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Speech prosody and developmental dyslexia: reduced phonological awareness
in the context of intact phonological representations

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Abstract

Recent research indicates that awareness of the rhythmic patterns present in spoken language (i.e. prosody) may be an important and relatively overlooked predictor of reading ability. Two studies investigated the prosodic processing abilities of skilled adult readers and adults with developmental dyslexia. Participants with dyslexia showed reduced awareness of lexical and metrical stress and these skills were found to be significantly associated with, and predictive of, phonological decoding ability. In contrast, the same individuals showed normal patterns of stress based priming at magnitudes similar to controls. These results – suggesting reduced phonological awareness in the context of intact phonological representations – are consistent with recent findings reported in the domain of phonemic processing. Implications for the phonological deficit theory of dyslexia are discussed.

Keywords: developmental dyslexia; lexical stress; metrical stress; prosody; reading

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Speech prosody and developmental dyslexia: reduced phonological awareness
in the context of intact phonological representations

Developmental dyslexia is a highly specific impairment of reading and spelling ability occurring in people with an average or above average IQ, normal sensory acuity, and experience of appropriate educational instruction (World Health Organisation, 1993). The phonological deficit account of dyslexia (Fowler, 1991; Mattingly, 1972; Snowling, 2000; Stanovich, 1988; 1998; Vellutino, 1977; 1979) argues that the proximal cause of reading impairment 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 lower levels of phoneme awareness and a reduced capacity for learning the mappings between graphemes and phonemes which support print-to-sound decoding. The aim of this paper is to investigate the recent hypothesis that sensitivity to another level of phonological structure – prosody – may also have substantial implications for literacy development.

Prosody refers to the rhythmic patterns which arise during the sequential articulation of the syllables within a word or utterance. The term encompasses the pragmatic use of intonation and emphasis as well as more structured and systematic variations in the assignment of syllabic stress. The perception of syllabic stress is associated with fluctuations in certain acoustic properties of the speech signal; amplitude, duration and fundamental frequency (F_0). Variations along these acoustic dimensions are perceived as differences in loudness, length, and pitch between syllables, with stressed syllables appearing to be louder, longer, and higher in pitch than unstressed syllables (Fry, 1955; 1958; Liberman, 1960). The systematic assignment of syllabic stress produces lexical stress patterns within words (e.g. the strong-weak, or trochaic, stress pattern of *cóllege* vs. the weak-strong, or iambic, stress pattern of *colláte*) as well as a metrical stress pattern – or speech rhythm – over the course of

an entire utterance. These regular patterns of syllabic stress assignment are exploited by children and adults in processing spoken and written language (Cutler & Butterfield, 1992; Cutler & Norris, 1988; Kelly, Morris & Verrechia, 1998).

Separate but related research literatures have indicated at least two mechanisms via which prosodic skills may influence literacy development; an indirect, early-onset mechanism, and a direct, late-onset mechanism. The indirect influence of prosodic skills on literacy development arises from the importance of prosodic cues to speech segmentation in infancy. The usefulness of prosodic cues for speech segmentation is well established (Cutler & Butterfield, 1992; Cutler & Norris, 1988) and children are known to make use of prosodic cues in segmenting words from the speech stream from an early age (Jusczyk, 1999). A number of researchers have suggested that good prosodic skills would therefore facilitate the learning of new words and the segmentation of those words into the sub-lexical units required for literacy development whereas, in contrast, reduced sensitivity to speech prosody would undermine the establishment of the robust phonological representations required for reading (Goswami, Thomson, Richardson, & Stainthorp et al., 2002; Richardson, Thomson, Scott, & Goswami, 2004).

Researchers have utilised a number of paradigms to study participants' sensitivity to temporal variations in the acoustic properties of the speech signal which convey syllabic stress information. Goswami et al. (2002) found that their beat perception task – a measure of sensitivity to amplitude rise-times in non-speech stimuli – produced group differences between children with dyslexia and chronological-age controls, as well as predicting unique variance in phonological awareness. More recent studies have also reported associations between rise-time sensitivity, phonological processing (Richardson et al., 2004) and visual-verbal associate learning (Thomson & Goswami, 2010). Converging findings have also been reported for samples of English speaking adults with dyslexia. In comparison with age/IQ

matched controls, students with dyslexia studying at UK universities are found to be impaired in the beat perception task (Pasquini, Corriveau & Goswami, 2007) and in discriminating between pairs of non-speech sounds on the basis of amplitude rise-time and duration (Thomson, Fryer, Maltby & Goswami, 2006). Research has suggested that adults with dyslexia may also be impaired relative to age/IQ matched controls in detecting frequency modulations and amplitude modulations in pairs of tones (Witton, Stein, Stoodley, Rosner, & Talcott, 2002). Consistent with the data from child samples, these studies report significant correlations and predictive relationships between the low-level auditory processing of prosodic cues and various measures of phonological awareness, which are in turn strong predictors of literacy ability.

In addition to this indirect or distal relationship between prosodic processing and literacy, studies suggest that there may also be direct links between conscious awareness of syllabic stress assignment and specific literacy skills such as phonological decoding, reading comprehension, and punctuating connected text. These direct links between prosody and literacy may only begin to emerge later in development, perhaps in response to children encountering written multisyllabic words and connected text for the first time (David, Wade-Woolley, Kirby, & Smithrim, 2007; Gombert, 1992). Several language tasks have been used to measure awareness of metrical and lexical prosody. Two such tasks are the DEEdee task (Kitzen, 2001) and the compound noun/noun phrase discrimination task (Blumstein & Goodglass, 1972). During the DEEdee task, participants are required to match a spoken stimulus to one of several length-matched response options on the basis of shared prosodic structure. The DEEdee stimuli are created using a reiterative syllable substitution technique (Liberman & Streeter, 1978; Nakatani & Schaffer, 1978) in which each syllable of a spoken utterance – commonly the title of a famous film, television programme, book, or nursery rhyme – is replaced with the nonsense syllable *dee*. The effect of this is to remove the

original phonemic content of the stimulus while retaining its prosodic structure (e.g. *the godfather* → *dee déedeede*). During the compound noun/noun phrase discrimination task, participants are asked to use prosodic cues to distinguish between compound nouns such as *hótdog* (i.e. a food item) and corresponding, phonemically identical noun phrases such as *hot dóg* (i.e. a dog, which needs a drink of water). The task was originally designed for use with adult neuropsychological patients but appropriately modified versions have also been utilised for testing children (e.g. Goodman, Libenson, & Wade-Woolley, 2010; Wells, Peppé, & Goulandris, 2004; Whalley & Hansen, 2006). In these tasks children are required to distinguish between compound nouns such as *íce-cream* and noun lists such as *íce, créam*.

A number of correlational studies now suggest that performance on the tasks outlined above, as well as other measures of prosodic awareness, are significantly related to reading ability. Whalley & Hansen (2006) found that performance on the DEEdee task and the compound noun/noun list discrimination task accounted for significant, unique variance in children's word reading after controlling for phonological awareness and sensitivity to rhythm in non-speech stimuli. Performance on the DEEdee task was also able to account for significant, unique variance in reading comprehension. Performance on the DEEdee task and the similar rhythmic matching task (Wood & Terrell, 1998) has also been found to account for significant, unique variance in a composite measure of reading ability encompassing word reading, nonword reading, passage reading and text comprehension after controlling for phonological and morphological awareness (Clin, Wade-Woolley, & Heggie, 2009). Similar relationships between prosodic skills and reading ability have also been reported in studies of Spanish speaking children (Gutiérrez-Palma & Palma-Reyes, 2007). This research has indicated that awareness of speech prosody may make specific contributions to reading ability, for example, by facilitating the learning of rules which govern stress assignment in multisyllabic word reading (Gutiérrez-Palma, Raya-García, & Palma-Reyes, 2009). There is

currently a shortage of longitudinal data investigating the relationship between sensitivity to speech prosody and later reading ability. However, Holliman, Wood, & Sheehy (2010) recently reported that the performance of six year old children ($n = 102$) in a task measuring awareness of lexical stress accounted for significant, unique variance in measures of word reading and reading fluency obtained one year later, even after controlling for the influence of age, vocabulary, and phonological awareness.

In addition to studies conducted with typically developing children, research has also suggested that children with reading problems may be impaired relative to chronological-age controls on several measures of prosodic processing ability. Wood and Terrell (1998) found that a sample of nine year old English children identified as poor readers were significantly impaired on the rhythmic matching task relative to chronological-age controls. Furthermore, performance in the rhythmic matching task correlated significantly with the poor readers' reading and spelling scores. Similar findings have also been reported by Goswami, Gerson and Astruc (2009) who administered a version of the DEEdee task in which participants saw a photograph depicting a famous person and were required to select which of two auditorily presented DEEdee stimuli matched the picture (e.g. *dávid béckham* → *déedee déedee*). Children with dyslexia (mean age twelve years) were found to be significantly impaired on this version of the DEEdee task relative to chronological-age controls. Performance on the DEEdee task correlated significantly with phoneme awareness, word reading, nonword reading, and spelling and DEEdee task performance accounted for significant, unique variance in the three literacy measures after controlling for age, IQ, rhyme awareness, and phoneme awareness. Sensitivity to amplitude rise-times was also found to be significantly related to DEEdee task performance, suggesting a developmental progression from the auditory processing of low level prosodic cues to the conscious awareness of prosodic structure.

This paper reports the results of two studies which investigate the prosodic processing abilities of adults with diagnoses of developmental dyslexia in relation to those of control participants matched for age and IQ¹. The primary aim of these experiments is to better understand the precise nature of the prosodic processing deficit associated with dyslexia. Cross modal priming paradigms are utilised alongside more conventional measures of prosodic awareness in order to contrast the underlying representation of syllabic stress assignment with the processes of conscious prosodic awareness. The first experiment utilised the DEEdee task (Kitzen, 2001) to investigate whether the impairment of prosodic awareness observed in samples of children with dyslexia persists into adulthood. The cross modal fragment priming paradigm (Cooper, Cutler & Wales, 2002) was also used in order to assess the ability of adults with developmental dyslexia to accurately represent the lexical prosody of words stored in the mental lexicon. During this task participants are required to respond to visually presented target words preceded by three types of spoken prime. In the stress congruent prime condition, the spoken prime is the first two syllables of the target word (e.g. *ádmir/al* → *ADMIRAL*). In contrast, in the stress incongruent prime condition, the spoken prime is the first two syllables of a word that shares segmental phonology with the target while differing in stress assignment (e.g. *àdmir/átion* → *ADMIRAL*). Priming effects are measured in each of these conditions in relation to a control condition in which the spoken prime is the first two syllables of a word phonologically unrelated to the target (e.g. *mosquí/to* → *ADMIRAL*). It was predicted that control participants would show significantly more priming for stress congruent primes than for stress incongruent primes. This pattern of responding has been observed previously in skilled adult readers of English, Spanish and Dutch (Cooper et al., 2002; Soto-Faraco, Sebastián-Gallés & Cutler, 2001; van Donselaar, Koster & Cutler, 2005). It was reasoned that if participants with dyslexia represent lexical prosody less clearly than controls, they would show evidence of a priming effect for both

stress congruent and stress incongruent primes due to the continued overlap in the segmental phonology of the prime and target in both conditions. Alternatively, if participants with dyslexia accurately encode lexical stress information in their phonological representations, they would be expected to show the same pattern of priming as control participants as well as similar priming effect magnitudes.

A number of researchers have demonstrated that phonological processing is multifaceted (e.g. Wagner & Torgesen, 1987) and that different phonological skills may make distinct, unique contributions to literacy difficulties (Wolf & Bowers, 1999). In the context of phonemic processing, a recent series of experiments by Ramus and Szenkovits (2008) demonstrated that highly educated adults with dyslexia show phonological similarity effects of equal magnitude to age/IQ matched controls in the context of nonword repetition and nonword discrimination tasks as well as normal repetition priming effects in a subliminal auditory priming paradigm. In contrast, the same participants continued to experience difficulties with more conventional measures of phoneme awareness. Despite these findings, and the growing literature linking prosodic processing skills with reading ability, there are currently no published studies that aim to determine exactly which aspects of prosodic processing cause difficulty for people with dyslexia. Ramus and Szenkovits argue that educated adults with dyslexia may show relatively pure impairments of phonological awareness and a reduced ability to access phonological information while having intact phonological representations. It was tentatively hypothesised that adults with dyslexia would show a similar dissociation at the prosodic level. Similar patterns and magnitudes of priming across the two reading groups, in the context of impaired performance on the DEEdee task, could be taken as evidence for a specific impairment of prosodic awareness in adults with dyslexia. In contrast, differences in either the pattern or magnitude of priming observed across the reading groups, as well as impaired performance on the DEEdee task, would be

consistent with a more far reaching impairment of prosodic processing in dyslexia, influencing the perception and representation of syllabic stress in addition to prosodic awareness.

Method

Participants

Participants were 80 students enrolled on undergraduate and postgraduate courses at a large university in the UK. The sample included 32 students with developmental dyslexia recruited through the university's disability support service (M age = 20 years, SD = 4.23, 13 males) and 48 age/IQ matched controls (M age = 21 years, SD = 7.11, 11 males). Participants with dyslexia had received formal statements of developmental dyslexia from a psychologist and, at the time of testing, were receiving additional academic support to assist them in their studies. Participants with dyslexia received payment of £10 and were included in the sample regardless of the severity of their reading impairment (i.e. no effort was made to select only the most impaired students). Control participants were psychology undergraduates who took part in the experiment in order to fulfil a course requirement. All participants were native speakers of British English.

Measures

Verbal and performance IQ. Participants completed the Similarities and Matrix Reasoning subscales of the Wechsler Abbreviated Scale of Intelligence (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. 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. Participants also completed the Nonsense Passage Reading subscale of the York Adult Assessment (Hatcher & Snowling, 2002). The dependent variable was the mean reading time for two short text passages containing real words and nonwords. The first passage contained 51 words and 14 nonwords and the second passage contained 44 words and 13 nonwords.

Literacy related skills. Phoneme awareness and verbal short-term memory were assessed with the Phoneme Reversal and Digit Span subscales of the Comprehensive Test of Phonological Processing (C-TOPP: Wagner, Torgesen & Rashotte, 1999). Participants' responses were scored for accuracy with maximum scores of 18 and 21 respectively. Vocabulary was assessed with the Vocabulary subscale of the WASI (The Psychological Corporation, 1999) and the scores were converted to a standardised scale with a mean of 50 and a standard deviation of 10 as described in the test manual.

DEEdee task (Kitzen, 2001). The DEEdee task utilises a reiterative syllable substitution technique (Liberman & Streeter, 1978; Nakatani and Schaffer, 1978) in which each syllable of a spoken utterance is replaced with the nonsense syllable *dee*. The effect of this is to remove the original phonemic content of the utterance whilst retaining its prosodic structure (e.g. *the gódfather* → *dee déedeedee*). During the DEEdee task, participants are required to match a spoken DEEdee stimulus to one of several response options. The response options each contain the same number of syllables but the locations of stressed and

unstressed syllables can be used to distinguish between them. The participants must determine which response option matches the prosodic structure of the DEEdee stimulus.

Following Kitzen (2001), the stimuli used here were famous film titles. The DEEdee stimuli were spoken by a female native speaker of British English and recorded as individual sound files. In order to mimic natural speech as closely as possible, the speaker was shown each of the film titles in turn and asked to produce the corresponding DEEdee stimulus in its entirety. This option was preferred to recording individual syllables out of context and concatenating them to produce the final stimuli. A complete list of the stimuli and response options used in the task is provided in Appendix A.

There were 20 trials presented in random order and participants also received 2 practice trials. Participants received feedback on their performance during the practice trials only. No time limit was placed on the task but participants were asked to respond as quickly as possible without making too many mistakes. Each trial began with a row of asterisks displayed in the centre of the screen for 3450ms. The asterisks remained on screen while participants listened to the DEEdee stimulus. Following the DEEdee stimulus and an inter-stimulus interval of 1000ms the asterisks were replaced on screen by 3 response options. The response options were only presented visually.

Participants were required to identify which of the response options matched the prosodic structure of the DEEdee film title by pressing the appropriate key (A, B, or C) on the keyboard. The correct answer appeared in positions A, B and C on an approximately equal number of trials. The dependent variables were accuracy (/20) and mean response time. Response times were measured from the onset of the response options.

Cross modal fragment priming (Cooper et al., 2002). In order to assess the representation of lexical stress assignment participants completed the cross modal fragment priming task. During this task, participants are required to make lexical decision responses

(real word or nonword) to visually presented letter strings preceded by three types of spoken prime. The relationship between prime and target is manipulated as a 3-level independent variable (stress congruent prime, stress incongruent prime, control prime). In the stress congruent prime condition, the spoken prime is the first 2 syllables of the target word (e.g. *ádmir/al* → *ADMIRAL*). In the stress incongruent prime condition, the prime is the first 2 syllables of a word that shares segmental phonology with the target but differs in stress assignment (e.g. *àdmir/átion* → *ADMIRAL*). Priming effects in each of these conditions are measured in relation to a control prime condition in which the prime is the first 2 syllables of a word phonologically unrelated to the target (e.g. *mosquí/to* → *ADMIRAL*).

The prime words used in the task were those developed by Cooper et al. (2002). These constituted 24 pairs of English words with identical segmental phonology but contrasting stress assignment in the first 2 syllables (e.g. *ádmiral*; *àdmirátion*) and 24 phonologically unrelated control primes (e.g. *mosquíto*). The 48 experimental primes also served as target words. The stimuli did not include any word pairs in which differences in stress assignment coincided with changes in vowel identity (e.g. *récord*; *recórd*). Experimental and control primes were matched for length (i.e. number of syllables) and Kucera-Francis (1967) written frequency (*M* experimental primes = 19.02 words per million, *M* control primes = 19.08 words per million) using the MRC Psycholinguistic Database (Coltheart, 1981; Wilson, 1988). Some of Cooper et al.'s original control primes were substituted in order to ensure the closest possible frequency match between experimental and control primes.

Primes were presented at the end of non-constraining carrier sentences (e.g. *Hank asked his wife to say ádmir*) adapted from Soto-Faraco et al. (2001) and Cooper et al. (2002). The primes and carrier sentences were spoken by a female native speaker of British English. Each prime word was recorded in the context of two different carrier sentences and the

speech analysis software PRAAT (Boersma, 2001) was used to remove the final syllable(s) from the prime word. A complete list of the experimental and control primes used in the task is provided in Appendix B.

A total of 8 presentation orders were constructed and 4 participants with dyslexia and 6 controls were assigned to each. All of the presentation orders contained the 48 target words as well as 48 filler items giving a total of 96 trials. The prime condition and sentence context in which the target words appeared was counterbalanced across presentation orders. The same filler items were used in each presentation order and the majority of these (40/48) had nonword targets. Participants also received 10 practice trials with feedback prior to beginning the task.

Each trial began with a row of asterisks displayed in the centre of the screen for 3450ms. The asterisks remained on screen for the duration of the carrier sentence and prime. Following the prime there was a brief inter-stimulus interval of 100ms before the asterisks were replaced with the target in upper case type. The dependent variable was the mean response time for lexical decision (correct trials only) in each prime condition. Response times for lexical decision were measured from the onset of the target word and were recorded via button presses on the computer keyboard (m = real word, z = nonword).

Procedure

Participants were tested individually in a quiet room over a period of 90 minutes and gave informed consent before beginning any of the tasks. The literacy measures were administered first, followed by the DEEdee task, the cross modal priming task, phoneme reversal, digit span, vocabulary, and the IQ subscales. During the DEEdee task and the cross modal priming task, stimuli were presented and responses recorded using DirectRT research software (Jarvis, 2006) and all auditory stimuli were presented at a comfortable volume over

headphones. Matching, literacy and literacy related measures were administered according to the instructions in the test manuals. At the end 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

Sample characteristics are provided in Table 1. Unless otherwise stated, all tests are two-tailed. Participants with dyslexia were significantly impaired relative to controls on the measures of word reading, nonword reading, nonsense passage reading, phoneme awareness and verbal short-term memory. The group difference in phoneme awareness was smaller than that observed for the literacy measures ($p = .020$) indicating some remediation of participants' phonological processing difficulties over time. This could also be due to the relative unfamiliarity of phoneme awareness tasks to control participants in comparison to those with a history of reading problems and experience of phonological intervention. However, approximately 1/3 of participants with dyslexia (11/32) still achieved phoneme awareness scores $> 1 SD$ below the control group mean. There were no significant reading group differences in age, verbal IQ, performance IQ or vocabulary.

<Table 1>

DEEdee Task

All participants scored above chance on the DEEdee task. However, control participants were significantly more accurate and significantly faster to respond than participants with dyslexia (Table 2). Approximately half (15/32) of the participants with

dyslexia achieved accuracy scores $> 1SD$ below the control group mean. Eight of those participants had also achieved scores $> 1SD$ below the control group mean on the phoneme awareness task.

<Table 2>

In order to control for the reading and short-term memory demands of the DEEdee task, the comparisons of reading group means reported in Table 2 were repeated as ANCOVA analyses with TOWRE word reading, TOWRE nonword reading and C-TOPP digit span scores entered as covariates. When the dyslexic sample was restricted to those participants with relatively severe deficits (accuracy scores $> 1SD$ below the control group mean, $n = 15$), reading group status continued to exert a significant effect on DEEdee task performance after controlling for the role of word reading, nonword reading and short-term memory ability (accuracy: $F(1, 58) = 9.46, p = .003$; response time: $F(1, 58) = 12.22, p = .001$). When all of the participants with dyslexia were included, reading group status was found to exert a significant effect on the response time measure ($F(1, 75) = 5.06, p = .027$) but not the accuracy measure ($F(1, 75) = 1.28, p = .261$).

Correlations between DEEdee task performance, the literacy measures, phoneme awareness, and verbal short-term memory were calculated first for the whole sample and then within reading groups (Tables 3 and 4). Taking the sample as a whole, significant correlations were observed between DEEdee task accuracy, DEEdee task response time and all of the literacy and literacy related measures.

<Tables 3 and 4>

Within the dyslexic group, DEEdee task accuracy correlated significantly with word reading, nonword reading, phoneme awareness, and verbal short-term memory. DEEdee task response time was significantly correlated with phoneme awareness and verbal short-term memory. Correlations between DEEdee task response time and nonword reading ($p = .052$) and DEEdee task response time and nonsense passage reading ($p = .067$) also approached significance. Within the control group, DEEdee task accuracy correlated significantly with nonword reading and phoneme awareness and DEEdee task response time correlated significantly with phoneme awareness. Once again, correlations between DEEdee task response time and nonword reading ($p = .086$) and DEEdee task response time and nonsense passage reading ($p = .077$) also approached significance.

Cross modal fragment priming

Mean lexical decision times were calculated for correct trials only. Previously, researchers using the cross modal fragment priming paradigm have chosen to remove all response times exceeding 2000ms from the analyses (Soto-Faraco et al., 2001). Initial inspection of the data suggested that this trimming method would have resulted in large numbers of trials being excluded from the data of participants with dyslexia, particularly in the control and incongruent prime conditions. As an alternative, the longest 5% of response times registered by each participant in each prime condition were removed. This trimming method allowed trials to be excluded in a way that took into account the overall response time of each individual participant.

Participants were excluded from the priming analyses if their overall percentage error rate exceeded 25%. This generous criterion was used in order to minimise exclusions in anticipation of high error rates amongst participants with the most severe reading problems. In total, 1 participant with dyslexia was excluded due to a high overall error rate (30%). A

further participant with dyslexia was excluded after registering extremely long response latencies (some in excess of 6000ms) in all experimental conditions.

In addition to the standard methods of hypothesis testing, Bayesian analyses were conducted to quantify the degree of support in favour of the null and alternative hypotheses associated with each effect (Masson, 2011; Wagenmakers, 2007). The posterior probability of the null hypothesis – $p(H_0|D)$ – is reported for each effect.

Priming effects measured relative to the control condition were calculated for the stress congruent and stress incongruent primes (Figure 1). A prime (congruent, incongruent) by reading group (dyslexia, age/IQ control) repeated measures ANOVA was conducted on the priming effects observed in the response time data. There was a significant main effect of prime condition indicating that significantly more priming was observed for the stress congruent primes than for the stress incongruent primes ($F_1(1, 76) = 13.84, p < .001, \eta_p^2 = .154, p(H_0|D) = .01; F_2(1, 47) = 19.33, p < .001, \eta_p^2 = .291, p(H_0|D) = .00$). The main effect of reading group ($F_1 < 1, p(H_0|D) = .87; F_2 < 1, p(H_0|D) = .88$) and the critical interaction between reading group and prime condition ($F_1 < 1, p(H_0|D) = .76; F_2(1, 47) = 1.53, p = .223, ns, p(H_0|D) = .89$) failed to reach significance indicating that participants in both reading groups showed similar patterns and magnitudes of priming across the experimental conditions.

<Figure 1>

Unsurprisingly, participants with dyslexia were slower to respond than control participants (M dyslexia = 1041.83ms, M control = 717.34ms). In order to be sure that the overall slowing of participants with dyslexia had not acted as a confound, the ANOVA analysis was repeated using standardised priming effects which controlled for differences in

overall response time between individuals (e.g. $M_{\text{control}} - M_{\text{congruent}} / M_{\text{control}}$). The pattern of results was identical to the original analysis. Most crucially, the critical interaction remained non-significant ($F_1 < 1$, $p(\text{H}_0|\text{D}) = .89$; $F_2 < 1$, $p(\text{H}_0|\text{D}) = .84$). The original analysis has been preferred in the text and Figure as maintaining the millisecond scale allows greater ease of interpretation.

As noted previously, no effort was made to include only the most severely impaired readers in the dyslexic sample. The sample characteristics presented in Table 1 confirm that there was a relatively broad range of reading abilities in each group. As such, the priming analyses were repeated with a sub-sample of participants with dyslexia whose reading was severely impaired (TOWRE word reading z -scores < -1 , $n = 15$) and a control group of average or above average reading ability (TOWRE word reading z -scores ≥ 0 , $n = 15$). This analysis yielded a virtually identical pattern of results for the main effects (Prime: $F(1, 28) = 6.59$, $p = .016$, $\eta_p^2 = .191$, $p(\text{H}_0|\text{D}) = .19$; Group: $F(1, 28) = 1.35$, ns, $p(\text{H}_0|\text{D}) = .73$) and the interaction ($F(1, 28) < 1$, ns, $p(\text{H}_0|\text{D}) = .84$) and thus confirmed that the equivalent patterns of priming performance were not an artifact of the inclusion criteria for the dyslexic sample.

Predicting reading ability as a continuous trait

Finally, hierarchical regression analyses were conducted using nonword reading and nonsense passage reading as dependent variables. No regression analyses were conducted for word reading because the pattern of correlations between DEEdee task performance and word reading ability differed between the reading groups. While an association between DEEdee task accuracy and word reading ability was observed in the dyslexic group, the correlations between DEEdee task accuracy and word reading and between DEEdee task response time and word reading were both non-significant in the control group ($p = .760$ and $.385$ respectively). In each analysis, age, verbal IQ, performance IQ, vocabulary, verbal short-term

memory, and phoneme awareness were entered as predictor variables at step 1, followed by DEEdee task accuracy, DEEdee task response time, magnitude of stress congruent priming, and magnitude of stress incongruent priming at step 2. In order to ensure that any unique contribution of these variables was due to the influence of prosodic skills and not the reading demands associated with the experimental tasks, TOWRE word reading was also entered at step 1 in both analyses.

The full model was able to account for 75% of the variance in nonword reading ($F(11, 68) = 18.59, p < .001, R^2 = .750$) and 57.8% of the variance in nonsense passage reading ($F(11, 68) = 8.47, p < .001, R^2 = .578$). When entered at step 2, the priming effects and the measures of DEEdee task performance accounted for a unique 6.4% of the variance in nonword reading ($F(4, 68) = 4.34, p = .003, \Delta R^2 = .064$). However, this effect was entirely driven by the DEEdee task variables. DEEdee task accuracy ($t(68) = 2.72, p = .008, \beta = .223$) and DEEdee task response time ($t(68) = 2.18, p = .033, \beta = -.161$) were both significant predictors of nonword reading. In contrast, the stress congruent ($t < 1$) and stress incongruent priming effects ($t(68) = 1.34, p = .185, ns$) were not. Similarly, the prosody variables accounted for a unique 8.8% of the variance in nonsense passage reading ($F(4, 68) = 3.56, p = .011, \Delta R^2 = .088$). DEEdee task response time was a significant predictor of nonsense passage reading ($t(70) = 3.29, p = .002, \beta = .315$) whereas DEEdee task accuracy ($t < 1$), stress congruent priming ($t(68) = 1.09, p = .282, ns$), and stress incongruent priming ($t(68) = 1.58, p = .119, ns$) were not.

Discussion

This experiment contrasted the mental representation of syllabic stress assignment with the conscious awareness of prosodic structure in a sample of skilled adult readers and

adults with developmental dyslexia. The relationship between participants' prosodic skills, phoneme awareness and phonological decoding abilities was also investigated.

Overall, relative to age/IQ matched controls, participants with dyslexia were significantly less accurate and significantly slower to respond during the DEEdee task. Approximately half of the participants with dyslexia showed severe impairments of prosodic awareness, with DEEdee accuracy scores more than one standard deviation below the control group mean. The prosodic awareness deficit observed in these participants remained even after controlling for differences in word reading, nonword reading and short-term memory ability between reading groups. Furthermore, when all of the participants with dyslexia were included in the ANCOVA analysis, reading group status continued to exert a significant effect on participants' DEEdee task response times. These findings confirm that a substantial proportion – although not all – of the participants with dyslexia experienced significant problems with the DEEdee task and that these difficulties cannot be attributed to lower levels of word reading, nonword reading, or verbal short-term memory ability.

Performance on the DEEdee task was correlated with a number of literacy and literacy related skills within both reading groups. Furthermore, after controlling for phoneme awareness, verbal short-term memory, and the reading demands inherent in the task, DEEdee task performance accounted for significant, unique variance in two measures of speeded phonological decoding ability; nonword reading and nonsense passage reading. Together, these findings suggest that adults with dyslexia show reduced levels of syllabic stress awareness and that these skills are significantly associated with literacy ability.

In contrast to their impaired performance on the DEEdee task, participants with dyslexia showed the same pattern of performance as age/IQ matched controls in the cross modal fragment priming paradigm. Both groups of participants showed more priming for stress congruent primes than for stress incongruent primes and the magnitudes of the priming

effects were not significantly different across the reading groups. The conclusions drawn from standard methods of hypothesis testing were also supported by the results of Bayesian analyses. According to a scale devised by Raftery (1995) and recently cited by Masson (2011), the reported posterior probabilities constitute positive evidence in favour of the null hypothesis for both the main effect of reading group and the interaction term. Furthermore, regression analyses indicated that regardless of whether reading ability is treated as a categorical variable or a continuous variable, it is prosodic awareness and not the quality of underlying representations that most reliably discriminates between better and poorer readers. Finally, priming analyses conducted on a sub-sample of participants with dyslexia confirmed that normal prosodic priming was observed amongst even the most severely impaired readers.

The findings from the DEEdee task and the cross modal fragment priming task, observed in the same sample of participants, suggest that adults with developmental dyslexia may show reduced awareness of prosody while their underlying representations of syllabic stress assignment remain intact. However, it should be noted that the need to consciously reflect upon prosodic structure is not the only point of difference between the DEEdee task and cross modal fragment priming. The priming task assesses lexical prosodic processing while the DEEdee task requires awareness of both lexical and metrical prosody. Therefore, these findings do not rule out the possibility that participants with dyslexia may be impaired in processing metrical prosody but not lexical prosody. The tasks also differ in terms of verbal short-term memory load, reading demands and the specific items used as stimuli. In order to confidently assert that adults with dyslexia are selectively impaired on tasks requiring conscious awareness of prosodic structure it is necessary to control the contribution of these factors to the observed differences in task performance. The subsequent experiment contrasted the underlying representation of syllabic stress assignment with participants' conscious awareness of prosodic structure utilising tasks that were better matched in terms of

their reading requirements, verbal short-term memory load, the specific items used as stimuli and the level of prosody addressed.

Experiment 2

The results of the previous experiment suggested that participants with dyslexia may show reduced awareness of metrical and lexical prosody despite accurately representing lexical stress information in the mental lexicon. The aim of Experiment 2 was to contrast these two distinct elements of prosodic processing using tasks that were more closely matched in terms of their stimuli and their processing demands. The experimental tasks addressed prosodic processing at the level of individual words, placed a minimal load on verbal short-term memory and entailed comparable amounts of reading during each trial. Finally, both of the tasks used the same set of items as stimuli.

Conscious awareness of lexical stress assignment was assessed using the fragment identification task (Mattys, 2000). During this task, participants are asked to match a spoken, disyllabic word fragment (e.g. *prósec*) to one of two visually presented response options. The response options are pairs of words derived from a common root word with matching segmental phonology but differing patterns of lexical stress assignment in the first two syllables (e.g. *prósecutor*; *pròsecútion*). In order to correctly identify the spoken word fragments participants must utilise the differences in lexical stress assignment between the response options. As in the previous experiment, cross modal fragment priming was used to assess participants underlying representations of lexical stress assignment (Cooper et al., 2002; Soto-Faraco et al., 2001; van Donselaar et al., 2005). On this occasion however, the items used as stimuli were the same as those used in the fragment identification task.

Utilising the same stimuli in the fragment identification task and in the priming task ensured that the two experimental tasks were matched in terms of the specific items presented

to the participants. The change of stimuli also introduced an interesting variation to the cross modal fragment priming paradigm. Until now, priming effects arising from the manipulation of lexical stress have necessarily been studied in a relatively selective set of stimuli. The word pairs developed by Cooper et al. 2002 are unusual in that the items in each pair are phonemically identical in the first two syllables but the words have no other phonological, morphological or semantic associations. In the majority of cases, word pairs in which the items share multiple syllables would also be expected to have some similarity in meaning or to share a common derivation. Investigating stress based priming in the context of stimuli that are also semantically and morphologically related may reveal something about the relative importance of these factors for the structure of the mental lexicon.

Based on the results of the previous experiment, it was hypothesised that participants with dyslexia would be impaired on the fragment identification task while the same pattern and magnitudes of priming effects would be observed in both of the reading groups during the cross modal priming task. This pattern of results, in combination with the findings from Experiment 1, would strongly suggest a selective impairment of conscious prosodic awareness in adults with dyslexia.

Method

Participants

Participants were 40 students enrolled on undergraduate or 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 = 24 years, SD = 10.98, 8 males) and 24 age/IQ matched controls (M age = 19 years, SD = 3.36, 4 males). Participants with dyslexia had received formal statements of developmental dyslexia from a psychologist and, at the time of testing, were receiving additional academic support to assist them in their

studies. Participants with dyslexia received payment of £4 and were included in the sample regardless of the severity of their reading impairment (i.e. no effort was made to select only the most impaired students). Control participants were psychology undergraduates who participated in order to fulfil a course requirement. All participants were native speakers of British English.

Measures

Verbal IQ, performance IQ and literacy. 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. Reading skills were assessed with the Sight Word (word reading) and Phonemic Decoding (nonword reading) subscales of the TOWRE (Torgesen et al., 1999). These tasks were administered and scored as described in Experiment 1.

Fragment identification task (Mattys, 2000). During the fragment identification task participants were asked to match a spoken word fragment (e.g. *prósec*) to one of two visually presented response options on the basis of lexical stress information. The response options comprised 24 pairs of words derived from a common root word with matching segmental phonology but differing patterns of lexical stress assignment in the first two syllables (e.g. *prósecutor*; *pròsecútion*). The word fragments were spoken by a female native speaker of British English and recorded as individual sound files. The speaker was asked to produce each of the items in its entirety and the speech analysis software PRAAT (Boersma, 2001) was used to isolate the first two syllables of the words. A full list of stimuli is provided in Appendix C.

Two presentation orders were constructed and the participants within each of the reading groups were divided between them equally. The first presentation order contained

one trial from each pair of words. The corresponding member of each word pair was placed in the second presentation order. As a result, each participant received one experimental trial from each pair of words giving a total of 24 trials. The experimental trials were presented in random order and participants also received 4 practice trials prior to beginning the task. Participants received feedback on their performance during the practice trials only.

No time limit was placed on the task but participants were asked to respond as quickly as possible without making too many mistakes. There was no reference to lexical stress in the participant instructions. Each trial began with the response options displayed on screen for 5000ms. This was to ensure that participants had time to read and identify the response options before the onset of the word fragment. The response options were only presented visually. Following the allotted reading time of 5000ms the participants heard the spoken word fragment and were required to match it to one of the response options. Participants responded by pressing the appropriate key (A or B) on the keyboard. The correct answer appeared in positions A and B on an equal number of trials. The dependent variables were accuracy (/24) and mean response time. Response times were measured from the offset of the spoken word fragment.

Cross modal fragment priming (Cooper et al., 2002). In order to assess the representation of lexical stress assignment participants completed the cross modal fragment priming task. The methodological details of this task were identical to that used in Experiment 1. However, on this occasion, the stimuli used as experimental primes were the same as those used in the fragment identification task. These constituted 24 pairs of English words with identical segmental phonology but contrasting stress assignment in the first 2 syllables (e.g. *prósecutor*; *pròsecútion*). Each pair of words shared a common root word meaning that there was also a substantial overlap in the semantic and morphological properties within each pair of items. The experimenters selected 24 phonologically unrelated

control primes matched to the experimental primes in length (i.e. number of syllables) and Kucera-Francis (1967) written frequency (M experimental primes = 8.40 words per million, M control primes = 8.12 words per million) using the MRC Psycholinguistic Database (Coltheart, 1981; Wilson, 1988). As before, the prime condition and sentence context in which the target words appeared was counterbalanced across 8 presentation orders and on this occasion 2 participants with dyslexia and 3 controls were assigned to each. A complete list of the experimental and control primes used in the task is provided in Appendix D.

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 cross modal priming task was completed first followed by the fragment identification task, the literacy measures, and the IQ subscales. During the priming task and the fragment identification task, stimuli were presented and responses recorded using DirectRT research software (Jarvis, 2006) and all auditory stimuli were presented at a comfortable volume over headphones. The matching and literacy measures were administered according to the instructions in the test manuals. At the end 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

Sample characteristics are provided in Table 5. 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.

There was notable but statistically non-significant difference in age between the reading groups ($p = .109$). As indicated by the standard deviations, the difference in mean age arose mainly because of outliers in the dyslexic sample. One participant with dyslexia was aged 57 years and another was aged 31 years.

<Table 5>

Fragment identification task

Five participants with dyslexia and one control participant were equal to or below chance on the fragment identification task. Overall, participants with dyslexia were significantly less accurate than controls (Table 6). More than half (9/16) of the participants with dyslexia achieved accuracy scores $> 1SD$ below the control group mean. Participants with dyslexia were also slower to respond than controls, although, after correcting for unequal variances this result failed to reach significance.

<Table 6>

Cross modal fragment priming

Lexical decision data were trimmed as described in Experiment 1. One participant with dyslexia was excluded from the priming analyses due to an overall error rate in excess of 25%.

A prime (congruent, incongruent) by reading group (dyslexia, age/IQ control) repeated measures ANOVA was conducted on the priming effects observed in the response time data (Figure 2). There was a significant main effect of prime condition indicating that significantly more priming was observed for the stress congruent primes than for the stress

incongruent primes ($F_1(1, 37) = 5.28, p = .027, \eta_p^2 = .125, p(H_0|D) = .32$; $F_2(1, 47) = 4.29, p = .044, \eta_p^2 = .084, p(H_0|D) = .46$). The critical interaction between reading group and prime condition failed to reach significance ($F_1(1, 37) = 1.14, p = .292, ns, p(H_0|D) = .78$; $F_2(1, 47) = 1.62, p = .209, ns, p(H_0|D) = .75$) indicating that participants in both reading groups showed the same pattern of priming performance across the experimental conditions.

<Figure2>

On this occasion, the main effect of reading group was significant by subjects – although not by items – ($F_1(1, 37) = 6.02, p = .019, \eta_p^2 = .140, p(H_0|D) = .25$; $F_2(1, 47) = 1.58, p = .215, ns, p(H_0|D) = .76$) indicating that participants with dyslexia may have shown larger priming effects than controls in both stress congruent and stress incongruent conditions. However, unsurprisingly, the participants with dyslexia were again slower to respond than the control participants (M dyslexia = 1352.18ms, M control = 794.48ms). As in Experiment 1, the ANOVA analysis was repeated using standardised priming effects which controlled for overall differences in response time between individuals. After correcting for the overall slowing of participants with dyslexia, the main effect of reading group was no longer significant ($F_1 < 1, p(H_0|D) = .80$; $F_2(1, 47) = 1.21, p = .278, ns, p(H_0|D) = .79$). This indicates that the magnitudes of both priming effects were in fact equivalent across groups. Otherwise, the pattern of results was identical to the original analysis with the critical interaction remaining non-significant ($F_1 < 1, p(H_0|D) = .85$; $F_2(1, 47) = 1.25, p = .270, ns, p(H_0|D) = .79$)².

Predicting reading ability as a continuous trait

As the primary purpose of this study was to contrast performance in the two experimental tasks, and the sample size and range of background variables was smaller than in the previous experiment, large scale correlation and regression analyses were not conducted. However, we were able to calculate partial correlations – controlling for age, verbal IQ and performance IQ – between performance on the fragment identification task and the literacy measures. Accuracy scores were significantly correlated with word reading ($r = .587, p < .001$) and nonword reading ($r = .677, p < .001$). Mean response time in the fragment identification task was also significantly correlated with word reading ($r = -.501, p = .002$) and nonword reading ($r = -.454, p = .005$). In contrast, the magnitudes of stress congruent (words: $r = -.088$, ns; nonwords: $r = -.167$, ns) and stress incongruent priming (words: $r = .009$, ns; nonwords: $r = -.156$) failed to correlate with either of the literacy measures.

Discussion

This experiment contrasted the mental representation of syllabic stress assignment with participants' conscious awareness of prosodic structure utilising tasks that were approximately matched in terms of their reading requirements, verbal short-term memory load, the specific items used as stimuli and the level of prosody addressed.

Participants with dyslexia again experienced difficulties with a task that required conscious awareness of lexical stress assignment; the fragment identification task (Mattys, 2000). As in Experiment 1, a substantial proportion – although not all – of the participants with dyslexia showed relatively severe impairments of prosodic awareness, with fragment identification scores more than a standard deviation below the control group mean. Five participants with dyslexia scored below chance on this task and there was a large overall difference in accuracy between the reading groups. Performance on this task was also

significantly correlated with participants' word and nonword reading scores. These results are consistent with the findings from the DEEdee task in suggesting that adults with dyslexia show reduced awareness of syllabic stress and that the conscious awareness of prosodic structure is significantly related to literacy ability. They also confirm that a deficit in syllabic stress awareness can be observed at the lexical and metrical levels.

A stark contrast was again observed between the task requiring conscious awareness of syllabic stress and the cross modal priming paradigm. Participants in both reading groups showed the same pattern of priming effects in their response time data with significantly more priming being observed for stress congruent primes than for stress incongruent primes. Furthermore, once the overall slowing of participants with dyslexia had been taken into account, there was no difference in the magnitude of either priming effect between reading groups. Conventional methods of hypothesis testing were supported by Bayesian analyses and the posterior probabilities reported for the main effect of reading group and the interaction term were found to provide positive evidence in favour of the null hypothesis (Masson, 2011; Raftery, 1995). Unlike the fragment identification task, the priming magnitudes also failed to correlate with reading ability.

These findings, like those of Experiment 1, suggest that adults with developmental dyslexia may show reduced awareness of prosody while their underlying representations of syllabic stress assignment remain intact. On this occasion the priming task and the stress awareness task entailed similar amounts of reading on each trial and utilised the same experimental items. Furthermore, both tasks placed a negligible load on verbal short-term memory and addressed prosodic processing solely at the lexical level. The closer match between the priming task and the fragment identification task in terms of their memory load, reading demands and item selection, rules out the possibility that the apparent differences in

performance may be the result of inconsistencies in the processing demands of the experimental tasks.

Together with the results of the previous experiment, these findings suggest that the prosodic processing problems associated with dyslexia in adulthood are limited to tasks requiring participants to access and consciously reflect upon their knowledge of prosodic structure. In contrast, the ability of adults with dyslexia to represent lexical stress assignment in the mental lexicon appears to be intact. Encouragingly, this pattern of results is consistent with recent findings reported in the domain of phonemic processing. These findings and their implications for the phonological account of developmental dyslexia are evaluated in the general discussion.

General Discussion

Two studies investigated the prosodic processing abilities of skilled adult readers and adults with developmental dyslexia. Experimental tasks were chosen in order to contrast the processes of conscious prosodic awareness with the underlying representation of lexical stress in the mental lexicon.

In Experiment 1, in comparison with the age/IQ matched controls, participants with dyslexia were significantly less accurate and significantly slower to respond during the DEEdee task. Approximately half of the participants with dyslexia experienced significant difficulties with this task, registering scores more than one standard deviation below the control group mean. The ANCOVA analyses conducted in Experiment 1 address serious criticisms of the DEEdee task – those of inherent reading demands and a high short-term memory load – and confirm that the prosodic awareness deficits observed in some of our dyslexic participants cannot be attributed to their lower levels of word reading, nonword reading or verbal short-term memory ability. Likewise, in Experiment 2, participants with

dyslexia were significantly less accurate than controls during the fragment identification task. This task was carefully designed to minimise reading and short-term memory demands yet approximately one third of participants with dyslexia registered scores below or equal to chance. Together, these findings are consistent with earlier studies of children with reading difficulties (Goswami et al., 2009; Wood & Terrell, 1998) and they confirm for the first time that a deficit in the conscious awareness of prosody persists into adulthood. These results also confirm that participants with dyslexia are impaired in processing both lexical and metrical prosody. This is significant as deficits at lexical and metrical levels may each make different contributions to reading impairment. For example, a deficit in processing lexical prosody would be expected to contribute to phonological decoding problems while a deficit in processing metrical prosody is more likely to cause difficulties with the phrasing of connected text (Goodman et al., 2010).

Conscious awareness of lexical and metrical stress was also found to be strongly associated with word reading, nonword reading and important reading related skills such as phoneme awareness and verbal short-term memory. DEEdee task performance – indexed by accuracy and response time – accounted for significant, unique variance in two separate measures of speeded phonological decoding. These relationships remained even after controlling for factors such as age, verbal and performance IQ, reading related skills such as phoneme awareness and the reading demands inherent in the DEEdee task itself. As such, our findings are also consistent with studies of typically developing children which suggest that prosodic knowledge makes a unique contribution to literacy performance that is independent of phoneme awareness (Clin et al., 2009; Holliman et al., 2010; Whalley & Hansen, 2006). As prosodic knowledge is specifically useful in decoding multisyllabic words (Duncan & Seymour, 2003), learning to assign lexical stress (Gutiérrez-Palma et al., 2009) and facilitating sentence-level processes such as comprehension (Whalley & Hansen, 2006), it is

likely to be these specific reading skills that account for the relatively late emerging, direct link between the conscious awareness of speech prosody and literacy performance. Although regression analyses were not conducted in Experiment 2, both measures of performance on the fragment identification task correlated significantly with word and nonword reading ability.

Prosodic awareness was also found to be significantly correlated with phoneme awareness (Experiment 1). The relationship between prosodic and phonemic skills is complex as an early-developing sensitivity to prosody is thought to influence literacy development via phoneme awareness, while later-developing prosodic awareness skills appear to have a direct effect on reading performance that is independent of phoneme awareness. Early in development therefore, certain prosodic skills – such as rise time processing – may influence the development of phonemic knowledge. In contrast, later in development, the relationship between prosodic and phonemic awareness is more likely to be reciprocal. The contribution of prosodic skills to the development of phoneme level knowledge has previously been proposed by a number of researchers (Goswami et al., 2002; Kuhl, 2004; Richardson et al., 2004) and understanding this link may provide new information about how phonemic skills develop. However, it is also important to consider why prosodic and phonemic awareness continue to be so strongly associated in the current sample of adult readers even after phonemic awareness and phonological representations are established. The reason for this continued association seems to be that measures of prosodic and phonemic awareness require the application of the same phonological processes to different levels of the phonological hierarchy. Phonemic and prosodic awareness tasks both measure the ability to access and process phonological information in an abstract way, for example, by producing phonemes or stress contours in isolation rather than in the context of a particular word or phrase.

The results of the cross modal fragment priming tasks contrast sharply with the impaired performance observed in the same samples of participants during the prosodic awareness tasks. In each of the cross modal fragment priming tasks adults with dyslexia showed normal patterns of stress based priming at similar effect magnitudes to the control participants. These findings suggest that adults with developmental dyslexia accurately represent lexical stress in the mental lexicon and, in the context of an implicit language task, are able to distinguish between words with overlapping segmental phonology, as well as shared morphological and semantic properties, on the basis of differences in lexical stress assignment. The results reported in Experiment 2, in which the priming task was approximately matched to the fragment identification task in terms of memory load, reading demands and item selection also rule out the possibility that these apparent differences in performance may be the result of inconsistencies in the processing demands of the experimental tasks.

In short, our results indicate an interesting dissociation: although adults with dyslexia represent lexical stress accurately in the mental lexicon, they continue to show difficulties in tasks requiring conscious or effortful processing of prosodic information. This pattern of performance mirrors that reported at the phonemic level by Ramus and Szenkovits (2008). While the results of the DEEdee task (Experiment 1) and the fragment identification task (Experiment 2) are consistent with previous observations of impaired prosodic processing in children with dyslexia (Goswami et al., 2009; Wood & Terrell, 1998), and the argument that such deficits make unique contributions to other phonological and literacy difficulties, they caution against assuming deficient representation of prosody from performance in a prosodic awareness task.

One possible criticism of this interpretation is that the failure to find different patterns of priming performance across reading groups constitutes a null effect and is therefore not

open to interpretation. However, this critique ignores the fact that the non-significant interactions were obtained because the main effect of prime condition – itself statistically significant – could clearly be observed in both reading groups (Figures 1 and 2). This provides positive evidence for the assertion that both groups of individuals were equally sensitive to the prosodic manipulations present in the stimuli. Furthermore, Bayesian statistics (Masson, 2011; Raftery, 1995) reported in both experiments have provided positive evidence in favour of the null hypothesis for each of the critical interaction terms. Given these observations and the clear hypotheses advanced in the introduction, it would be unfair to claim that the findings cannot be interpreted.

Other readers may take issue with our interpretation on the basis that it tacitly assumes localist phonological representations for words in the form of a mental lexicon. Our argument is consistent with that put forward by Ramus and Szenkovits (2008) to account for their observation that highly educated adults with dyslexia show phonological similarity effects of equal magnitude to age/IQ matched controls, as well as normal repetition priming effects, while continuing to experience difficulties with more conventional measures of phonological awareness. Those authors argue that adults with dyslexia have intact phonological representations but suffer from a reduced ability to access phonological information to support tasks such as print-to-sound decoding. However, research in the field of connectionist modelling has provided an alternative to this view. It has been noted that adults and children with dyslexia, despite being impaired in overall reading ability, show effects of spelling-sound regularity that are comparable to those of chronological- and reading-age controls (Metsala, Stanovich, & Brown, 1998). The finding that an effect arising from the phonological properties of linguistic stimuli is present in dyslexia, while overall reading/phonological performance is impaired, is consistent with the data reported in the current experiments and those of Ramus and Szenkovits. Metsala et al. argue that

connectionist models, in which words are represented in a distributed fashion, can account for this pattern of performance. Evidence in support of this claim comes from a study by Brown (1997) in which two connectionist models – one with coarse-grained phonological representations and one with fine-grained, or fully segmented, phonological representations – were contrasted in their reading of regular words, irregular words and nonwords. The model with the lower quality phonological representations was found to show impaired performance in nonword reading analogous to that seen in dyslexia (e.g. Rack, Snowling & Olsen, 1992) while also showing normal effects of spelling-sound regularity in word reading. These findings suggest that a model in which phonological representations are distributed rather than localised may be able to account for our data without the hypothesised dissociation between phonological representation and phonological awareness/access. The ability of these two types of model to account for the pattern of reading impairment seen in dyslexia in adulthood is an open empirical question that strongly merits further research.

Finally, researchers may take issue with the sample of relatively compensated dyslexic individuals who took part in the current research and the inclusion criteria adopted in the experiments. As noted above, rather than use a strict cut-off point to determine reading group status (e.g. including only participants with reading scores $> 1SD$ below the mean in the dyslexic sample), no effort was made to select only the most impaired students. The aim of this approach was to capture the heterogeneous and continuous nature of reading ability and avoid drawing artificial comparisons between highly skilled readers on the one hand and very impaired readers on the other. A disadvantage of this approach is that it creates an overlap in reading ability between groups that may inflate the chances of finding hypothesised null effects. However, if the failure to find differences in the overall magnitude and pattern of prosodic priming were a result of undue overlap in reading ability between groups, treating reading ability as a continuous variable (e.g. collapsing across reading groups

in a regression analysis, Experiment 1) should reveal a significant association between reading ability and priming performance. As described above, this is not the case. It should also be remembered that equivalent patterns and magnitudes of priming performance were also observed in a sub-sample of participants in which there was no overlap in word reading ability between groups (Experiment 1). Such a critique of our design also fails to explain why we were able to identify differences in stress awareness between reading groups, but not differences in priming performance.

However, it should be noted that although many participants with dyslexia experienced significant difficulties with the prosodic awareness tasks, such deficits were not universal. In Experiment 1 for example, the effect of reading group status on DEEdee task accuracy failed to reach significance when all participants with dyslexia were included. This is partly due to the conservative nature of the ANCOVA analysis – which included three defining characteristics of dyslexia as covariates – however, this result also underlines the heterogeneity that often characterises dyslexic samples (Ramus, Rosen, Dakin, & Day et al., 2003; White, Milne, Rosen, & Hansen et al., 2006).

Finally, it should also be acknowledged that the highly educated adults with dyslexia who took part in the current studies are not necessarily representative of the broader population of dyslexic individuals. Many of our participants have received substantial amounts of remedial reading tuition and phonological training. Furthermore, their IQ, high educational level, application of compensatory strategies, and experience of reading intervention will all have shaped the particular nature of their individual phonological deficits. Taking this view, other samples of dyslexic individuals, and particularly children or less educated adults, may show a broader impairment of prosodic and phonemic processing. Indeed, there is a large and compelling evidence base, including findings from priming (Boada & Pennington, 2006), eye-tracking (Desroches, Joanisse & Robertson, 2006) and

neurophysiological methodologies (Maurer, Bucher, Brem, & Brandeis, 2003; Schulte-Kórne, Deinel, Bartling, & Remschmidt, 1998), pointing to a highly fundamental difficulty with phonological processing in children with dyslexia. However, our data suggest that, at least in the case of prosodic processing, it may be more parsimonious to attribute the difficulties of educated adults with dyslexia to specific problems with higher level phonological processes involved in accessing and manipulating phonological information.

More speculatively, there may be multiple phonological deficits that characterise dyslexia at different stages of development and phonological impairments may vary quantitatively and qualitatively across samples of dyslexic individuals who differ in terms of background variables such as age, educational level and experience of reading intervention. The phonological account of dyslexia may therefore be strengthened by a systematic understanding of the types of phonological processes that are impaired in different dyslexic samples.

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Footnotes

1. To our knowledge the only existing data addressing the links between prosodic skills and reading impairment in adulthood are unpublished findings involving adults with self-reported histories of reading problems (Kitzen, 2001).
2. Sub-group analyses of severely impaired readers were not conducted in Experiment 2. Given the outcome of such analyses in Experiment 1 there was no reason to suspect that they would produce a different pattern of results.

Table 1.

Reading group means (SD) and significance tests for matching, literacy and literacy related measures

Measure	Dyslexia	Age/IQ Control	<i>t</i> (78)	sig.	<i>d</i>
Age (yrs.)	20.34 (4.23)	20.71 (7.11)	<1	-	-
Verbal IQ	57.72 (4.87)	56.58 (6.02)	<1	-	-
Performance IQ	56.72 (6.15)	56.75 (5.66)	<1	-	-
Vocabulary	57.50 (4.87)	57.63 (6.67)	<1	-	-
Word Reading	87.25 (12.06)	95.21 (10.68)	3.10	<i>p</i> = .003	0.70
Nonword Reading	89.66 (12.72)	102.79 (11.41)	4.82	<i>p</i> < .001	1.09
Passages (sec.)	31.03 (11.49)	21.92 (3.85)	4.33	<i>p</i> < .001	1.15
Phon. Awareness	9.59 (3.40)	11.48 (3.55)	2.37	<i>p</i> = .020	0.54
Verbal STM	15.53 (2.79)	17.40 (2.17)	3.35	<i>p</i> = .001	0.77

Table 2.

Reading group means (SD) and significance tests for the DEEdee task

Measure	Dyslexia	Age/IQ Control	<i>t</i> (78)	sig.	<i>d</i>
Accuracy (/20)	14.34 (3.00)	16.96 (2.88)	3.91	$p < .001$	0.89
RT (sec.)	6.76 (2.72)	4.56 (1.63)	4.12	$p < .001$	1.03

Table 3.

Correlations calculated for the entire sample

	1	2	3	4	5	6	7
1. Word Reading	-						
2. Nonword Reading	.786	-					
3. Passages (sec.)	-.669	-.808	-				
4. Phon. Awareness	.443	.533	-.340	-			
5. Verbal STM	.275	.303	-.278	.322	-		
6. DEEdee Acc.	.355	.538	-.301	.519	.429	-	
7. DEEdee RT (sec.)	-.327	-.460	.461	-.406	-.379	-.433	-

Note: All correlations are significant ($p < .05$, $df = 78$)

Table 4.

Correlations calculated within each reading group (dyslexic group below and control group above centre line)

	1	2	3	4	5	6	7
1. Word Reading	-	.566	-.489	.213	-.137	.045	-.128
2. Nonword Reading	.871	-	-.712	.478	-.165	.312	-.251
3. Passages (sec.)	-.683	.803	-	-.262	.106	-.033	.258
4. Phon. Awareness	.594	.513	-.304	-	.077	.447	-.322
5. Verbal STM	.412	.418	-.228	.479	-	.200	-.138
6. DEEdee Acc.	.444	.558	-.193	.501	.489	-	.165
7. DEEdee RT (sec.)	-.229	-.347	.328	-.372	-.352	.442	-

Note: Significant correlations ($p < .05$) indicated by bold font (df age/IQ control = 46, df

dyslexia = 30)

Table 5.

Reading group means (SD) and significance tests for matching and literacy measures

Measure	Dyslexia	Age/IQ Control	<i>t</i> (38)	sig.	<i>d</i>
Age (yrs.)	24.25 (10.98)	19.46 (3.36)	1.69	$p = .109$	-
Verbal IQ	51.38 (7.56)	51.33 (5.56)	<1	-	-
Performance IQ	52.19 (10.04)	53.33 (6.21)	<1	-	-
Word Reading	84.88 (9.42)	102.29 (10.71)	5.28	$p < .001$	1.67
Nonword Reading	83.19 (11.14)	104.00 (10.08)	6.13	$p < .001$	1.94

Table 6.

Reading group means (SD) and significance tests for the fragment identification task

Measure	Dyslexia	Age/IQ Control	<i>t</i> (38)	sig.	<i>d</i>
Accuracy (/24)	15.56 (3.97)	20.33 (3.32)	4.12	$p < .001$	1.30
RT (sec.)	3.49 (3.29)	1.88 (0.96)	1.91	$p = .074$	0.72

Figure Captions

Figure 1. Mean priming effect magnitudes by reading group and prime condition

Figure 2. Mean priming effect magnitudes by reading group and prime condition

Figure 1

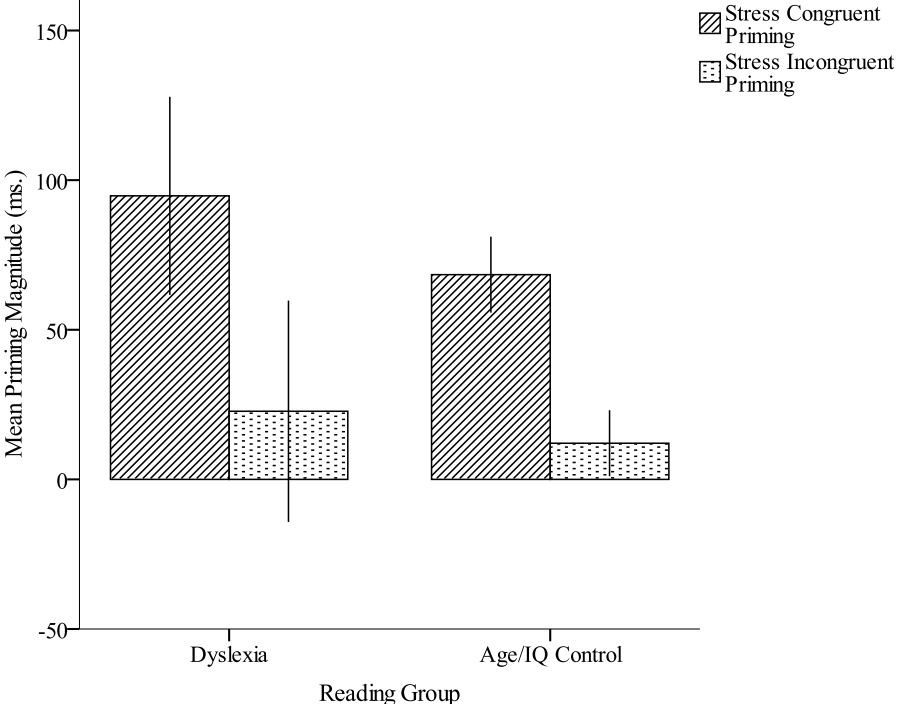
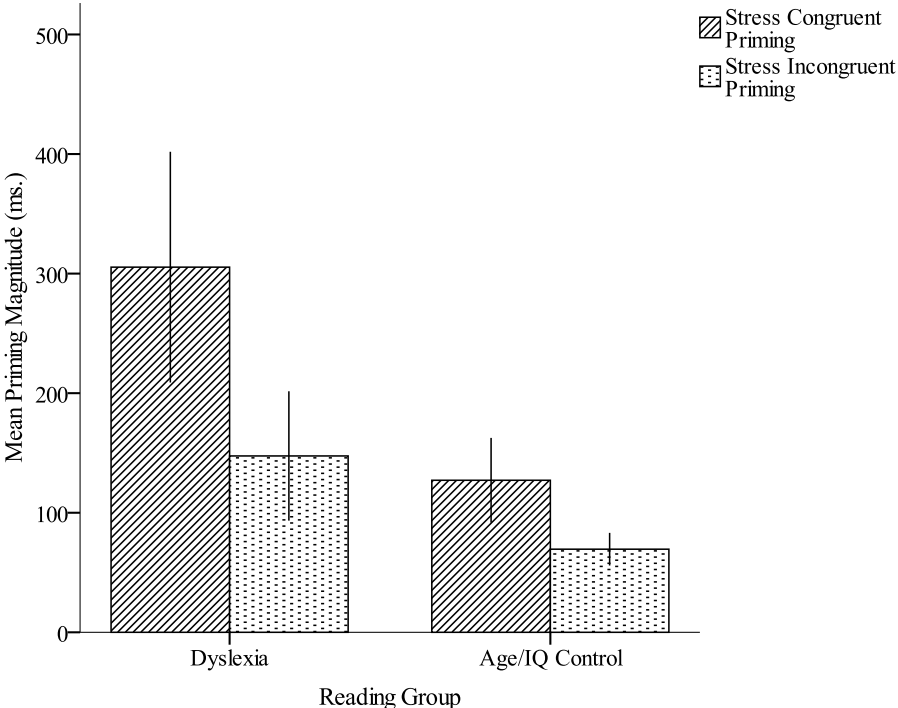


Figure 2



Appendix A

Table A1.

Spoken stimuli and response options presented during the DEEdee task

Spoken DEEdee Stimulus	Response Option (correct answer in italics)
deeDEEdee	<i>Aláddin; Hóme Alóne; Lóst in Spáce</i>
DEEdee dee DEE	<i>Jékyl and Hýde; The Gódfather; Oméga Mán</i>
deeDEEdeedee DEE	<i>Apócalypse Nów; Fúll Métal Jácket; Dríving Miss Dáisy</i>
DEE dee DEE	<i>Lóst In Spáce; Drácula; Góodfellas</i>
DEE dee dee DEEdee	<i>Báck to the Fúture; On the Wáterfront; Sílence of the Lámb</i>
dee deeDEEdeedee DEEdee	<i>The Magníficent Séven; Bórn on the Fóurth of Julý; The Húnt for Réd Octóber</i>
DEEdeedee dee	<i>Ánimal House; Tráding Pláces; Blázing Sáddles</i>
deedeeDEEdee DEE	<i>Indepéndence Dáy; Plánet of the Ápes; The Términator</i>
DEEdee dee dee DEE	<i>Sílence of the Lámb; On the Wáterfront; The Sóund of Músic</i>
DEE dee dee DEEdee	<i>Jáck and the Béanstalk; Béauty and the Béast; Fríday the Thirtéenth</i>
deedeeDEEdee	<i>Cinderélla; The Tínder Bóx; Díck Whíttington</i>
DEE DEE dee dee DEEdee	<i>Snów Whíte and the Séven Dwárves; Góldilocks and the Threé Béars;</i>
DEE	<i>The Twélfve Dáncing Princésses</i>
dee DEEdee DEEdee	<i>The Líttle Mérrmaid; Hánsel and Grétal; The Gréat Escápe</i>
DEEdee dee deeDEE	<i>Thélma and Louíse; The Líttle Princéss; The Úgly Dúckling</i>
deeDEEdee	<i>Chicágo; Chínatown; Fíeld of Dréams</i>
DEEdeedee	<i>Góodfellas; Cool Rúnning; The Snów Queen</i>
DEEdeedee	<i>Drácula; Godzília; Aláddin</i>
DEEdee DEEdee	<i>Tótal Récall; Jékyl and Hýde; Ánimal House</i>
deeDEEdee DEE	<i>Oméga Mán; Góne with the Wínd; Tráding Pláces</i>
DEEdee dee DEEdee	<i>Dríving Miss Dáisy; Béverley Hílls Cóp; The Términator</i>

Note: To improve readability, upper case font has been used to indicate the syllable(s)

carrying primary stress in the DEEdee stimuli. Accents are used to indicate primary stress

in the response options. Correct response options are italicised.

Appendix B

Table A2.

Spoken primes and target words presented during the cross modal fragment priming task

(Experiment 1)

Experimental Prime (Initial Stress)	Experimental Prime (Non-Initial Stress)	Control Prime
Admiral	Admiration	Mosquito
Analogue	Analytic	Compensation
Animal	Anniversary	Proportion
Arrogant	Aromatic	Generous
Ceremony	Cerebellum	Permission
Compromise	Comprehend	Discipline
Conference	Confirmation	Manipulate
Consequence	Conservation	Obnoxious
Corridor	Correspond	Invention
Diagram	Diabetes	Apology
Enterprise	Entertain	Foundations
Etiquette	Etymology	Volcano
Exercise	Exhibition	Messenger
Horrible	Horizontal	Reputation
Immigrant	Immature	Catastrophe
Impotent	Impolite	Reflection
Interval	Interfere	Residence
Manicure	Manifestation	Accelerate
Metaphor	Metamorphosis	Seriously
Motorbike	Motivation	Umbrella
Opera	Opposition	Encouragement
Prominent	Promenade	Illusion
Property	Propaganda	Hesitation
Repertoire	Repetition	Initiative

Note: Only the first two syllables of each word were included in the

spoken prime. Words used to form the experimental primes also

served as target words.

Appendix C

Table A3.

Word pairs used in the fragment identification task

Initial Stress	Non-Initial Stress	Initial Stress	Non-Initial Stress
Prosecutor	Prosecution	Celebrating	Celebration
Delegating	Delegation	Indicator	Indication
Presidency	Presidential	Calculated	Calculation
Category	Categorical	Generator	Generation
Consequently	Consequential	Fascinating	Fascination
Navigator	Navigation	Dominating	Domination
Vindicating	Vindication	Terminating	Termination
Fabricating	Fabrication	Decorator	Decoration
Segregating	Segregation	Demonstrator	Demonstration
Replicating	Replication	Cultivating	Cultivation
Hesitating	Hesitation	Aggravating	Aggravation
Agitating	Agitation	Ceremony	Ceremonial

Appendix D

Table A4.

Spoken primes and target words presented during the cross modal fragment priming task

(Experiment 2)

Experimental Prime (Initial Stress)	Experimental Prime (Non-Initial Stress)	Control Prime
Prosecutor	Prosecution	Accelerate
Delegating	Delegation	Exaggerate
Presidency	Presidential	Audacity
Category	Categorical	Solicitor
Consequently	Consequential	Biography
Navigator	Navigation	Conservative
Vindicating	Vindication	Thermometer
Fabricating	Fabrication	Malevolent
Segregating	Segregation	Coincidence
Replicating	Replication	Academy
Hesitating	Hesitation	Kaleidoscope
Agitating	Agitation	Hypocrisy
Celebrating	Celebration	Philosopher
Indicator	Indication	Apology
Calculated	Calculation	Triangular
Generator	Generation	Enthusiast
Fascinating	Fascination	Supremacy
Dominating	Domination	Symmetrical
Terminating	Termination	Evaporate
Decorator	Decoration	Illuminate
Demonstrator	Demonstration	Collaborate
Cultivating	Cultivation	Photography
Aggravating	Aggravation	Revitalise
Ceremony	Ceremonial	Utility

Note: Only the first two syllables of each word were included in the

spoken prime. Words used to form the experimental primes also

served as target words.