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Spelling-stress regularity effects are intact in developmental dyslexia

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Abstract

The current experiment investigated conflicting predictions regarding the effects of spelling-stress regularity on the lexical decision performance of skilled adult readers and adults with developmental dyslexia. In both reading groups, lexical decision responses were significantly faster and significantly more accurate when the orthographic structure of a word ending was a reliable, as opposed to an unreliable, predictor of lexical stress assignment. Furthermore, the magnitude of this spelling-stress regularity effect was found to be equivalent across reading groups. These findings are consistent with intact phoneme-level regularity effects also observed in dyslexia. The paper discusses how findings of intact spelling-sound regularity effects at both prosodic and phonemic levels, as well as other similar results, can be reconciled with the obvious difficulties that people with dyslexia experience in other domains of phonological processing.

Keywords: Dyslexia, lexical stress, spelling-sound regularity

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Spelling-stress regularity effects are intact in developmental dyslexia

Theoretical accounts of reading and reading disability have long emphasised the importance of phoneme awareness and phonological recoding skills in literacy development (Mattingly, 1972; Vellutino, 1977; 1979). A basic experimental finding that demonstrates the role of phonological recoding in reading is the regularity effect; a tendency for low-frequency monosyllabic words in which spelling-sound mappings violate pronunciation rules (irregular words: e.g. *aisle*; *sword*; *yacht*) to be read more slowly than those with regular spelling-sound mappings (Seidenberg, Waters, Barnes, & Tanenhaus, 1984).

In recent years researchers have begun to expand theoretical models of the reading process in order to address the additional challenges associated with decoding multisyllabic words (Arciuli, Monaghan & Ševa, 2010; Perry, Ziegler & Zorzi, 2010; Ševa, Monaghan & Arciuli, 2009). The spelling-sound consistency of several intra- and inter-syllabic units has been shown to affect naming latencies for English disyllables (Chateau & Jared, 2003; Yap & Balota, 2009).

Spelling-stress regularity in multisyllabic word reading

When presented with a multisyllabic word, in addition to decoding the segmental phonology of the letter string, the reading system must also correctly assign a lexical stress pattern. For example, readers must learn to produce a strong-weak (trochaic) pronunciation in the case of *cóllege* as opposed to a weak-strong (iambic) pronunciation in the case of *colláte*. Corpus analyses of English disyllables indicate that the number of consonants in word onset position (Kelly, 2004) and the spelling patterns of word endings (Kelly, Morris & Verrekia, 1998) are highly predictive of lexical stress assignment. For example, word endings such as –*ette, –que* and *–umb* are strongly associated with iambic stress (e.g. *cassétte; physíque;*

succúmb). More recent corpus analyses have indicated that orthographic cues to lexical stress assignment are present in the reading materials of children aged 5-12 years and that the constraining influence of word endings relative to word onsets increases with age (Arciuli et al., 2010). Researchers have also demonstrated a relationship between grammatical category and lexical stress, with iambic stress assignment found to be more common in verbs, and trochaic stress more common in nouns (Arciuli & Cupples, 2006; 2007). Orthographic cues present in word endings and – to a lesser extent – word onsets are important sources of grammatical category information (Arciuli & Monaghan, 2009).

Behavioural data confirm that typically developing children and skilled adult readers utilise spelling-sound relationships to guide stress assignment and that the regularity of the spelling-stress relationship influences naming and lexical decision performance. Kelly and colleagues (1998) devised a lexical decision task contrasting words in which the orthographic structure of the final syllable was a reliable indicator of lexical stress assignment (e.g. the iambic *cassétte* and the trochaic *péllet*) with words in which the orthographic structure of the final syllable was an unreliable indicator of lexical stress assignment (e.g. the iambic *cadét* and the trochaic *pálette*). Participants' lexical decision times were significantly shorter, and error rates significantly lower, for words in which orthography was a reliable indicator of stress assignment. Arciuli and Cupples (2006) utilised the relationship between orthography, grammatical category, and stress assignment to define stress regularity. In both naming and lexical decision, skilled adult readers produced significantly more errors in response to atypically stressed words (i.e. iambic nouns and trochaic verbs) than in response to typically stressed words (i.e. trochaic nouns and iambic verbs).

Analogous findings have also been reported for Italian words in which stress neighbourhoods have been used to define the relationship between orthographic structure and stress assignment. Stress friends are words which share the same final syllable, the same vowel in the penultimate syllable and the same pattern of lexical stress assignment (e.g. *allóro; ristóro*). In contrast, stress enemies are words which share the same final syllable and the same vowel in the penultimate syllable but differ in lexical stress assignment (e.g. *fucíle; fértile*). Studies of skilled adult readers (Colombo, 1992) and typically developing children (Paizi, Zoccolotti & Burani, 2011) have shown that words with large stress neighbourhoods (i.e. a large proportion of stress friends) show a naming advantage over words with small stress neighbourhoods.

Orthographic onsets (Kelly, 2004) and endings (Arciuli & Cupples, 2006; Smith & Baker, 1976) have also been shown to guide stress assignment in nonword reading. Most recently, Arciuli et al. (2010) reported that a large sample of children aged 5-12 years assigned stress to nonword items in accordance with spelling-stress relationships and that older children showed a greater preference for ending cues over onset cues in accordance with the lexical statistics of different age-appropriate corpora.

Modelling spelling-stress regularity effects

In the context of monosyllabic word reading, the dual route model (Coltheart, 1978; Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001) gives a straightforward account of spelling-sound regularity effects. Specifically, low-frequency words with irregular spelling-sound mappings elicit conflicting pronunciations from the lexical and sub-lexical reading mechanisms hypothesised in the model. The extra time and effort required to resolve such a conflict accounts for participants' poorer performance with irregular words.

Researchers have also proposed several mechanisms via which lexical stress may be assigned during multisyllabic word reading. These include a sub-lexical mechanism, required for assigning stress to nonwords, in which stress assignment is supported by learned spelling-sound mappings, and a lexical mechanism, required for reading irregularly stressed words (e.g. *hotél*), in which the correct stress pattern is retrieved from the mental lexicon (Colombo, 1992; Colombo & Zevin, 2009). Lexical and sub-lexical routes to stress assignment are implemented in the Connectionist Dual Process model (CDP++) and have allowed the successful simulation of stress regularity effects in a comparable manner to those operating at the grapheme-phoneme level (Perry et al., 2010).

The sub-lexical route specified in the CDP++ and other recent models (e.g. Ševa et al., 2009) also simulates the acquisition of spelling-stress correspondences. This is achieved by training a connectionist network to associate orthographic cues with distinct patterns of lexical stress assignment and is directly comparable to the learning of grapheme-phoneme correspondences (Perry et al., 2010). These models assign stress to words and nonwords with a high degree of accuracy and, like typically developing children, adapt to changes in the input statistics of different age-appropriate corpora to place increasing emphasis on word ending cues (Arciuli et al., 2010).

Regularity effects and developmental dyslexia

The phonological representations hypothesis (Fowler, 1991; Snowling, 2000) argues that the proximal cause of reading impairment in dyslexia is a failure to establish robust phonological representations which accurately encode the sequences of phonemes within spoken words. It is proposed that this in turn leads to a reduced capacity for learning the mappings between graphemes and phonemes which support print-to-sound decoding. Within the original version of the dual route model (Coltheart 1978; Coltheart et al., 2001) this is characterised as a specific impairment of the sub-lexical reading mechanism and consequently a greater reliance on a lexical reading strategy utilising whole-word orthographic representations.

If we presume – as these models suggest – that people with dyslexia are less able to acquire spelling-sound mappings (Snowling, 2000) and therefore make greater use of lexical information to support their reading (Castles & Coltheart, 1993), it follows that their naming and lexical decision performance should be characterised by a diminished spelling-sound regularity effect (Manis, Szeszulski, Holt, & Colheart, 1991). Contrary to this expectation, a review and meta-analysis of seventeen studies found that children with reading disabilities showed spelling-sound regularity effects of a comparable magnitude to reading-age controls (Metsala, Stanovich & Brown, 1998). This finding appears to challenge the assertion that the well established deficits in phonological awareness and literacy which define dyslexia emerge from more fundamental weaknesses in the accurate representation of phonemes.

Other findings have also led researchers to question the extent to which phonological representations may be impaired in dyslexia. In studies of French-speaking adults with dyslexia, an interesting dissociation has been observed between implicit tasks tapping phonological representations (e.g. repetition priming), on which participants appear to perform normally, and measures of phoneme awareness on which participants show persistent difficulties (Ramus & Szenkovits, 2008). The same authors have also demonstrated that participants with dyslexia show phonological similarity effects of equal magnitude to controls in the context of both nonword repetition and nonword discrimination tasks. Furthermore, French- and Dutch-speaking children with dyslexia have been shown to compensate for the effects of place assimilation in spoken word identification (Blomert, Mitterer, & Paffen, 2004; Marshall, Ramus, & van der Lely, 2012), a skill that requires detailed representations of target phonemes as well as the surrounding phonemes constituting the assimilation context. These results were obtained despite the same participants showing clear impairments in domains such as phoneme awareness, rapid automatised naming, and verbal short-term memory span. Finally, research in the field of psycholinguistics has indicated that phonological difficulties observed in adults with dyslexia are directly related to the degree of metalinguistic processing required in a given task, with no apparent deficits in the simple perception and representation of phonemes (Dickie, Ota, & Clark, 2012).

On the basis of such findings it has been argued that the phonological representations hypothesis predicts deficits in many situations in which people with dyslexia are apparently unimpaired and that our understanding of the core phonological deficit in dyslexia is in need of refinement (Ramus & Ahissar, 2012). One possibility is that that the phonological deficit may actually reflect a reduced ability to access phonological representations in the context of tasks which exert certain specific pressures on the phonological system (Ramus & Szenkovits, 2008).

The current study

The current paper aims to extend this literature by investigating conflicting predictions concerning spelling-stress regularity effects in dyslexia. Several researchers now argue that sensitivity to speech prosody is an important and relatively overlooked predictor of reading ability and a number of recent findings suggest that children and adults with dyslexia show reduced awareness of syllabic stress patterns (Leong, Hämäläinen, Soltész, & Goswami, 2011; Goswami, Gerson & Astruc, 2009). Longitudinal data also suggest that knowledge of syllabic stress assignment accounts for unique variance in the literacy performance of typically developing children (Holliman, Wood, & Sheehy, 2010).

Some researchers have argued that the stress awareness deficits observed in dyslexia result from fundamental problems in the perception and representation of syllabic stress (Goswami, 2011; Goswami, Thomson, Richardson, & Stainthorp et al., 2002). On the basis of these claims, it seems reasonable to predict that people with dyslexia should also be less able to acquire spelling-stress mappings and thus show greater reliance on lexical knowledge in assigning stress to written words. In terms of the CDP++ model (Perry et al., 2010) this could be characterised as a specific impairment of the sub-lexical route to stress assignment. If this is indeed the case, the reading performance of people with dyslexia should be characterised by a diminished spelling-stress regularity effect.

In contrast, the findings from the domain of phoneme-level regularity effects (Metsala et al., 1998) suggest that spelling-stress congruency will in fact exert comparable effects on the performance of skilled adult readers and adults with dyslexia. Recent findings demonstrating normal patterns of stress priming and intact stress perception in dyslexia, despite a reduction in stress awareness, also lead to this prediction (Barry, Harbodt, Cantiani, Sabisch, & Zobay, 2012; Dickie et al., 2012; Mundy & Carroll, 2012), as does evidence that Italian-speaking children with dyslexia show a naming advantage for words with large stress neighbourhoods comparable to that of controls (Paizi et al., 2011). The current experiment investigated these conflicting predictions utilising the lexical decision task devised by Kelly et al. (1998).

Method

Participants

Participants were 37 students enrolled in undergraduate and postgraduate courses at a large university in the UK. The sample included 16 students with developmental dyslexia recruited through the university's disability support service (*M* age = 23 years, *SD* = 6.01, 4 males) and 21 IQ-matched controls (*M* age = 20 years, *SD* = 2.87, 4 males).

Participants with dyslexia had received formal statements of developmental dyslexia from a psychologist on the basis of an extensive battery of reading and phonological tasks. The diagnoses were current, formally acknowledged by the university and, at the time of testing, all of the students were receiving additional academic support to assist them in their studies. Participants with dyslexia received payment of £4. Control participants were psychology undergraduates who participated in order to fulfil a course requirement. All participants were native speakers of British English.

Some of the participants in the dyslexic sample showed evidence of having compensated for their reading difficulties. Confirmatory measures of phonological processing ability were not obtained but all of the participants with dyslexia reported ongoing difficulties with their phonological skills and verbal short-term memory. This is consistent with data from other samples of dyslexic students in higher education (Gallagher, Laxon, Armstrong, & Frith, 1996; Hatcher, Snowling, & Griffiths, 2002).

Measures

Verbal and non-verbal IQ. Participants completed the Similarities and Matrix Reasoning subscales of the WASI (The Psychological Corporation, 1999) to ensure that there were no significant group differences in verbal or performance IQ. Participants' responses were scored for accuracy and raw scores were converted to a standardised scale with a mean of 50 and a standard deviation of 10 as described in the test manual.

Literacy ability. Reading skills were assessed with the Sight Word (word reading) and Phonemic Decoding (nonword reading) subscales of the Test of Word Reading Efficiency (TOWRE: Torgesen, Wagner, & Rashotte, 1999). On each subscale the dependent variable was the number of items read correctly in 45 seconds. Raw scores were converted to a standardised scale with a mean of 100 and a standard deviation of 15 as described in the test manual.

Lexical decision task (Kelly et al., 1998). During this task participants were asked to make lexical decision responses (word or nonword) to a series of letter strings presented visually on a computer monitor. The experimental items were 64 disyllabic English words which were manipulated according to whether or not the orthographic structure of the final syllable was a reliable indicator of lexical stress assignment. The 32 words in which the orthographic structure of the final syllable was a reliable indicator of lexical stress assignment were divided equally into those with an iambic stress pattern (e.g. *shampóo*) and those with a trochaic stress pattern (e.g. *chórus*). The 32 words in which the orthographic structure of the final syllable was an unreliable indicator of lexical stress assignment were also divided equally into those with iambic (e.g. *guitár*) and trochaic stress (e.g. *cómpass*). This resulted in a 2x2x2 design with independent variables of orthographic reliability (reliable indicator, unreliable indicator), stress assignment (trochaic, iambic), and reading group status (dyslexia, control). A complete list of the experimental items used in the task is provided in the Appendix.

The majority of the items had been used previously by Kelly et al. (1998, Experiments 2 and 3) although a small number of substitutions were made. Proper nouns were excluded (e.g. *Cornéll*) as were words that were likely to be less familiar to speakers of British English (e.g. *corvétte*) and words that receive different patterns of stress assignment in British and American English (e.g. *báton*/ *batón*). The stimuli with reliable and unreliable spelling-stress relationships were matched for length in letters (*M* (*SD*) reliable = 6.34 (1.23), *M* (*SD*) unreliable = 5.94 (1.08): t (62) = 1.40, *ns*). Frequency estimates based on the SUBTLEX corpus (*M* (*SD*) reliable = 4.81 (5.72), *M* (*SD*) unreliable = 5.47 (11.33): t (62) < 1, *ns*) were obtained via the English Lexicon Project (ELP: Balota et al., 2007; Brysbaert & New, 2009). The small differences in length and frequency were statistically non-significant and the direction of the differences worked against the hypothesis (i.e. they would be expected to improve performance for the unreliable words relative to the reliable words). Finally, reliable and unreliable items were also matched for orthographic typicality (*M* (*SD*) reliable = 2.40 (.57), *M* (*SD*) unreliable = 2.38 (.51): t (62) < 1, *ns*) and phonological typicality (*M* (*SD*) reliable = 2.09 (.48), *M* (*SD*) unreliable = 2.16 (.36): t (62) < 1, *ns*) using Levenshtein distances obtained from the ELP (Balota et al., 2007; Yarkoni, Balota, & Yap, 2008).

In addition to the experimental items, participants were presented with 32 foils and 96 filler items thus giving a total of 192 trials. Participants also received 10 practice trials with feedback prior to beginning the task. The foil items were real English words and the filler items were pronounceable nonwords. Following Kelly et al., the foils and filler items were either 1 or 3 syllables in length in order that the stress patterns assigned to the filler and foil items were not able to prime responses to the disyllabic experimental words. Items were presented in a random order and participants were allowed a short break after each block of 48 trials.

Participants were instructed to respond as quickly as they could to the letter strings without making too many mistakes. Each trial began with a white fixation cross displayed on a black background in the centre of the screen. The cross was then replaced with the target string. Targets were displayed in 18-point lower case Courier font and remained on screen until a response was registered. The dependent variables were mean response time for lexical decision (correct trials only) and percentage error rates recorded in each experimental condition. Participants registered their responses with button presses on the computer keyboard (z = nonword, m = word) and response times were measured from the onset of the target string.

Procedure

Participants were tested individually in a quiet room over a period of approximately 40 minutes and gave informed consent before beginning any of the tasks. The literacy measures were administered first followed by the lexical decision task and the IQ subscales. During the lexical decision task stimuli were presented and responses were recorded using

DirectRT research software (Jarvis, 2006). All other tasks were administered according to the instructions in the test manuals. Following completion of the experiment participants were invited to ask any questions that they may have, and were issued with a debriefing statement explaining the aims of the research.

Results

Sample characteristics and statistical analyses

Sample characteristics are provided in Table 1. Participants with dyslexia were significantly impaired relative to controls on the measures of word reading and nonword reading. There were no significant reading group differences in verbal IQ or performance IQ.

<Table 1>

There was a small but significant difference in age between the groups that remained after correcting for unequal variances (p = .043). However, this difference was largely due to a small number of outliers in the dyslexic group (participants aged 35 and 37 years). The age contrast failed to reach significance when these participants were excluded from the sample (*M* dyslexic = 21.36 (*SD* = 3.57), *M* control = 19.67 (*SD* = 2.87), t (33) = 1.55, p = .131, *ns*). Analyses of the lexical decision data were first conducted on the full sample and then repeated with the two age outliers excluded from the dyslexic group. Identical patterns of results were obtained for all effects and interactions in both the subjects and items analyses. Therefore, the age outliers have been retained in the dyslexic group and the results of the analyses conducted on the full sample are reported.

In addition to the traditional methods of hypothesis testing, Bayesian analyses were conducted in order to quantify the degree of support in favour of the various null and alternative hypotheses (Masson, 2011; Wagenmakers, 2007). Such analyses provide an indication of whether a null outcome is likely to have resulted from a lack of statistical power or the genuine absence of an effect. The posterior probability of the null hypothesis – *p*(H0|D) – is reported for each effect. Values in excess of .75 indicate positive evidence in favour of the null hypothesis (Raftery, 1995).

As noted previously, some participants showed evidence of having compensated for their reading problems. The sample characteristics presented in Table 1 confirm that, despite large mean differences in word and nonword reading scores, there was a relatively broad range of literacy abilities in each group. Two sets of additional analyses were conducted to ensure that any null interaction effects were not simply due to the inclusion of highly compensated dyslexic individuals and a consequent overlap in reading ability between groups. Firstly, analyses were repeated with non-overlapping sub-samples of dyslexic and non-dyslexic readers. Secondly, reading ability was re-characterised as a continuous variable in two regression analyses.

Lexical decision task

The longest 5% of response times registered by each participant in each experimental condition were removed from the data. Participants were excluded from the analyses if their overall error rate exceeded 25%. This generous criterion was adopted in order to minimise exclusions in anticipation of high error rates in the dyslexic sample. Two participants with dyslexia were excluded from the analyses on the basis of high overall error rates (42% and 29%).

A 2 (reading group) by 2 (orthographic reliability) by 2 (stress assignment) repeated measures ANOVA was conducted on the response time data (Figure 1). The main effects of reading group (F_1 (1, 33) = 17.43, p < .001, d = 1.38, $p(H_0|D)$ < .01; F_2 (1, 60) = 201.00, p <

.001, η_p^2 = .770, $p(H_0|D) < .001$) and orthographic reliability (F_1 (1, 33) = 11.46, $p = .002$, η_p^2 = .258, $p(H_0|D) = .03$; F_2 (1, 60) = 6.27, $p = .015$, $d = .35$, $p(H_0|D) = .28$) were significant by subjects and by items. Overall, participants with dyslexia were slower to respond than the control participants and words in which orthographic structure reliably predicted stress assignment elicited faster response times than those in which orthographic structure was an unreliable predictor of stress assignment. Crucially, the interaction between reading group and orthographic reliability failed to reach significance ($F_1 < 1$, $p(H_0|D) = .85$; $F_2 < 1$, $p(H_0|D) = .89$) and the magnitude of the reliability effect – standardised to control for overall differences in lexical decision time ($M_{\text{unreliable}} – M_{\text{reliable}} / M_{\text{overall}}$) – did not differ between reading groups ($t < 1$). The main effect of stress assignment and all other two- and three-way interactions failed to reach significance in both the subjects and the items analyses ($p > .1$ in all cases).

<Figures 1 & 2>

A 2 (reading group) by 2 (orthographic reliability) by 2 (stress assignment) repeated measures ANOVA was also conducted on the error data (Figure 2). The main effect of orthographic reliability was again significant by subjects and by items (F_1 (1, 33) = 84.12, $p <$ .001, η_p^2 = .718, $p(H_0|D) < .001$; F_2 (1, 60) = 7.42, $p = .008$, $d = .60$, $p(H_0|D) = .29$). Overall, words in which orthographic structure reliably predicted stress assignment elicited fewer errors than those in which orthographic structure was an unreliable predictor of stress assignment. The main effect of stress was significant by subjects but not by items (F_1 (1, 33) = 12.32, $p = .001$, η_p^2 = .272, $p(H_0|D) = .01$; $F_2 < 1$, $p(H_0|D) = .88$). Overall, error rates appeared to be higher for iambic stress words than for trochaic stress words. The main effect of reading group ($F_1 < 1$, $p(H_0|D) = .82$; F_2 (1, 60) = 1.56, $p = .217$, ns, $p(H_0|D) = .86$) and the interaction between reading group and reliability (F_1 (1, 33) = 2.41, p = .130, ns, $p(H_0|D)$ = .63; F_2 < 1, $p(H_0|D)$ = .88) failed to reach significance in either the items or subjects analyses. Furthermore, the magnitude of the reliability effect ($M_{\text{unreliable}} - M_{\text{reliable}}$) did not differ between reading groups (t (33) = 1.58, *ns*). All other two- and three-way interactions also failed to reach significance (p > .1 in all cases).

Further ANOVA analyses were conducted with non-overlapping sub-samples of below-average readers with dyslexia (n = 10, TOWRE word reading scores < 100, range 74 – 98) and average or above-average readers from the control group (n = 10, TOWRE word reading scores ≥ 100, range 100 – 113). This analysis yielded an identical pattern of results for the error data (Group: F < 1, *ns*; Reliability: F (1, 18) = 36.74, p < .001; η_p^2 = .671; Stress: F (1, 18) = 5.06, p = .037, η_p^2 = .220; Group x Reliability: F < 1, *ns*). An identical pattern of results was also obtained for the response time data (Group: F (1, 18) = 21.45, p < .001, d = 1.77; Reliability: F (1, 18) = 4.03, p = .06; η_p^2 = .183; Stress: F < 1, *ns*; Group x Reliability: F < 1, *ns*), although the reliability effect became marginal due to the reduced sample size.

Finally, reading ability was re-characterised as a continuous variable in two regression analyses. TOWRE word reading scores were entered as the sole predictor variable in each analysis. The outcome variables were the reliability effects ($M_{\text{unreliable}} - M_{\text{reliable}}$) observed in the response time and error data of each participant. Standardised effects were used in the response time analysis in order to control for overall differences in lexical decision latencies between better and poorer readers. Consistent with the results of earlier analyses, TOWRE word reading was not a significant predictor of the reliability effects observed in either the response time data (R^2 = .003, p = .950, β = -.051) or the error data (R^2 = .007, p = .637, β = -.083).

Discussion

This experiment utilised the lexical decision paradigm devised by Kelly et al. (1998) to investigate conflicting predictions regarding the influence of spelling-stress regularity on the reading of adults with developmental dyslexia and IQ-matched controls. Participants in both reading groups were significantly faster and significantly more accurate in making lexical decision responses to words in which the orthographic structure of the final syllable was a reliable indicator of lexical stress assignment compared to words in which orthographic structure was an unreliable indicator of lexical stress assignment. The absence of significant group x reliability interactions was generally confirmed by Bayesian analyses providing positive evidence in favour of the null hypothesis (i.e. $p(H_0|D) > .75$: Masson, 2011; Raftery, 1995). The single exception to this was the F_1 analysis of the error data. Furthermore, sub-group analyses confirmed that the absence of the critical interaction cannot be attributed to an overlap in reading ability between groups. Likewise, regression analyses demonstrate that spelling-stress regularity did not differ reliably between better and poorer readers, even when a continuous measure of reading ability was utilised.

There was a main effect of reading group in the response time data. This is likely to result, at least in part, from the difference in reading ability between the two groups and the longer time required for participants with dyslexia to decode the target string and generate their lexical decision response. The main effect of reading group in the response time data could also reflect reduced speed in accessing stored phonological representations. Finally, the fact that there was a main effect of reading group in the response time data, but not in the error data in this experiment, suggests that participants with dyslexia may also have made a strategic choice to ensure accuracy in their responses at the expense of speed.

The main effect of stress assignment generally failed to reach significance. However, there was a significant effect of stress assignment observed in the F_1 analysis of the error data. This reflects the fact that a small number of iambic stress items – both orthographically reliable (e.g. *duréss*) and unreliable (e.g. *chagrín*) – elicited relatively large numbers of errors in both reading groups. Iambic stress assignment is less common than trochaic stress assignment in English disyllabic words (Cutler & Carter, 1987) and words carrying iambic stress often contain orthographically longer second syllables than words carrying trochaic stress (Kelly et al., 1998). As a result of this, a small number of the iambic stress words utilised in the current experiment may have been longer and/or less familiar to participants than the majority of the trochaic stress items.

The central finding of this study is that, perhaps counter intuitively, spelling-stress regularity effects are intact in developmental dyslexia and of a comparable magnitude to those observed in IQ-matched controls. This pattern of results suggests that spelling-stress regularity in disyllabic words exerts a similar effect on the reading of skilled adult readers and adults with dyslexia. Similar findings have already been reported in a study of Italian-speaking children by Paizi and colleagues (2011). These researchers found that typically developing children and children with developmental dyslexia showed an equivalent naming advantage for low frequency words with larger proportions of stress friends. Our results are also consistent with the observation of intact sensitivity to grapheme-phoneme regularity in English-speaking children with dyslexia (Metsala et al., 1998).

More broadly, our results are also in accord with a number of other recent findings. For example, researchers have identified dissociations between implicit tasks which tap phonemic representations, in which participants with dyslexia appear to perform normally, and measures of phonemic awareness, rapid naming, and verbal short-term memory ability which elicit large and persistent deficits (Blomert et al., 2004; Marshall et al., 2012; Ramus & Szenkovits, 2008). Likewise, other researchers have demonstrated intact perception and representation of stress contrasts in adults with dyslexia, despite ongoing difficulties with stress awareness (Barry et al., 2012; Dickie et al., 2012; Mundy & Carroll, 2012). While acknowledging that people with dyslexia clearly experience profound difficulty with certain aspects of phonological processing, researchers have begun to question the assertion that the well established deficits in phonological awareness and literacy which define dyslexia must necessarily emerge from more fundamental weaknesses in the accurate representation of phonology (Ramus & Ahissar, 2012). The question that remains to be answered is: how can findings of intact spelling-sound regularity effects at prosodic and phonemic levels, as well as intact perception, priming and assimilation performance, be reconciled with the clear difficulties that dyslexic individuals experience in other domains of phonological processing?

One interpretation of these results (Marshall et al., 2012; Ramus & Szenkovits, 2008) has led to the suggestion that phonological representations are intact in dyslexia and that the core phonological deficit is instead characterised by a reduced ability to access these representations in the context of tasks which exert certain specific pressures on the phonological system, such as retrieval under time pressure. This interpretation is consistent with the observation that phonological processing difficulties in adults with dyslexia are elicited by tasks with relatively high metalinguistic demands but not those measuring simple phonemic and prosodic perception (Dickie et al., 2012).

It could be argued that such an interpretation treats phonological representations in an all-or-nothing manner rather than acknowledging that differing degrees of detail may be present in phonological representations across different individuals, words and contrasts. An alternative possibility therefore, is that people with dyslexia may have very subtly impaired phonological representations that are unable to support age-appropriate reading but nevertheless sufficiently detailed to capture some broad properties of the input language such as regularity effects. For example, Metsala et al. (1998) argue that damaging the distributed phonological representations acquired by a connectionist model can elicit a pattern of reading performance that is characterised by impaired overall performance but intact item-level effects.

A further possibility is that the nature of the phonological deficit in dyslexia may vary, not only in severity, but also in scope, between different samples of dyslexic individuals. It should be remembered that the current study had a relatively modest sample size and included adults who had compensated for their dyslexia. As a result, these participants may be considered unrepresentative of the wider dyslexia population. Although similar findings have been reported in samples of children with dyslexia (Metsala et al., 1998; Paizi et al., 2011), the absence of a direct replication means that the extent to which the current findings may generalise to the dyslexia population as a whole is an open question. Future research may seek to replicate (or not) intact spelling-stress regularity effects in samples of English-speaking dyslexic children or adults with pronounced and persistent reading difficulties.

Evidence suggests that increasing numbers of adults with dyslexia are compensating for their reading problems and entering higher education (Callens, Tops, & Brysbaert, 2012). Despite this, these individuals often continue to experience significant difficulties with specific aspects of phonological processing that necessitate additional academic support (Callens et al., 2012; Gallagher et al., 1996; Hatcher et al., 2002). Regardless of how representative these individuals are are of other dyslexic samples, the ongoing difficulties of compensated poor readers merit serious attention from researchers. Evaluating the ability of different models to account for the performance of different samples of dyslexic individuals across a full range of experimental tasks and item-level effects has the potential to resolve the question regarding the true nature of the phonological deficit.

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