, MD3: $t(9)=2.77$, $p=.01$, $r=0.68$, MD4: $t(12)=3.39$, $p=.003$, $r=0.70$). For nonword spelling the three children with a profile of phonological dyslexia were significantly less accurate than controls (PD1: $t(9)=3.4$, $p=.004$, $r=0.75$, PD2: $t(11)=4.2$, $p=.001$,

r=0.78, PD3: $t(12)$=5.6, p<.0001, r=0.85). This was also the case for one of the children with a mixed profile (MD3: $t(9)$=5.97, p<.0001, r=0.89), and for MD1 and MD4 the difference approached significance (MD1: $t(9)$=1.4, p=.09, MD4: $t(12)$=1.58, p=.07, r=0.41).

SD1 and SD2 were significantly better at spelling regular words than irregular words (χ^2=10.2, p<.001 and χ^2=28.8, p<.0001, respectively). This was not the case for the children with the profile of phonological dyslexia. The children with the mixed profile were also significantly better at spelling regular words than irregular words (MD1: χ^2=22.4, p<.0001, MD2: χ^2=12.1, p<.001, MD3: χ^2=6.84, p<.01 and MD4: χ^2=16.5, p<.0001).

Qualitative analysis of spelling errors

We carried out a qualitative analysis of the errors made in spelling the twenty irregular words in order to look for further evidence of use of lexical or sublexical processes. This involved categorizing them as phonologically appropriate or phonologically inappropriate. The spelling errors of the dyslexic children are given in Appendix A. The children with the profile of phonological dyslexia made less phonologically appropriate errors than controls (PD1=82%, TD controls = 96.3% (*SD*:6.6), $t(7)$=2.1, p=.045, r=0.62, PD2=78%, TD controls = 97.5% (*SD*:7.1), $t(8)$=2.5, p=.018, r=0.66, PD3=58%, TD controls=94.8% (*SD*:8.1), $t(9)$=4.3, p=.001, r=0.82). In contrast, the two children with surface dyslexia made predominantly phonologically appropriate errors, and the rate did not differ from that of their respective controls (SD1=100%, TD controls=96.3% (*SD*:6.6), p>.05, SD2=92%, TD controls=94.8% (*SD*:8.1), p>.05). The same was the case for three of the children with a mixed profile (MD1=100%, TD controls= 96.3% (*SD*:6.6), p>.05, MD2=100%, TD controls=96.3% (*SD*:6.6), p>.05, MD4=100%, TD controls=94.8% (*SD*:8.1), $p>.05$. MD3 made significantly less phonologically appropriate errors than controls (50%, TD controls=96.3% (*SD*:6.6), $t(7)=6.6$, $p<.0001$, $r=0.93$).

4. *Phonological awareness and rapid naming*

Results for the dyslexic children and controls are given in Table 6. Blending scores were significantly worse than those of controls for PD1 ($t(9)=3.6$, $p=.004$, $r=0.77$) and PD2 ($t(10)=2.4$, $p=.021$, $r=0.61$), and the difference approached significance for PD3 ($t(13)=1.69$, $p=.058$, $r=0$). For spoonerisms, children with the profile of phonological dyslexia and those with a mixed profile all showed worse performance than controls (PD1: $t(9)=2.5$, $p=.018$, $r=0.6$, PD2: $t(10)=2.4$, $p=.018$, $r=0.61$, PD3: $t(13)=2.8$, $p=.009$, $r=0.61$, MD1: $t(9)=2.2$, $p=.025$, $r=0.59$, MD2: $t(9)=2.1$, $p=.035$, $r=0.57$, MD3: $t(9)=2.5$, $p=.037$, $r=0.64$ and MD4: $t(13)=2.2$, $p=.023$, $r=0.52$). For rapid naming of digits and rapid naming of letter sounds MD3 was the only child whose scores differed significantly from those of controls (rapid naming digits: $t(9)=2.8$, $p=.012$, $r=0.68$, rapid naming letter sounds: $t(7)=2.9$, $p=.014$, $r=0.74$).

(Table 6 about here)

5. *Visual memory*

The results in the two visual memory tasks for the dyslexic children and controls are presented in Table 7. The scores of the children with dyslexia did not differ significantly from those of controls, with the exception that MD2 scored worse than controls in visual memory for designs ($t(9)=2.6$, $p=.015$, $r=0.66$).

(Table 7 about here)

6. Letter report

The scores for global and partial letter report for the dyslexic children and controls are given in Table 8.

(Table 8 about here)

For global report arrays correct the scores of the two children with a profile of surface dyslexia and three of the children with a mixed profile were worse than those of controls (SD1: $t(6)=2.1$, $p=.046$, $r=0.66$, SD2: t (7) = 2.4, p =.028, r= 0.67, MD1: $t(6)=2.1$, $p=.045$, $r=0.65$, MD3: $t(6)=2.1$, $p=.045$, $r=0.65$, MD4: $t(7)=2.3$, $p=.040$, $r=0.66$) and for MD2 the difference approached significance ($t(6)=1.5$, $p=.091$, $r=0.52$). The same results were found for global report letters correct except that the difference for MD4 was significant (SD1: $t(6)=3.6$, $p=.008$, $r=0.83$, SD2: $t(7)=3.7$, $p=.005$, $r=0.81$, MD1: $t(6)=2.4$, $p=.028$, $r=0.70$, MD2: $t(6)=2.8$, $p=.020$, $r=0.75$, MD3: $t(6)=4.5$, $p=.003$, $r=0.87$ and MD4 $t(7)=2.8$, $p=.016$, $r=0.73$).

In partial report only the scores of SD2 and MD4 were worse than those of controls (SD2: $t(13)=2.7$, $p=.011$, $r=0.60$, MD4: $t(13)=2.7$, $p=.015$, $r=0.60$). A deficit in global report but not in partial report has previously been reported for a Greek-speaking dyslexic child by Niolaki and Masterson (2013).

General Discussion

The study investigated subtypes of developmental dyslexia in a group of Greek-speaking dyslexic children. Before carrying out a regression-based subtyping analysis we examined the results for the dyslexic group as a whole in assessments of reading and spelling, phonological awareness, rapid naming, visual memory and letter report. The findings revealed a number of characteristics previously reported for children with dyslexia in studies with transparent and opaque orthographies. The dyslexic children were slower than typically developing readers at reading both text and single words, although their word reading was relatively accurate. This has been reported in a number of studies with transparent writing systems (e.g., Wimmer, 1993 for German; Nikolopoulos, Goulandris, & Snowling, 2003, for Greek; Davis, Cuetos, & Glez-Seijas, 2007, for Spanish; Zoccolotti, De Luca, Di Pace, Judica, Orlandi, & Spinelli, 1999, for Italian). The dyslexic children's spelling and nonword reading were overall less accurate than those of the TDR children, and they showed impairment in tasks of phonological awareness, rapid naming and letter report. These results have also been found for dyslexic children in many previous studies (e.g., Bowers & Wolf, 1993; Dubois et al., 2010; Hatcher, 1994; Manis et al., 1999; Moll et al., 2009; Snowling, 2000; Peyrin et al., 2012; Valdois et al., 2003). We can say then, that as a group the dyslexic children in the present study showed results in tasks of reading, spelling and literacy-related skills that are in line with those of previous studies.

In order to look for the surface and phonological subtypes of developmental dyslexia, previously identified in Greek-speaking poor readers by Douklias et al. (2009), we used the regression outlier technique (Castles & Coltheart, 1993; Manis et al., 1996; Stanovich et al., 1997). As in the study of Douklias et al. we used nonword reading accuracy as a measure of sublexical processing, and word reading latency as a measure of lexical processes. We found that three of the dyslexic children exhibited the profile of phonological dyslexia (poor nonword reading accuracy but relatively fast word reading latencies) and two children the profile of surface dyslexia (slow word reading latencies but relatively good nonword reading accuracy). We also found that four of the children had a mixed profile.

The findings support the existence of distinct types of developmental dyslexia in Greek. A difference in the results of the present study and those of Douklias et al. is that five of the nine dyslexic children in the present study had a selective deficit, and this proportion is much higher than in the Douklias et al. study, where only four of 84 children showed the selective profile of phonological or surface dyslexia. It is not clear what the reason for this difference is, since the same reading task was used in both studies for subtyping purposes, however, there are differences in the participant samples that may be relevant. The typically developing readers in the present study were slightly older than those in the Douklias et al. study, and in addition, the poor readers in the present study had all had a formal diagnosis of dyslexia, while in the Douklias et al. study this was not the case. We note that the poor readers in Douklias et al. scored more poorly that the typically developing readers in tasks of nonverbal reasoning and receptive vocabulary, while that was not the case in the present study. It is not clear whether any (or all) of these factors may have led to the difference in prevalence rate of selective deficits between the studies but it seems important to examine the effect of these variables systematically in future studies.

We carried out assessments of single word reading and spelling, phonological awareness, rapid naming, visual memory and letter report to look for patterns of deficit that might be associated with the different reading profiles in the dyslexic children. The findings revealed that those with the profile of phonological dyslexia (PD1, PD2 and PD3) performed poorly in phonological awareness tasks, consistent with a deficit in phonological processing, and in contrast to the performance of the children who showed the profile of surface dyslexia (SD1 and SD2). The association of a phonological deficit and developmental phonological dyslexia has been extensively documented. Children with phonological dyslexia are usually also reported to have impaired nonword spelling, and this was found to be the case for PD1, PD2 and PD3 who scored significantly worse than controls. SD1 and SD2, scored close to ceiling in nonword spelling, and on a par with controls. In contrast, they performed worse than controls in irregular word spelling. The association of poor irregular word spelling and developmental surface dyslexia is also reasonably well documented (e.g., Hanley & Gard, 1995; Rowse & Wilshire, 2007; Valdois, 1996).

An unexpected result was that two of the children with profiles of phonological dyslexia (PD2 and PD3) were also significantly poorer than controls at irregular word spelling. The result can perhaps be explained according to the self-teaching hypothesis (Share, 1995, 1999), whereby poor phonological processing will also impede normal acquisition of orthographic knowledge and thus lead to poor spelling of all types of printed letter strings. While Douklias et al. did not find poor irregular word spelling in children with a profile of phonological dyslexia in their study we speculate that this may due to age differences in the cases across the two studies and the severity of the sublexical deficit. The two phonological dyslexic cases in Douklias et al. were younger than PD2 and PD3, and they seem to have been less impaired in nonword reading and in phonological awareness tasks. It may be that the nature of Greek means that for more advanced spelling, with longer and more complex words, a severe sublexical deficit will affect spelling performance for all types of words (that is, in the case of irregularly spelled words, apart from the irregular segments, there are plenty of other opportunities for poor phonological skills to have an effect on spelling production). Further examination of spelling performance with older Greek speaking children will help to address this issue.

Importantly, for SD1 and SD2 regular word spelling was significantly more accurate than irregular word spelling, whereas this was not the case for any of the children with a profile of phonological dyslexia. An advantage for regular words over irregular words in reading and spelling has been considered a defining characteristic of surface dyslexia in English-speaking cases (e.g., Marshall & Newcombe, 1973; Shallice & Warrington, 1980; Temple, 1984), and the disorder has been interpreted as a reliance on sublexical processes due to an impairment of lexical processes. We carried out a qualitative analysis of spelling errors with irregular words to see whether the responses would reveal further evidence for differential use of lexical and sublexical processes in the dyslexic children. We found that the responses of SD1 and SD2 were almost all phonologically appropriate, as for the typically developing readers. The rate for the children with a profile of phonological dyslexia was significantly lower. Examples of the phonologically inappropriate responses of PD1, PD2 and PD3 are <άγκυρα> (anchor) /agira/-> <ΑΓΙΡΑ> /ayira/ and <δύσπνοια> (shortness of breath) /ðispnia/-> <ΔΙΣΠΛΙΑ> /ðisplia/. The findings provide additional support for a dissociation in reading and spelling processes in the dyslexic cases.

An aspect of the findings from the reading task that may seem anomalous is that SD1 and SD2 both had slow nonword reading latencies (as well as slow word reading latencies) with respect to controls. Slow nonword reading might seem an anomaly in surface dyslexia since good accuracy and naming speed for nonwords might be expected when sublexical processes are relatively intact. However, Douklias et al. noted that nonword reading latencies were slow in the poor readers with the surface dyslexic profile in their study, and that in other case of developmental surface dyslexia nonword latencies were recorded as being slow. Douklias et al. suggested that this could be explained within a dual route cascaded framework (Coltheart, Rastle, Perry, Langdon & Ziegler, 2001) in terms of lack of feedback from the orthographic lexicon to sublexical processes when the lexical route is inefficient. Slow nonword reading can also be explained within the multi-trace memory model (Ans et al., 1998). The multi-character simultaneous processing hypothesis holds that both slow nonword reading and impaired irregular word reading can derive from a visual attention span disorder (Valdois et al., 2004; 2011) since, in this framework, nonword reading speed is associated with the size of the sublexical units that individuals use to read nonwords. The larger the sublexical unit the faster the reading speed. A multi-character simultaneous processing deficit, if severe enough, can limit performance to the smaller graphemes (letters and digraphs). While typically developing readers will use larger graphemic units (syllables or morphemes) to decode fast and accurately, children with limited multi-character simultaneous processing will rely on smaller segments and their reading will be laborious.

As noted above, the pattern of relatively accurate nonword reading and slow word (and nonword) reading that we observed in SD1 and SD2 is in accordance with findings from previous studies with dyslexics that have been carried out in more transparent orthographies. However, the results confirm that slow reading speed is not characteristic of all children with developmental dyslexia learning to read in a transparent writing system, since we found that the dyslexics with the profile of phonological dyslexia did not exhibit slow reading latency.

The deficit shared by both children with the profile of surface dyslexia in the present study was a deficit of multi-character simultaneous processing. The present findings support the hypothesis that postulates that a multi-character simultaneous processing deficit will hamper the processing of larger graphemic units, that is necessary to build up the lexical store during the course of literacy acquisition. Instead the child will be forced to rely on slow, serial processing (Ans et al., 1993; Bosse et al., 2007). As noted in the Introduction, the association of surface dyslexia and letter report difficulty has been reported before (Valdois et al. 2003; Dubois et al., 2010; Peyrin et al., 2012). A difference between previous studies and the present one is that multi-character processing was assessed using letter sounds in this study, and not letter names. It has been suggested that a deficit in performance in letter report tasks may not be the result of reduced visual attention span, but is rather due to impaired visual to phonological mapping (Hawelka & Wimmer, 2008; Ziegler et al., 2010), in line with the phonological deficit theory of dyslexia. The letter report task undoubtedly does involve the activation of phonological information, and phonological processing should be in evidence even more when the task involves letter sounds rather than names, however, the interpretation of performance in the task has been that it allows us to assess the ability to process multiple elements in parallel. If the former interpretation was correct then we should expect to see poor performance in our letter report task in children with a phonological processing deficit. However, it was the children with a profile of surface dyslexia, and no apparent phonological deficit, who exhibited poor performance in the task. The finding argues for a visual processing account of the multi-character processing deficit (but see *Limitations* section for a caveat concerning our results in letter report).

Discussion of the findings so far has indicated a unique association of impaired sublexical processes with a phonological processing deficit, and of impaired lexical processes with a multi-character processing deficit. Examination of the findings in the experimental tasks from the dyslexic children with a mixed profile was important in providing confirmatory or disconfirmatory evidence for these associations. Since a mixed profile indicates deficits of both lexical and sublexical processes then if we found some children with this profile who had only a phonological deficit and some who had only a multi-character processing difficulty then this would call into question the relationship between the reading profiles and underlying disorders. The results in the experimental tasks, however, indicated that the four children with a mixed profile had a deficit in both phonological awareness and in letter report.

Two of the children with a mixed profile exhibited an additional difficulty, as well as in phonological awareness and letter report. MD2 was less accurate than controls in visual memory for designs, and MD3 exhibited poor rapid naming for digits and for letter sounds. MD3 had a severe difficulty in reading and spelling of both words and nonwords, which is in agreement with previous studies reporting that children with a double deficit of phonological awareness and rapid naming experienced the most severe difficulties in reading and spelling (e.g., Papadopoulos et al., 2009; Torppa et al., 2013). The two children with the surface dyslexic profile in the present study did not show evidence of a rapid naming deficit. Douklias et al. (2009) and Manis et al. (1999) reported that children with the characteristics of surface dyslexia had a deficit in rapid naming. However, Wolf et al. (2002) found that 15% of dyslexic children with a phonological deficit in their sample had a deficit of rapid naming while 6% of dyslexic children with no phonological deficit did.

In conclusion, we found support for profiles of developmental surface and phonological dyslexia in Greek speaking children with literacy difficulties, as reported previously by Doukias et al. In addition, the results indicated an association between developmental phonological dyslexia and a phonological deficit, on the one hand, and developmental surface dyslexia and letter report difficulty on the other.

Limitations of the present study

A limitation of the present study is that the sample size is small. It will be important to see whether the associations we observed will be found to hold for a larger sample of Greek speaking children. A further limitation of the present study has to do with the fact that we did not administer a control task to provide evidence, especially in the children who performed poorly in letter report, of unimpaired single letter processing. However, the children with a letter report difficulty (with the exception of MD3) did not score worse than controls in the task of letter processing that was included as one of the rapid naming tasks. We acknowledge, though that this is not a task of individual letter identification and it will be important to include such a task in future studies. With these caveats in mind, we can say that the findings from the children with specific profiles support the notion that different subtypes of developmental dyslexia exist, and the associated deficits indicate that the subtypes have different underlying disorders. The findings also suggest that the regression outlier technique can be successfully applied in a more transparent language than English, such as Greek. As well as having theoretical implications, the ability to differentiate among subtypes of dyslexia is vitally important for educationalists and clinicians for the purposes of effective intervention.

[1]Footnote: The first and second authors, native speakers of Greek, devised the experimental tasks reported in the paper. Computer-presented tasks were programmed using the DMDX programme developed by Forster and Forster (2003).

[2]Footnote: For the rapid naming of letter sounds task 18 TDR children formed the control group.

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Appendix A

Spelling errors of the dyslexic children in irregular words

		Phonological dyslexics			*Surface dyslexics*	
items	translation	PD3	PD2	PD1	SD2	SD1
<πλημμυρίζω>	to flood	<πλυμηριζω>	<πλιμιριζο>	<πληρειμαζω>	<πλυμιρίζω>	<πλιμιρίζω>
/plimirizo/		/plimirizo/	/plimirizo/	/plirimazo/	/plimirizo/	/plimirizo/
<εκκλησία>	church	<εκλυσεια>	✓	<εκλησεία>	<εκλησία>	<εκκλισία>
/eklisia/		/eklisia/		/eklisia/	/eklisia/	/eklisia/
<τυρί >	cheese	✓	<τιρι>	✓	✓	<τιρί>
/tiri/			/tiri/			/tiri/
<μαγειρεύω>	to cook	<μαγιρευο>	<μαμαγιρευω>	<μαγυρεβω>	<μαγιρεύω>	<μαγιρεύω>
/mayirevo/		/mayirevo/	/mamayirevo/	/mayirevo/	/mayirevo/	/mayirevo/
<άγγελος>	angel	✓	<αγγελως>	<αγκελο>	<αγελως>	✓
/agelos/			/agelos/	/agelo/	/ayelos/	
<παίζω>	to play	✓	✓	✓	<πεζω>	✓
/pezo/					/pezo/	
<φωτογραφίζω>	to take	✓	<φοτογραφιζω>	<φοτογραφυζω>	✓	<φοτογραφίζω>
/fotoyrafizo/	photo		/fotoyrafizo/	/fotoyrafizo/		/fotoyrafizo/
<ήχος >	sound	✓	✓	<ειχος>	✓	<ίχος> /ihos/
/ihos/				/ihos/		
<παιδιά>	children	✓	<παιζια>	✓	✓	✓
/pethia/			/pezia/			
<ενοχλητικός>	nuisance	<ενοχλιτης>	<ενοχλιτικος>	<ενοχλιτικος>	<ενοχλιτικος>	<ενοχλιτικός>
/enohlitikos/		/enohlitis/	/enohlitikos/	/enohlitikos/	/enohlitikos/	/enohlitikos/
<γραμματόσημα>	stamps	<γροματιζω>	<γραματοσιμα>	<γραμοτωσειμα	<γραματόσιμα>	<γραμματόσιμα>
/yramatosima/		/yromatizo/	/yramatosima/	> /yramotosima/	/yramatosima/	/yramatosima/
<άρωμα >	perfume	<αρομα>	<αρομα>	<αρομα>	✓	<άρομα>
/aroma/		/aroma/	/aroma/	/aroma/		/aroma/
<άγκυρα>	anchor	<αγιρα>	<αγγιρα>	✓	<αγκιρα>	<άγγιρα>
/agira/		/ayira/	/agira/		/agira/	/agira/
<καθήκον>	duty	<καθικος>	<ακοθικον>	<καθικον>	<καθικον>	<καθίκον>
/kathikon/		/kathikos/	/akothikon/	/kathikon/	/kathikon/	/kathikon/
<ηφαίστειο>	volcano	<ηφαιστιο>	<ηφεστιο>	<ιφαστηο>	<ειφαιστιο>	<ηφέστιο>
/ifestio/		/ifestio/	/ifestio/	/ifastio/	/ifestio/	/ifestio/
<δύσπνοια>	shortness	<δισπλια>	<δισπνια>	<δισπνια>	<δυσπνια>	<δίσπνια>
/thispnja/	of breath	/thisplja/	/thispnja/	/thispnja/	/thispnja/	/thispnja/
<αστείο>	joke	<αστιο>	<αστιο>	✓	<αστίο>	<αστίο>
/astio/		/astio/	/astio/		/astio/	/astio/

<ζητιανεύω>	to beg	<ζητανευο>	<ζιτιανευω>	<ζιτιανεβο>	✓	<ζιτιανεύω>
/zitjanevo/		/zitanevo/	/zitjanevo/	/zitjanevo/		/zitjanevo/
<είσοδος>	entrance	<υσοδος>	<ησοδος>		✓	<ήσοδος>
/isothos/		/isothos/	/isothos/			/isothos/
<μεταβλητός>	fluxionary	<μεταβλιτος>	<μεταβιλιτος>	<μεταβλιτος>	<μεταβλιτος>	<μεταβλιτός>
/metavlitos/		/metavlitos/	/metavilitos/	/metavlitos/	/metavlitos/	/metavlitos/

		Mixed dyslexics			
items	translation	MD1	MD2	MD3	MD4
<πλημμυρίζω>	to flood	<πλυμηρίζω>/pl	<πλιμηρίζω>	<πλιμρζω>	<πλιμιρίζω>
/plimirizo/		imirizo/	/plimirizo/	/plimrzo/	/plimirizo/
<εκκλησία>	church	<εκλισία>	<εκλισία>	<εκλσία> /eklsia/	<εκλισία>
/eklisia/		/eklisia/	/eklisia/		/eklisia/
<τυρί >	cheese	✓	<τιρί>	<τιρί>	<τιρί>
/tiri/			/tiri/	/tiri/	/tiri/
<μαγειρεύω>	to cook	<μαγιρεύω>	<μαγιρεύω>	<μαγκιρεύω>	<μαγιρεύω>
/mayirevo/		/mayirevo/	/mayirevo/	/magirevo/	/mayirevo/
<άγγελος>	angel	<αγγελως>	✓	<αγελος>	<αγκελos>
/agelos/		/agelos/		/ayelos/	/agelo/
<παίζω>	to play	✓	✓	✓	✓
/pezo/					
<φωτογραφίζω>	to take	<φοτογραφίζω>	<φοτογραφίζω>	<φοτογρφίζω>	<φοτογραφίζω>
/fotoyrafizo/	photo	/fotoyrafizo/	/fotoyrafizo/	/fotoyrfizo/	/fotoyrafizo/
<ήχος >	sound	<ίχος> /ihos/	<ίχος> /ihos/	<ίχος>	✓
/ihos/				/ihos/	
<παιδιά>	children	✓	✓	<πεδια>	✓
/pethia/				/pethia/	
<ενοχλητικός>	nuisance	<ενοχλιτικός>	<ενοχλιτικός>	<ενοχλτκός>	<ενοχλιτικός>
/enohlitikos/		/enohlitikos/	/enohlitikos/	/enohltkos/	/enohlitikos/
<γραμματόσημα>	stamps	<γραματόσιμα>	<γραματόσιμα>	<γρατόσιμα>	<γραμματόσιμα>
/yramatosima/		/yramatosima/	/yramatosima/	/yratosima/	/yramatosima/
<άρωμα >	perfume	<άρομα>	<άρομα>	<άρομα>	<άρομα>
/aroma/		/aroma/	/aroma/	/aroma/	/aroma/
<άγκυρα>	anchor	<άγκιρα>	<άγκιρα>	<άγκιρα>	<αγκιρα>
/agira/		/agira/	/agira/	/agira/	/agira/
<καθήκον>	duty	<καθίκον>	<καθίκον>	<καφίκον>	<καθικον>
/kathikon/		/kathikon/	/kathikon/	/kafikon/	/kathikon/
<ηφαίστειο>	volcano	<ηφέστιο>	<ιφέστιο>	<ιθέστιο>	<ιφέστιο>
/ifestio/		/ifestio/	/ifestio/	/ithestio/	/ifestio/
<δύσπνοια>	shortness	<δίσπνια>	<δίσπνια>	<δίσπνια>	<δίσπνια>
/thispnja/	of breath	/thispnja/	/thispnja/	/thispnja/	/thispnja/

<αστείο>	joke	<αστίο>	<αστίο>	<αστίο>	<αστίο>
/astio/		/astio/	/astio/	/astio/	/astio/
<ζητιανεύω>	to beg	<ζιτιανεύω>	<ζιτιανεύω>	<ζιτιανεβω>	<ζιτιανεύω>
/zitjanevo/		/zitjanevo/	/zitjanevo/	/zitjanevo/	/zitjanevo/
<είσοδος>	entrance	<ήσοδος>	<ίσοδος>	<ίσοδος>	<ίσοδος>
/isothos/		/isothos/	/isothos/	/isothos/	/isothos/
<μεταβλητός>	fluxionary	<μεταβλιτός>	<μεταβλιτός>	<μεταβιτός>	<μεταβλιτός>
/metavlitos/		/metavlitos/	/metavlitos/	/metavitos/	/metavlitos/

"Table 1": Mean chronological age and standardised scores in the background assessments for dyslexic children and TDR children (digit span and receptive vocabulary scores are raw scores as standardised scores were unavailable, standard deviations are in parentheses)

	Dyslexic group (N=9)	TDR (N=33)	*Cronbach's α*
Age in months	119 (10)	121 (9)	
Non-verbal reasoning[α]	96 (12)	100 (12)	.80
Digit Span[b] (max. correct=32)	19.4 (6.7)	22 (5.6)	.90
Reading fluency[c]	76 (6.1)***	107 (14)	.74-.87
Spelling[d]	74 (4.1)***	98 (15)	.94
Receptive vocabulary[e] (max. correct=174)	124 (4.6)	111 (28)	.96

Note: [α]Matrix Analogies Test (Naglieri, 1985), [b]Digit Span subtest from the Athena Test (Paraskevopoulos et al., 1999), [c] Reading fluency (Panteliadou & Antoniou, 2007), [d]Single word spelling (Mouzaki et al., 2007), [e] PPVT adapted for Greek (Simos et al., 2011).

"Table 2": Mean scores in word and nonword reading and spelling and experimental tasks for the dyslexic and TDR groups (standard deviations are in parentheses)

	Dyslexic Group	TDR
Word reading accuracy (max. correct 40)[a]	37 (2.9)	39 (2.1)
Word reading latency (msecs)	1527 (616)**	820 (142)
Nonword reading accuracy (max. correct 40)[a]	25 (8.9)**	37 (2.8)
Nonword reading latency (msecs)	1426 (528)	1054 (193)
Regular word spelling (max correct= 20)	14.67 (3.6)*	18.06 (2.03)
Irregular word spelling (max correct= 20)	4 (1.9)****	13.25 (2.9)
Nonword spelling (max correct= 40)	30.3 (7.1)*	36.75 (2.6)
Blending (max. correct 32)	23 (6.9)*	28 (4.2)
Spoonerisms (max. correct 20)	4.7 (6.6)***	15.3 (5.6)
Rapid naming of digits (seconds)	32.25 (7.3)**	23.9 (5.6)
Rapid naming of letters (seconds)	25.35 (7.5)*	17.9 (5.6)
Visual memory pictures (max. correct 32)	18.4 (4.4)	19 (5.9)
Visual memory designs (max. correct 32)	16 (6.3)	17.2 (4.5)
Global letter report arrays (max. correct 20)	2.1 (2.8)***	6.2 (3.4)
Global letter report letters (max. correct 100)	59 (9.6)****	75 (11)
Partial letter report (max. correct 45)	33.8 (4.6)	36 (4.6)

[a]Words and nonwords from Loizidou et al. (2009), **p*<.05, ***p*<.01, ****p*<.001, *****p*<.0001

“Table 3”: Age, gender and scores in background assessments for dyslexic children in the surface, phonological and mixed subtype groups and controls (scores for digit span and receptive vocabulary are raw scores as standardized scores were unavailable for these assessments, standard deviations are in parentheses)

	Phonological dyslexics			*Surface dyslexics*		*Mixed Dyslexics*			
	PD1	PD2	PD3	SD1	SD2	MD1	MD2	MD3	MD4
Age in years	9;05	10;02	11;01	9;00	11;00	9;00	9;08	9;06	11;00
Gender	M	M	F	F	M	F	M	M	M
Non-verbal reasoning (standard scores)[α]	85	94	88	120	88	105	85	94	107
Controls	95.5 (8.4)	98 (13.6)	97.1 (11.1)	95.5 (8.4)	97.1 (11.1)	95.5 (8.4)	95.5 (8.4)	95.5 (8.4)	97.1 (11.1)
Digit Span (max correct= 32)[b]	11**	21	11*	22	22	26**	23*	11**	28
Controls	19.1 (1.9)	20.7 (6.0)	25.1 (5.8)	19.1 (1.9)	25.1 (5.8)	19.1 (1.9)	19.1 (1.9)	19.1 (1.9)	25.1 (5.8)
Reading fluency (standard scores) [c]	81	88	67**	76*	76**	73*	77*	70*	76**
Controls	111 (16)	106 (11.2)	105.3 (9.8)	111 (16)	105.3 (9.8)	111 (16)	111 (16)	111 (16)	105.3 (9.8)
Spelling (standard scores)[d]	72*	72*	67*	74	82	77	74	72*	74*
Controls	102 (15.3)	102 (14.6)	97 (11.1)	102 (15.3)	97 (11.1)	102 (15.3)	102 (15.3)	102 (15.3)	97 (11.1)

Receptive vocabulary (max correct=174) [e]	120	125	131	119	128	117	125	118	123
Controls	117 (8.8)	112 (6.8)	131 (14.6)	117 (8.8)	131 (14.6)	117 (8.8)	117 (8.8)	117 (8.8)	131 (14.6)

Note: [α]Matrix Analogies Test (Naglieri, 1985b), [b]Digit Span subtest the from Athena Test (Paraskevopoulos et al., 1999), [c] Reading fluency (Panteliadou & Antoniou, 2007), [d]Single word spelling (Mouzaki et al., 2007), [e] PPVT adapted for Greek (Simos et al., 2011), * p<.05, **p<.01

“Table 4”: Accuracy and latency in word and nonword reading for dyslexic children in the surface, phonological and mixed subtype groups and controls (standard deviations are in parentheses)

	Phonological dyslexics			*Surface dyslexics*		*Mixed dyslexics*			
	PD1	PD2	PD3	SD1	SD2	MD1	MD2	MD3	MD4
Word accuracy[a] (max correct=40)	36	40	37***	40	40	37	39	32	35****
Controls	36.8 (3.2)	38.3 (1.6)	39.6 (0.65)	36.8 (3.2)	39.6 (0.65)	36.8 (3.2)	36.8 (3.2)	36.8 (3.2)	39.6 (0.65)
Word latency (msecs)	980	948	1050	1536**	1429****	1248*	1605**	2953****	1890****
Controls	911 (160)	832 (119)	774 (153)	911 (160)	774 (153)	911 (160)	911 (160)	911 (160)	774 (153)
Nonword accuracy (max correct =40)	27*	21****	11****	35	36	32	29*	12****	23****
Controls	34.3 (2.4)	37 (2.9)	39 (1.6)	34.3 (2.4)	39 (1.6)	34.3 (2.4)	34.3 (2.4)	34.3 (2.4)	39 (1.6)
Nonword latency (msecs)	1378	1091	935	1592*	1467*	1022	1215	2705****	1413*
Controls	1103 (176)	1068 (219)	1017 (187)	1103 (176)	1017 (187)	1103 (176)	1103 (176)	1103 (176)	1017 (187)

Note: [α]List of words and nonwords from Loizidou et al. (2009), *p<.05, **p<.01, ***p<.001, ****p<.0001

“Table 5”: Accuracy in regular and irregular word and nonword spelling for the dyslexic children in the surface, phonological and mixed subtype groups and controls (standard deviations are in parentheses)

	Phonological dyslexics			*Surface dyslexics*		*Mixed dyslexics*			
	PD1	PD2	PD3	SD1	SD2	MD1	MD2	MD3	MD4
Regular words (max correct= 20)	11*	8***	12***	19	17	19	14	8**	16*
Controls	17.1 (2.2)	17.9 (2.0)	18.9 (1.5)	17.1 (2.2)	18.9 (1.5)	17.1 (2.2)	17.1 (2.2)	17.1 (2.2)	18.9 (1.5)
Irregular words (max correct=20)	6	3**	6*	3*	7*	4*	3*	1*	3**
Controls	10.4 (3.2)	13 (2.7)	14.3 (3.2)	10.4 (3.2)	14.3 (3.2)	10.4 (3.2)	10.4 (3.2)	10.4 (3.2)	14.3 (3.2)
Nonwords (max correct=40)	26**	25**	22****	39	38	32	36	19****	33
Controls	36 (2.7)	37 (2.7)	37.3 (2.6)	36 (2.7)	37.3 (2.6)	36 (2.7)	36 (2.7)	36 (2.7)	37.3 (2.6)

Note:* $p<.05$, ** $p<.01$, *** $p<.001$, **** $p<.0001$

“Table 6”: Scores in assessments of phonological awareness and rapid naming for dyslexic children in the surface, phonological and mixed subtype groups and controls (standard deviations are in parentheses)

	Phonological dyslexics			*Surface dyslexics*		*Mixed dyslexics*			
	PD1	PD2	PD3	SD1	SD2	MD1	MD2	MD3	MD4
Blending (max correct = 32)	6**	21*	22	28	24	28	25	22	27
Controls	25.3	28.2	29	25.3	29	25.3	25.3	25.3	29
	(5.1)	(2.9)	(4.0)	(5.1)	(4.0)	(5.1)	(5.1)	(5.1)	(4.0)
Spoonerisms (max correct = 20)	0*	0*	1**	10	9	1*	2*	0*	4*
Controls	12.7	16.2	16.5	12.7	16.5	12.7	12.7	12.7	16.5
	(4.8)	(6.3)	(5.4)	(4.8)	(5.4)	(4.8)	(4.8)	(4.8)	(5.4)
Rapid naming digits (secs)	21	30	29	30	33	35	32	47*	33
Controls	27	25	26	27	26	27	27	27	26
	(6.9)	(4.6)	(5.6)	(6.9)	(5.6)	(6.9)	(6.9)	(6.9)	(5.6)
Rapid naming letter sounds (secs)	23	19	17	24	22	24	19	42*	23

Controls	21.2	15.8	15.7	21.2	15.7	21.2	21.2	21.2	15.7
	(6.7)	(3.3)	(4.6)	(6.7)	(4.6)	(6.7)	(6.7)	(6.7)	(4.6)

Note: *p<.05,** p<.01

“Table 7”: Accuracy in visual memory tasks for dyslexic children in the surface, phonological and mixed subtype groups and controls (standard deviations are in parentheses)

	Phonological dyslexics			*Surface dyslexics*		*Mixed dyslexics*			
	PD1	PD2	PD3	SD1	SD2	MD1	MD2	MD3	MD4
Visual memory pictures (max correct = 32)	14	21	21	21	18	21	12	13	24
Controls	16.4 (4.8)	18.5 (5.2)	21.1 (6.6)	16.4 (4.8)	21.1 (6.6)	16.4 (4.8)	16.4 (4.8)	16.4 (4.8)	21.1 (6.6)
Visual memory designs (max correct = 32)	14	16	23	12	12	12	4*	16	21
Controls	15.1 (4.0)	17 (5.3)	18.7 (4.1)	15.1 (4.0)	18.7 (4.1)	15.1 (4.0)	15.1 (4.0)	15.1 (4.0)	18.7 (4.1)

Note: *p<.05

"Table 8": Accuracy in the global and partial letter report tasks for dyslexic children in the surface, phonological and mixed subtype groups and controls (standard deviations are in parentheses)

	Phonological dyslexic			*Surface dyslexic*		*Mixed dyslexic*			
	PD1	PD2	PD3	SD1	SD2	MD1	MD2	MD3	MD4
Global report arrays (max. correct = 20)	5	7	5	0*	0*	0*	2	0*	0*
Controls	7.67 (3.4)	8.3 (3.9)	5.3 (2.1)	7.67 (3.4)	5.3 (2.1)	7.67 (3.4)	7.67 (3.4)	7.67 (3.4)	5.3 (2.1)
Global report letters (max. correct = 100)	74	72	60	54**	47**	62*	60*	47**	54*
Controls	80.2 (6.7)	75.4 (15)	76 (7.3)	80.2 (6.7)	76 (7.3)	80.2 (6.7)	80.2 (6.7)	80.2 (6.7)	76 (7.3)
Partial report (max. correct = 45)	36	33	37	40	24*	35	35	35	24*
Controls	36.4 (3.2)	36.6 (4.3)	35.2 (4.1)	36.4 (3.2)	35.2 (4.1)	36.4 (3.2)	36.4 (3.2)	36.4 (3.2)	35.2 (4.1)

Note: $*p<.05$, $**p<.01$

Figure 1: Nonword reading accuracy by word reading latency for the TDR children, and 90% confidence intervals. Results for the dyslexic children are also plotted: stars represent dyslexic children with the profile of phonological dyslexia, diamonds represent dyslexic children with the profile of surface dyslexia and hourglass symbols represent dyslexic children with a mixed profile.