

# Difficulties in Lexical Stress Versus Difficulties in Segmental Phonology Among Adolescents With Dyslexia

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Dyslexic difficulties in lexical stress were compared to difficulties in segmental phonology. Twenty-nine adolescents with dyslexia and 29 typically developing adolescents, matched on age and nonverbal ability, were assessed on reading, spelling, phonological and stress awareness, rapid naming, and short-term memory. Group differences in stress assignment were larger than in segmental phonology in reading and spelling pseudowords but not words, indicating a fragility of explicit processes that manipulate stress representations. Despite impaired stress performance in dyslexia at the group level, individual variability failed to reveal evidence for a stress-specific deficit or for a distinct stress-impaired subgroup.

Developmental dyslexia is a specific learning disability characterized by difficulties with accurate and/or fluent word recognition and by poor spelling and decoding abilities. These difficulties are thought to result from a phonological deficit that is unexpected given other cognitive abilities and effective classroom instruction (Lyon, Shaywitz, & Shaywitz, 2003). Two main cognitive processing domains have been identified as relevant for the difficulties observed in dyslexia, namely, segmental phonological processing and rapid naming. In addition, there are indications that the processing of lexical stress may be an additional, potentially independent, domain of impairment. In the present study we examined the relative difficulties in stress versus segmental phonology in the written language skills of a sample of Greek adolescents with dyslexia.

## TWO DOMAINS OF IMPAIRMENT

Converging evidence from longitudinal, concurrent correlational, and training studies suggests that students with dyslexia have difficulties in processing segmental phonology, assessed by phonemic awareness tasks and phonemic accuracy in reading and spelling words and non-words (Bowyer-Crane et al., 2008; Hatcher, Hulme, & Snowling, 2004; Melby-Lervåg, Lyster, &

Hulme, 2012; Torgesen et al., 2001; Wagner & Torgesen, 1987). Phonological awareness (PA) is usually defined as the conscious ability to identify, analyze, and manipulate the sound structure of spoken words at the syllable, onset and rime, and phoneme level. Persisting difficulties at the phoneme level have been observed even among adult students with dyslexia and are viewed as a crucial stumbling block for the development of reading skills throughout the life span (Bruck, 1992). Difficulties of individuals with dyslexia in processing segmental phonology are documented across languages with alphabetic orthographies varying in orthographic transparency (Caravolas, Volin, & Hulme, 2005; Landerl et al., 2013; Paulesu et al., 2001; Ziegler et al., 2010). Given the compelling evidence for difficulties in segmental phonological tasks, researchers have theorized that word-level reading difficulties are manifestations of an underlying deficit in the phonological system of language. Thus, the phonological deficit (Stanovich, 1988; Stanovich & Siegel, 1994) has been viewed as a deficit in the formation, retrieval, and/or maintenance of representations obtained through inefficient phonological processing (Fowler, 1991; Snowling, 2000; Vellutino, Fletcher, Snowling, & Scanlon, 2004).

In alphabetic orthographies, rapid automatized naming (RAN) is another established predictor of reading development and difficulties (Georgiou, Parrila, & Liao, 2008; Georgiou, Torppa, Manolitsis, Lyytinen, & Parrila, 2012; Landerl et al., 2013; Papadopoulos, Georgiou, & Kendeou, 2009; Wolf & Bowers, 1999; Ziegler et al., 2010). RAN is a task in which children name aloud printed sequences of symbols (letters or digits), objects, or colors as quickly as possible. The relationship between RAN and reading fluency has been attributed to the cognitive processes RAN taps, such as the speed of lexical retrieval from long-term memory (e.g., Wimmer, Mayringer, & Landerl, 2000; Wolf & Bowers, 1999), the mediation of orthographic knowledge (Georgiou, Parrila, Kirby, & Stephenson, 2008), or other factors (see reviews in Kirby, Georgiou, Martinussen, & Parrila, 2010; Norton & Wolf, 2012). Wolf and Bowers (1999), in their double-deficit hypothesis, suggested that rapid naming and PA operate as relatively independent domains that are equally important in reading development and contribute to different forms or aspects of dyslexia. Evidence in support of this hypothesis has been obtained in Greek as well (Papadopoulos et al., 2009).

### PROSODY AND STRESS IN DYSLEXIA

The impaired phonological representations in dyslexia are thought to concern the segmental level, that is, the specification of phonemes and of words as sequences of phonemes. An important question is whether the phonological deficit may extend beyond segmental phonology and over suprasegmental (or “prosodic”) features like stress, intonation, pitch, timing, and rhythm. These are features of the phonological system of language that operate at the level of word, phrase, or utterance, concerning linguistic organization over sequences of multiple segments (Fernández & Cairns, 2011; Fox, 2000). Despite extensive research on the role of segmental phonology in the acquisition of literacy skills and in dyslexia, the role of the suprasegmental component remains understudied.

Recent studies have revealed that aspects of prosodic sensitivity may be related to the development of phonological awareness, reading, and spelling skills (Holliman et al., 2014; Holliman, Wood, & Sheehy, 2008; Wood, 2006; Wood & Terrell, 1998; Wood, Wade-Woolley, & Holliman, 2009). The term “prosodic sensitivity” refers to explicit or implicit effects of prosodic features,

in general. It encompasses the more specific term “stress sensitivity,” which refers exclusively to stress, a component of suprasegmental phonology (Fox, 2000; Holliman et al., 2014). Within the stress domain, “lexical stress” refers to differences in relative prominence among syllables within a phonological word, whereas “metrical stress” refers more generally to rhythmic patterns at the phrase level (Goodman, Libenson, & Wade-Woolley, 2010).

In English, Goswami, Gerson, and Astruc (2010) found that prosodic sensitivity and phonological awareness contributed independently to reading and were impaired in 8- to 15-year-old children with dyslexia. They measured prosodic sensitivity using a reiterative speech task, which involves sequences of identical syllables (e.g., “dee”) that retain stress and rhythm patterns of words and phrases in the absence of lexical identity. In a longitudinal study using this task, Goswami et al. (2013) found impaired sensitivity in 9-year-old children with dyslexia and in follow-up 4 years later. Prosodic sensitivity was a longitudinal predictor of reading development, accounting for unique variance beyond sublexical phonological sensitivity (rhyme awareness). In a related study, adults with dyslexia (25–42 years old) performed poorly in stress discrimination tasks, indicating a persistence of stress perception deficits throughout the life span (Leong, Hämäläinen, Soltész, & Goswami, 2011).

Wood (2006) measured metrical stress sensitivity with a mispronounced-word recognition task and found that it accounted for variance in word recognition and spelling development in 5- to 7-year-old children. Using the same task as well as a compound-noun recognition task, Goodman et al. (2010) found that lexical stress but not metrical stress sensitivity was related to PA and early reading ability in kindergarten; however, lexical stress sensitivity did not contribute to reading ability after controlling for PA. Evidence for a link between lexical stress sensitivity and reading performance in first and second graders has also been reported in the transparent Spanish orthography, using a stress-pattern identification task (Gutiérrez-Palma & Palma-Reyes, 2007; Gutiérrez-Palma, Raya-Garcia, & Palma-Reyes, 2009). Notably, all of the aforementioned studies have used tasks requiring participants to pay explicit attention to stress or metrical patterns.

Other approaches have led to mixed results. In the study of Mundy and Carroll (2012) students with dyslexia in higher education showed reduced awareness of both lexical and metrical stress as measured by a reiterative speech task. Both lexical and metrical stress sensitivity were associated with phonological decoding. In contrast, no impairments were detected in a cross-modal fragment priming task, which requires no explicit awareness or manipulation of stress. Subsequently, Mundy and Carroll (2013) used a lexical decision task contrasting items with regular and irregular spelling–stress relationship. This task requires no explicit attention to stress patterns. They did not find differences in the regularity effect between adults with and without dyslexia and concluded that phonological representations in dyslexia are either intact or only very subtly impaired.

In the same vein, Barry, Harboudt, Cantiani, Sabisch, and Zobay (2012) studied adult German-speaking students with reading difficulty, distinguishing tasks directly tapping lexical stress usage from cognitively demanding tasks at the metalinguistic level.<sup>1</sup> No difficulties were observed at the level of lexical stress perception. In contrast, the performance of students with reading difficulties was impaired in two tasks requiring explicit stress awareness: one in which listeners

<sup>1</sup>Metalinguistic tasks require explicit attention to linguistic units or features (e.g., phonemes, words, stress patterns) as objects of manipulation, in contrast to normal language use, in which linguistic features are processed implicitly to support communicative functions.

indicated the location of a word's most prominent syllable, and another in which they judged the appropriateness of stress patterns for their semantic frame.

In sum, performance in tasks requiring explicit attention to stress and other prosodic features has been associated with reading ability or difficulties in several languages and age groups, although adolescents with dyslexia are relatively understudied. It remains unclear whether stress-related performance is specifically affected, beyond well-attested effects in segmental phonology, and whether it affects written language specifically, in terms of stress assignment in reading and spelling.

### LEXICAL STRESS IN GREEK

Greek is particularly suited to the study of stress assignment in reading and spelling because it is a free-stress language and stress is orthographically marked with a special diacritic. Therefore, there is contrastive variation among words and syllables that can be studied and there are visual sources of information that can be manipulated.

In particular, every Greek word with two or more syllables carries stress on a single stressed syllable, which stands out phonetically and phonologically. This syllable must be one of the last three syllables of the word, regardless of how many syllables may precede them (Malikouti-Drachman & Drachman, 1989). Unstressed vowels have lower amplitude and duration than stressed ones but little difference in phonetic quality, exhibiting only limited centralization (Arvaniti, 2007); that is, there is no vowel reduction associated with lack of stress. Greek has relatively few single-syllable content words (less than 2.5% of tokens; Protopapas & Vlahou, 2009). Therefore stress assignment concerns the vast majority of spoken and written content words in typical language use. There are no known segmental or weight constraints on stress assignment in Greek; thus stress is phonologically unpredictable. A relative preponderance of penultimate stress words (about 28% of all word tokens, or 44% of multisyllables; Protopapas, 2006) offers only weak basis for a structural default (Protopapas & Gerakaki, 2009).

The Greek orthography is relatively transparent at the grapheme-phoneme level (estimated consistency 95% for reading and 80% for spelling; Protopapas & Vlahou, 2009). Alphabetic strategies for effective reading of words and pseudowords are observed as early as the middle of first grade, with very high performance (98%) on simple single-syllable items (Seymour, Aro, & Erskine, 2003). Stress is marked with an acute accent on the vowel of the stressed syllable in every word with two or more syllables. Therefore, there is a reliable visual stimulus associated with stress position in the orthography. This diacritic is obligatory, and it is taught at school as part of regular reading instruction starting in Grade 1. Nevertheless, it is demonstrably underutilized by beginning readers (Grades 2–4; Protopapas & Gerakaki, 2009) and early adolescents (Grades 7–9; Protopapas, 2006; Protopapas, Gerakaki, & Alexandri, 2006) in the general student population, as well as by adult skilled readers, who are not delayed in pseudoword naming by the absence of the diacritic (Protopapas, Gerakaki, & Alexandri, 2007). Imperfect utilization of the diacritic in unimpaired populations indicates that it may be difficult to process (Protopapas, 2006; Protopapas & Gerakaki, 2009). If that is the case, one may expect to observe substantial difficulties in stress assignment among students with reading difficulties in addition to the segmental and rapid naming difficulties.

## AIMS AND RESEARCH QUESTIONS

In this study we investigated the role of lexical stress in reading and spelling difficulties among adolescents with dyslexia, focusing specifically on three questions:

1. Do adolescents with dyslexia have difficulties with stress in written language? This is quantified by stress accuracy in reading and spelling tasks.
2. If stress difficulties exist, are they excessive or comparable to difficulties with segmental phonology? This is examined by directly comparing stress and segmental accuracy in reading and spelling tasks.
3. Do the difficulties with stress constitute a distinct domain of performance affecting (some or all) adolescents with dyslexia, or do they belong within a single general phonological and literacy profile? This is assessed by interrelations among stress and segmental accuracy and by their association with stress versus segmental phonological awareness.

## METHOD

### Participants

Participants were 58 Greek students (12–17 years of age) from 50 secondary education schools in northern Greece. The sample included 29 students with developmental dyslexia (9 girls; age  $M = 14;8$  years;months,  $SD = 1;9$ ) and 29 typically developing readers (19 girls; age  $M = 14;9$ ,  $SD = 1;8$ ). They were selected from a larger sample of 75 adolescents (32 with dyslexia) by matching on age and nonverbal ability.

Most participants with dyslexia (19) were recruited through parents' associations. All had received formal diagnosis of developmental dyslexia from official services based on reading, spelling, IQ, and phonological tasks (see Anastasiou & Polychronopoulou, 2009, about dyslexia diagnosis in Greece). All participants were native speakers of Greek and had normal hearing, nonverbal ability at or above the 9th percentile (U.S. norms), no reported neurological or psychiatric disorder, and no history of hearing impairment (parent- and self-report). All participated with parental consent.

### Measures

#### *Nonverbal Ability*

*Raven's Standard Progressive Matrices.* The full 60-item version of the Raven's Standard Progressive Matrices test was used, noting the number of correct choices (raw score) and the percentile (using the detailed norms for the United States; Raven, 1990).

#### *Phonological Awareness*

*Phoneme deletion.* The test (from Protopapas & Skaloumbakas, 2007) included 22 two-syllable and three-syllable nonwords with a high proportion of consonant clusters. In each

nonword one phoneme was the designated target, varying in phoneme type, word position, and syllable position. The nonword was presented orally and, once repeated correctly, was presented again along with the phoneme to be deleted. Participants were asked to repeat the nonword omitting the target phoneme. The correct response was also a nonword. The total number of correct responses was noted.

**Spooonerisms.** The task required the exchange of single initial consonants of pairs of words (e.g., /kalo taksiði/ “have a nice trip” to become nonword pair /talo kaksidi/) presented orally. Two practice items gradually introduced the participant to the task. To reduce memory load, all 12 test items consisted of collocations. One point was given for each correct word per item, for a maximum score of 24.

### RAN

**RAN of letters and digits.** Random sequences of five Greek lowercase letters ( $\alpha$ ,  $\delta$ ,  $\kappa$ ,  $\lambda$ ,  $\sigma$ ) and five digits (1, 2, 5, 7, 9) were printed in 16-point Times Roman on A4 sheets. Each sheet contained 50 stimuli in five rows of 10. After naming the five individual letters or digits, participants were asked to name all items on each sheet in sequence as quickly as possible. Errors and time to complete the task were noted. The total time to complete both sheets was used in the analyses. In this and all other timed tasks, a stopwatch was used to time performance in seconds.

### Short-Term and Working Memory

**Digit span.** The Digit Span subscale from the Greek standardized version of the Wechsler Intelligence Scale for Children, Third Edition (Georgas, Paraskevopoulos, Bezevegis, & Giannitsas, 1997) was used, including forward and backward span, following standard administration procedure and termination criterion. Participants repeated strings of digits, in forward and backward tasks, presented at a rate of one digit per second. The total number of sequences reproduced correctly (raw score) was noted.

### Stress Awareness

**Stress pattern identification.** The task included 15 nonwords consisting of three repetitions of the same syllable (e.g., /lololo/, /tatata/), presented orally. Stress was equally distributed across the three syllables. For each nonword, the participant was asked to indicate the position of the stress with their finger or by drawing a vertical line on one of three lines (\_\_\_ \_\_\_ \_\_\_) drawn to represent the syllables. The total number of correct responses was noted.

**Diacritic placement.** The stimuli were 54 familiar Greek words (27 three-syllabic and 27 four-syllabic, five to 11 letters long, from Protopapas & Gerakaki, 2009; all appearing in the elementary school language textbooks), printed without stress diacritics in lowercase 14-point Times Roman in two columns on one sheet. Stress was equally distributed across the three final syllables. Participants were asked to place stress diacritics on the words. The total number of correct responses and the time to complete the task was noted.

### *Literacy*

*Word reading.* Participants were asked to read aloud a list of 53 words presented in two columns on two A4 sheets. For segmental accuracy, 1 point was given for each word pronounced with the correct phoneme sequence, irrespective of stress. For stress accuracy, 1 point was given for each word stressed on the correct syllable, ignoring phonemic errors. In addition, the total time to read the entire word list was noted.

*Word spelling.* A list of 50 words (based on Sideridis, Mouzaki, Protopapas, & Simos, 2008) was dictated at a pace determined by the child's writing. Words were chosen to be frequent and to include several morphological (on prefixes and suffixes) and orthographic (on word roots) spelling patterns. For segmental accuracy, 1 point was given for each word spelled with the correct letter sequence, regardless of stress. For stress accuracy, 1 point was given for each word spelled with the diacritic placed over the correct vowel, ignoring letter errors.

*Reading comprehension.* Two passages, one narrative and one expository, 367 and 369 words long, were read aloud by the students. After reading each passage, seven multiple-choice questions (with three distractors) were asked, assessing (a) integration of previous knowledge with information in the text, (b) recall of essential pieces of information in the text, and (c) inferences based on information provided in the text (Hannon & Daneman, 2001). One point was given for each correct response. In addition, the total time to read both passages was noted.

### *Phonological Decoding*

*Nonword reading.* A list of 30 nonwords two to five syllables long (from Protopapas et al., 2006, Table A2) was printed in two columns. Diacritics were used, as in words, to indicate stress placement. Participants were asked to read aloud the nonwords. Segmental and stress accuracy were scored as for word reading.

*Nonword spelling.* A list of 27 nonwords three syllables long (from Protopapas & Gerakaki, 2009) was dictated at a pace determined by the child's writing. All nonwords were derived from existing Greek words by replacing consonants. Segmental and stress accuracy were scored as for word spelling, except that all legal graphemic transcriptions of dictated phonemes were considered correct.

*Cued nonword spelling.* This task was identical to (uncued) nonword spelling, using a different list of 27 nonwords four syllables long, except that at the beginning of the task the experimenter cued attention on stress by asking the participant to make sure that they have placed the stress diacritics correctly on the nonwords. This manipulation was meant to ensure that participants were aware of the importance of stress diacritics and would not forget them or strategically ignore them to emphasize letter graphemes.

### *Procedure*

Participants were tested individually at home by specially trained senior undergraduate research assistants. Testing lasted approximately two 50-min periods, with a break in between. Additional

breaks were provided when participants became tired. The phonological awareness measures were administered first, followed by the word and text reading tasks, the rapid naming tasks, word spelling, nonword reading, Raven’s matrices, nonword spelling tasks (uncued and cued), diacritic placement, stress pattern identification, and finally the digit span.

RESULTS

Figure 1 displays the data from all the demographic and profile variables by participant group; descriptive statistics are listed in Table 1. As ensured by the matching process, the two groups did not differ in age,  $F(1, 56) = 0.10, p = .758, \eta^2_G = .002$ ; grade,  $F(1, 56) = 0.02, p = .875,$

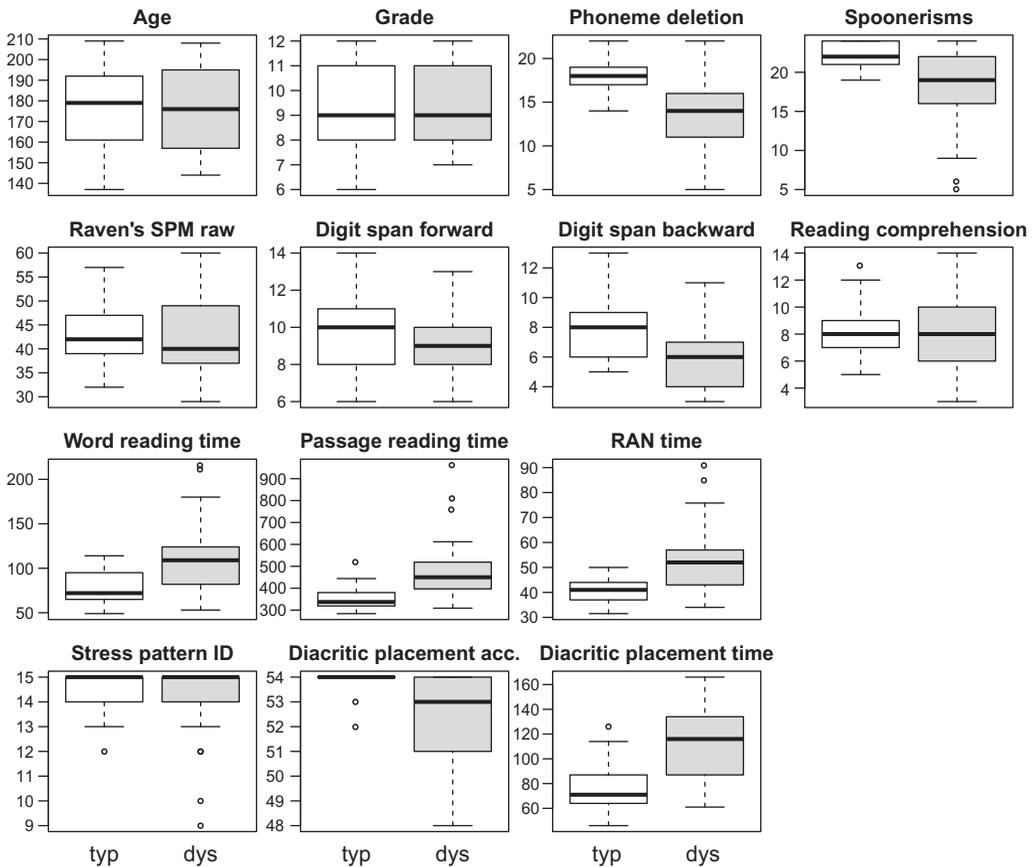


FIGURE 1 Performance in demographic, cognitive, and timed reading measures by group (unfilled boxes for the typically developing group [typ], gray boxes for the group with dyslexia [dys]). Boxes enclose the middle 50% of the data. The median is denoted by a thick horizontal line. See Method section and Table 1 for units. SPM = Standard Progressive Matrices; RAN = rapid automatized naming.

<sup>2</sup>Effect sizes are reported as generalized eta square (Bakeman, 2005; Olejnik & Algina, 2003), provided by R package ez (Lawrence, 2012).

TABLE 1  
Descriptive Statistics for All Profile and Experimental Measures

Measure	i	$\alpha$	Typically Developing					Dyslexia				
			M	SD	Mdn	Skew	Kurt.	M	SD	Mdn	Skew	Kurt.
Age (months)			177.17	19.68	179	0.00	-1.12	175.52	21.07	176	0.11	-1.54
Grade			9.31	1.65	9	-0.02	-1.03	9.38	1.68	9	0.29	-1.32
Phoneme deletion	22	.78	18.34	2.07	18	0.20	-0.74	13.62	4.03	14	-0.04	-0.68
Spoonerisms	12	.83	22.17	1.69	22	-0.65	-0.79	18.00	5.15	19	-1.08	0.24
Raven's SPM (raw)	60		43.10	6.52	42	0.38	-0.64	42.90	7.94	40	0.35	-0.88
Digit span forward (raw)	16		9.46	2.19	10	-0.03	-0.83	9.07	1.93	9	0.20	-0.91
Digit span backward (raw)	14		8.17	2.35	8	0.46	-0.65	5.97	2.08	6	0.53	-0.55
Reading comprehension	14		8.10	1.88	8	0.45	0.26	8.10	2.82	8	0.12	-0.50
Word reading time (s)			77.00	18.30	72	0.59	-0.88	110.21	42.99	109	0.84	0.08
Passage reading time (s)			351.14	48.80	337	1.56	2.62	492.28	155.56	450	1.42	1.59
RAN time (s)			41.31	5.19	41	0.03	-1.10	52.38	13.74	52	1.09	0.95
Stress pattern identification	15	.66	14.62	0.73	15	-2.02	3.81	14.07	1.58	15	-1.79	2.47
Diacritic placement (accuracy)	54	.67	53.76	0.58	54	-2.13	3.30	52.38	2.01	53	-1.04	-0.16
Diacritic placement time (s)			77.69	19.40	71	0.74	-0.25	109.55	29.40	116	-0.09	-1.15
<i>Word reading</i>												
Segmental accuracy	53	.80	51.76	1.57	52	-1.47	1.56	47.41	3.97	48	-0.66	-0.37
Stress accuracy	53	.63	52.83	0.66	53	-3.45	10.78	50.69	1.85	51	-0.31	-1.22
<i>Word spelling</i>												
Segmental accuracy	50	.95	45.03	3.90	46	-0.93	0.08	26.72	7.89	26	0.54	-0.50
Stress accuracy	50	.98	49.31	1.56	50	-2.68	6.29	38.45	14.82	45	-1.22	0.33
<i>Pseudoword reading</i>												
Segmental accuracy	30	.74	27.28	2.14	27	-0.71	-0.27	23.00	3.81	23	-0.69	0.10
Stress accuracy	30	.91	29.00	1.81	30	-2.99	10.25	21.76	5.96	23	-0.07	-1.55
<i>Pseudoword spelling</i>												
Segmental accuracy	27	.68	25.59	1.78	26	-1.50	1.67	23.76	2.65	24	-1.02	0.69
Stress accuracy	27	.98	26.45	1.72	27	-4.08	16.95	17.38	10.32	21	-0.77	-1.11
<i>Cued pseudoword spelling</i>												
Segmental accuracy	27	.60	24.93	1.93	25	-0.98	0.09	23.03	2.64	24	-0.91	-0.07
Stress accuracy	27	.97	26.62	0.73	27	-2.02	3.81	22.10	7.40	25	-1.74	2.06

Note. *i* = number of items;  $\alpha$  = Cronbach's coefficient of reliability; SPM = Standard Progressive Matrices; RAN = rapid automatized naming.

$\eta^2_G < .001$ ; or Raven's matrices, raw score:  $F(1, 56) = 0.01, p = .914, \eta^2_G < .001$ ; percentile score:  $F(1, 56) = .04, p = .833, \eta^2_G < .001$ . Moreover, the groups did not differ in reading comprehension,  $F(1, 56) = 0, p = 1, \eta^2_G = 0$ , or digit span forward, raw score:  $F(1, 55) = 0.53, p = .471, \eta^2_G = .009$ . As expected, the groups differed significantly in the phonological awareness measures, namely, phoneme deletion,  $F(1, 56) = 31.50, p < .001, \eta^2_G = .360$ , and spoonerisms,  $F(1, 56) = 17.19, p < .001, \eta^2_G = .235$ , as well as in word reading time,  $F(1, 55) = 14.21, p < .001, \eta^2_G = .205$ ; passage reading time,  $F(1, 52) = 21.48, p < .001, \eta^2_G = .292$ ; and rapid naming,  $F(1, 56) = 16.44, p < .001, \eta^2_G = .227$ . The groups also differed in digit span backward, raw score:  $F(1, 56) = 14.38, p < .001, \eta^2_G = .204$ , and in stress diacritic placement, accuracy:  $F(1, 56) = 12.65, p < .001, \eta^2_G = .184$ ; time:  $F(1, 56) = 23.73, p < .001, \eta^2_G = .298$ . The difference in stress pattern identification was marginal,  $F(1, 56) = 2.92, p = .09, \eta^2_G = .050$ ,<sup>3</sup> apparently due to a few low-performing participants with dyslexia. Thus, a typical dyslexic profile was revealed, with phonological, reading fluency, and spelling deficits, as well as some evidence for impaired stress awareness.

Figure 2 shows the segmental and stress accuracy performance of the two groups in the reading and spelling tasks. To examine differences between groups and error types, trial-level data were submitted to generalized linear mixed-effects modeling for binomial distributions (Dixon, 2008) via a logit transformation (Jaeger, 2008) with maximal random structures (Barr, Levy, Scheepers, & Tily, 2013) including crossed random effects of participants and items, using function `lmer` of the `lme4` package (Bates, Maechler, & Bolker, 2012) in R (R Core Team, 2012). Models were specified in R notation as

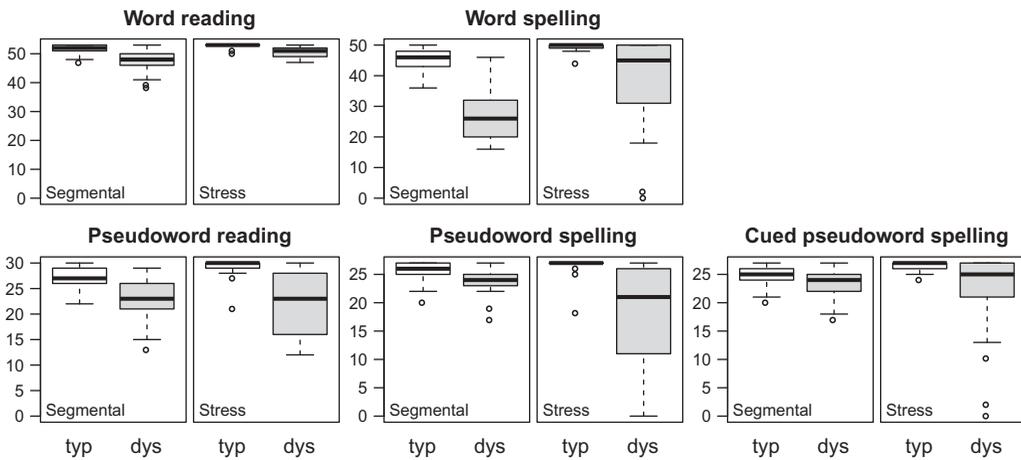


FIGURE 2 Segmental and stress accuracy (raw number of correct items) in the reading and spelling measures by group (unfilled boxes for the typically developing group [typ], gray boxes for the group with dyslexia [dys]). Boxes enclose the middle 50% of the data. The median is denoted by a thick horizontal line. The vertical axis corresponds to the entire possible performance range (0–100%) in each case.

<sup>3</sup>Not significant by the low-power nonparametric Mann-Whitney test ( $W = 482.5, p = .250$ ) but significant by the more powerful generalized (via logit) mixed-effects modeling ( $\hat{\beta} = 2.98, z = 2.90, p = .004$ ).

$$\text{accu} \sim \text{group} * \text{type} + (\text{type} | \text{subject}) + (\text{group} * \text{type} | \text{item}),$$

with response accuracy (correct/incorrect) as the dependent variable, group (typical/dyslexia) and type (segmental/stress) as fixed-effects factors, and participant and item as random-effects (grouping) factors. Asterisks indicate fully interacting effects, whereas crosses indicate additive effects. This analytic approach allows generalization over both sampling populations (participants and items) and is not severely limited by ceiling effects (observed especially in control group accuracy).

Table 2 lists the results of these analyses. For word reading and word spelling there was no interaction, suggesting that the difference between participants with and without dyslexia in segmental accuracy was comparable to their difference in stress accuracy. In both tasks, accuracy was lower for participants with dyslexia compared to typically developing learners. For both groups stress accuracy was higher than segmental accuracy. In contrast, there was a significant interaction between group and type in all pseudoword tasks, consistent with an increased difference between participants with and without dyslexia in stress accuracy relative to segmental accuracy. This difference may have been somewhat less pronounced in the cued spelling task, compared to uncued spelling, as the three-way interaction in a follow-up analysis including both pseudoword spelling tasks was marginally significant ( $\hat{\beta} = 2.27$ ,  $z = 1.89$ ,  $p = .059$ ). In all three nonword tasks accuracy was lower for participants with dyslexia. For participants without dyslexia stress accuracy was higher than segmental accuracy (error type effect in Table 2). In contrast, for participants with dyslexia stress accuracy was lower (spelling:  $\hat{\beta} = 1.39$ ,  $z = 2.00$ ,  $p = .045$ ) or there was no difference (reading:  $\hat{\beta} = 0.21$ ,  $z = .67$ ,  $p = .502$ ; cued spelling:  $\hat{\beta} = 0.84$ ,  $z = 1.63$ ,  $p = .103$ ).

Table 3 lists the correlations among naming, reading, spelling, and awareness measures in the group of participants with dyslexia. Nonparametric coefficients were calculated due to severe skew in some measures. Despite several statistically significant correlations between similar tasks, no overall stress-related pattern seems to emerge encompassing both reading and spelling. Stress assignment accuracy in reading was correlated with phoneme deletion rather than with a stress awareness measure.

To examine whether low stress accuracy is associated with a particular deficit profile we selected participants with dyslexia on the basis of relatively low performance in rapid naming

TABLE 2  
Group  $\times$  Error Type Comparisons in Reading and Spelling Accuracy

Measure	Effect of Group			Effect of Error Type			Interaction		
	$\hat{\beta}$	$z$	$p$	$\hat{\beta}$	$z$	$p$	$\hat{\beta}$	$z$	$p$
Word reading	-2.17	-6.41	<.001	2.49	3.59	<.001	-1.16	-1.56	.120
Word spelling	-3.41	-10.67	<.001	3.06	4.01	<.001	-0.77	-0.86	.389
Pseudoword reading	-1.19	-5.48	<.001	2.13	5.25	<.001	-1.92	-4.02	<.001
Pseudoword spelling	-0.87	-2.84	.004	1.03	2.37	.018	-2.37	-4.48	<.001
Cued pseudoword spelling	-0.75	-3.07	.002	4.31	5.20	<.001	-3.48	-3.77	<.001

Note. Results of generalized linear mixed-effects modeling for binomial distributions with crossed random effects for participants and items. Effect of group, estimated for segmental accuracy; effect of error type, estimated for typical readers; interaction, stress accuracy for participants with dyslexia. Group: readers with versus without dyslexia; Error type: stress versus segmental accuracy.

TABLE 3  
Correlations (Spearman's  $\rho$ ) Between Tasks in the Participant Group With Dyslexia

	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1 Rapid naming	-.15	-.09	.25	-.19	.05	-.18	-.17	-.28	-.01	-.16	.46*	-.25	.24	-.10
2 Phoneme deletion		.47*	-.04	.01	.25	.45*	.08	-.04	.28	.04	-.11	-.19	-.38*	-.05
3 Spoonerisms			-.03	.06	.03	.21	.48**	.04	.06	-.06	.10	.08	-.26	.00
4 Diacritic placement				.10	.02	.22	.32	.52**	.28	.21	.12	.45*	.07	.51**
5 Stress pattern identification					-.17	-.02	.22	.18	.29	.21	.23	-.08	.30	.44*
<i>Word reading</i>														
6 Segmental accuracy						.54**	.01	-.13	.19	.03	-.32	-.12	-.17	-.16
7 Stress accuracy							.29	.26	.37	.48**	-.17	.28	-.07	.19
<i>Word spelling</i>														
8 Segmental accuracy								.40*	.04	.20	-.16	.46*	-.05	.21
9 Stress accuracy									.10	.41*	.07	.82**	-.05	.67**
<i>Pseudoword reading</i>														
10 Segmental accuracy										.39*	.10	.08	.09	.23
11 Stress accuracy											.01	.42*	.23	.23
<i>Pseudoword spelling</i>														
12 Segmental accuracy												.11	.26	.32
13 Stress accuracy													.00	.53**
<i>Cued pseudoword spelling</i>														
14 Segmental accuracy														.25
15 Stress accuracy														

Note.  $N = 29$ .

\* $p < .05$ . \*\* $p < .01$ .

(two RAN tasks), PA (phoneme deletion and spoonerisms), or stress awareness (stress pattern identification and diacritic placement). For each of these three domains,  $z$  scores from the two corresponding tasks were calculated, for the group with dyslexia only. The average of the two  $z$  scores was then split on the median<sup>4</sup> to produce “high” and “low” performance subgroups for each domain. The concordance<sup>5</sup> among the three classifications was very low ( $\kappa = .031$ ; not significantly different from zero:  $z = 0.29, p = .77$ ).

Each grouping was used as a between-participants factor in a new set of analyses involving only participants with dyslexia, comparing high to low performers (separately in the three domains). The dependent variables were stress and segmental accuracy in the word and pseudoword reading and spelling tasks (two error types by five tasks, for a total of 10 comparisons for each grouping). Table 4 lists the results of these analyses. Low rapid naming performance was associated only with low segmental accuracy in pseudoword spelling. Low PA was barely associated with low segmental accuracy in uncued pseudoword spelling. Stress awareness was associated with both segmental and stress accuracy in word spelling and with segmental accuracy in uncued pseudoword spelling and stress accuracy in cued pseudoword spelling. Only the latter difference would survive Bonferroni correction for 10 comparisons (per grouping; none of the differences would survive correction for all 30 comparisons).

TABLE 4  
Accuracy Differences Between Subgroups of Participants With Dyslexia Formed by Median Splits in Three Performance Domains

Measure	Rapid Naming			Phonological Awareness			Stress Awareness		
	$\hat{\beta}$	$z$	$p$	$\hat{\beta}$	$z$	$p$	$\hat{\beta}$	$z$	$p$
<i>Word reading</i>									
Segmental accuracy	-0.59	-1.55	.122	-0.36	-1.00	.318	0.50	1.42	.156
Stress accuracy	-0.26	-0.60	.547	-0.38	-1.09	.278	-0.59	-1.56	.120
<i>Word spelling</i>									
Segmental accuracy	0.06	0.14	.885	-0.56	-1.45	.147	-0.95	-2.62	.009
Stress accuracy	0.80	0.61	.540	-0.64	-0.53	.596	-2.71	-2.37	.018
<i>Pseudoword reading</i>									
Segmental accuracy	-0.22	-0.79	.429	-0.27	-1.00	.315	-0.27	-0.91	.364
Stress accuracy	0.15	0.28	.779	0.08	0.15	.883	-0.31	-0.57	.568
<i>Pseudoword spelling</i>									
Segmental accuracy	-1.21	-3.19	.001	-0.79	-2.06	.040	-0.85	-2.20	.028
Stress accuracy	1.39	1.00	.317	-1.60	-1.20	.231	-1.43	-1.03	.305
<i>Cued pseudoword spelling</i>									
Segmental accuracy	-0.68	-2.40	.016	0.44	1.43	.152	-0.49	-1.60	.109
Stress accuracy	-0.03	-0.02	.983	-1.60	-1.36	.175	-3.18	-3.05	.002

*Note.* Subgroups formed by median splits on average  $z$  scores in two measures for each domain (see text for details). Results of generalized linear mixed-effects modeling for binomial distributions with crossed random effects for participants and items. Negative coefficients indicate lower accuracy of the low-performance subgroup.

<sup>4</sup>A first-quartile split produced the same pattern of results as the median split.

<sup>5</sup>Concordance was quantified with Fleiss's (1971) kappa using R package irr (Gamer, Lemon, Fellows, & Singh, 2012).

To ensure that the median split did not obscure patterns of extreme difficulty we examined the performance of the two individuals with dyslexia who scored outside the range of the control group in stress pattern identification (arguably a direct if explicit test of stress sensitivity). Their median ranks<sup>6</sup> within the group with dyslexia in the reading and spelling measures were 13 and 23 for segmental accuracy (range = 2–26.5 and 10–27.5, respectively) and 18.5 and 11 for stress accuracy (range = 1–24.5 and 9–24.5). Thus, there is no evidence that these “stress outliers” exhibited systematically low performance in stress-related reading and spelling tasks.

## DISCUSSION

In this study we focused on stress assignment performance and its relation to literacy and phonological awareness measures. Our experimental group came from a well-characterized sample of adolescents with dyslexia exhibiting a typical dyslexic profile. This profile includes deficits with large effect sizes in PA, rapid naming, reading fluency, and spelling but no deficits in nonverbal intelligence, short-term memory, or reading comprehension. This profile is consistent with previous reports in Greek (for younger children: Protopapas & Skaloumbakas, 2007, 2008; Protopapas, Skaloumbakas, & Bali, 2008) and other languages with relatively transparent orthographies (Landerl et al., 2013; Ziegler et al., 2010). Notably, substantial deficits in phonological awareness were observable in secondary education, despite the relatively high transparency of the Greek orthography, presumably due to the demanding design of the spoonerism and phoneme deletion tasks (cf. de Jong & van der Leij, 2003; van der Leij & Morfidi, 2006). There was no significant concordance between particularly low performance in rapid naming, PA, and stress awareness in the group with dyslexia, consistent with a view in which they constitute separable domains of skill (or risk).

The first question addressed in our study concerns the existence of stress deficits in the written language performance of adolescents with dyslexia, for which a clear positive answer emerged from the data. As a group, participants with dyslexia exhibited significantly impaired performance in measures of stress assignment accuracy, in both reading and spelling, using both words and pseudowords. Significant deficits were also observed in the diacritic placement task, in both accuracy and time, consistent with a genuine impairment rather than a strategic speed-accuracy trade-off. The effect size in diacritic placement time exceeded that of word reading time, despite the lack of word production requirements, suggesting that the observed difference cannot be attributed entirely to the reading demands of the task but at least in part to stress assignment processes. Results from the stress pattern identification task were less clear-cut, perhaps because this was an easier task overall. Still, there was an increased proportion of participants with dyslexia toward the lowest levels of recorded performance.

Widespread neglect of the diacritic in Greek children’s spelling has been previously reported (Protopapas, Fakou, Drakopoulou, Skaloumbakas, & Mouzaki, 2013). In that study, a nonnegligible proportion of younger (Grades 3–4) children from the general population, without reading difficulties, was found to underutilize the stress diacritic in spelling. In the older (Grade 7) group, only children with a diagnosis of dyslexia or with poor reading performance were found

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<sup>6</sup>A rank of 1 corresponds to lowest performance and a rank of 29 to highest.

to consistently omit or otherwise misuse the diacritic in spelling. The present study confirms that diacritic placement remains a persistent spelling problem in the manifestation of dyslexia in Greek throughout secondary education.

Stress assignment problems in word reading are less commonly reported. In a study of Grade 7 general school population, stress assignment errors in word reading were infrequent (fewer than segmental errors) whereas in pseudoword reading they were much more numerous (and more than segmental errors; Protopapas, 2006). Gerakaki and Protopapas (2006) examined stress assignment errors in word and pseudoword reading in subgroups selected for their low performance in reading fluency and spelling, compared to the general population. For the older children (Grade 7) performance was only slightly impaired, whereas for the younger children (Grades 3–4) effect sizes for stress accuracy exceeded those for segmental accuracy. The present study extends the findings to adolescents with diagnosed dyslexia and confirms that stress assignment errors are observed in their reading performance significantly more often than in the control group. This is consistent with their reading impairment insofar as stress assignment is a subcomponent of reading.

The second question addressed in this study concerns relative prominence: Is stress accuracy affected more than segmental accuracy? For word reading and spelling, our data have provided a negative answer to this question. However, for pseudoword reading and spelling it seems that stress accuracy was significantly more impaired than segmental accuracy in adolescents with dyslexia. This pattern of findings can be interpreted by taking into account that (a) stress patterns of words are supported by representations in the mental lexicon, whereas pseudowords must stand on their own in verbal working memory; and (b) stress assignment decoding processes are cognitively costly and largely unpracticed (Protopapas, 2006; Protopapas & Gerakaki, 2009) because stress assignment in reading is primarily based on the lexicon (Protopapas & Gerakaki, 2009; Protopapas et al., 2006, 2007) and the decoding of diacritic is usually unnecessary for lexical access (Protopapas, 2006). The difficulty of stress assignment is exacerbated by inefficient verbal working memory, resulting in compounded deficits. In comparison, unimpaired readers have more efficient stress assignment and verbal working memory processes, hence no particular difficulty with nonwords.

Ramus and Szenkovits (2008) addressed the nature of the purported phonological deficit in dyslexia and concluded in favor of intact phonological representations, including an intact phonological mental lexicon. They attributed poor dyslexic performance in phonological processing tasks to deficits in the cognitive processes that access and manipulate those representations. According to this account, task requirements such as explicit manipulation or increased memory load limit the performance of individuals with dyslexia. Our findings are consistent with this approach insofar as tasks with pseudowords can be thought to place disproportionate burden on working memory to hold the unfamiliar stimuli before spelling or pronouncing them, thus taking resources away from the cognitively demanding task of stress assignment (in reading) or diacritic placement (in spelling). This theoretical interpretation posits no specific difficulty or impairment in the stress domain beyond the cognitive load associated with explicit processing of stress patterns.

The third question concerns the specificity of stress assignment problems. Is stress a distinct domain of performance that may be affected in adolescents with dyslexia, or are the observed impairments in stress assignment simply part and parcel of a general literacy profile? Evidence for a distinct domain is provided by the lack of concordance between the PA, rapid naming,

and stress awareness groupings. If the adolescents with lowest performance in the stress awareness tasks are not the same as those with the lowest performance in the segmental awareness tasks, then perhaps there are two different kinds of potential impairments. However, this conclusion is unwarranted because the three groupings did not differentially predict performance along the corresponding dividing lines. That is, although low stress awareness was associated with poor stress spelling accuracy, it was not similarly associated with poor stress reading accuracy. Thus the association with spelling may be attributed to the nature of the diacritic placement task, which—beyond its reading component—can be conceived of as a kind of a spelling task. There is no evidence from Table 3 that the observed correlations among stress accuracy measures go beyond the reading–spelling divide; instead, the patterns seem fully attributable to task method variance rather than some latent construct related to stress representation or stress processing skill. Unfortunately the present sample was too small to explore the pattern of correlations with multivariate dimensionality reduction techniques.

It must be emphasized that our stress awareness tasks made explicit requirements on stress (or diacritic) manipulation, therefore they constitute meta-linguistic rather than linguistic assessments of stress-related performance (see Ramus & Szenkovits, 2008). Therefore, even though impaired performance was observed in stress-related measures, it cannot be concluded that Greek children with dyslexia have reduced sensitivity to (oral) stress patterns or impaired stress processing. There is no evidence from tasks requiring implicit use—rather than explicit judgment or manipulation—of stress representations that children with dyslexia are impaired in the domain of stress. Thus, our findings are consistent with the general pattern in the literature whereby “stress impairments” in dyslexia are observed using meta-linguistic tasks involving explicit identification, comparison, or manipulation of stress patterns (Barry et al., 2012; Goswami et al., 2010; Goswami et al., 2013; Leong et al., 2011; Mundy & Carroll, 2012; Soroli, Szenkovits, & Ramus, 2010). If “sensitivity” is conceptualized as an index of explicit awareness and task performance, rather than concerning the integrity of underlying linguistic representations, our findings may be related to approaches positing domain-specific links between prosodic sensitivity and reading. For example, the ability to attend to linguistic objects, such as words and phrases, and to their components and features, such as phonemes and stress patterns, may proceed in a developmental sequence linking early rhythmic awareness to later phoneme identification (as in Pathway 3 of Wood et al., 2009).

A limitation of the present study that needs to be addressed in future approaches concerns the assessment of stress awareness. Our tasks (stress pattern identification and diacritic placement) used a response format similar or identical to the orthographic convention of the diacritic, differing primarily in stimulus delivery (oral vs. written) and lexicality (pseudowords formed by syllable repetition vs. known words). For the purpose of relating to stress performance in reading and spelling this choice strengthens our aforementioned conclusions because it overlaps not only in the hypothetical stress performance domain but also in the orthographic aspect. However, for a literacy-neutral assessment of stress awareness, focused on spoken language, different tasks must be used. Finally, timed tasks may be more effective in bringing out minor weaknesses in stress sensitivity, because task demands may be relatively low for accuracy measures like stress pattern identification, at least for adolescents.

In conclusion, we have examined stress-related performance in adolescents with a typical dyslexic profile in cognitive and literacy measures, including impairments in PA and rapid naming. Our findings showed stress assignment impairments in reading and spelling that exceeded

segmental deficits in pseudoword tasks. In contrast, when reading or spelling words, stress accuracy was commensurate with segmental accuracy. Low performance in explicit manipulation of the stress diacritic was also observed. These deficits did not cluster around some general stress deficit and did not characterize any particular subgroup of participants. Although individuals having specific pronounced difficulties with stress in general may exist, this is not the typical situation of Greek adolescents with dyslexia. There was no evidence for impaired representations of stress in the mental lexicon. This pattern of results is interpreted as consistent with impairments in explicit metalinguistic manipulation of phonological components, including segmental and stress patterns.

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