The Conscious Awareness and Underlying Representation of Syllabic Stress in Skilled Adult Readers and Adults with Developmental Dyslexia

by

Ian R. Mundy

A thesis submitted in partial fulfilment of the requirements for the degree of Doctor of Philosophy in Psychology

Department of Psychology, University of Warwick

March 2011

Table of contents

Chapter 3

Chapter 4

Chapter 5

Chapter 6

Chapter 7

List of Tables

List of Figures

Chapter 4

Chapter 5

Chapter 6

Acknowledgements

The research described in this thesis was supported by a Warwick Postgraduate Research Fellowship awarded to Ian R. Mundy in January 2008 by the Department of Psychology at the University of Warwick.

I am extremely grateful to my supervisor at Warwick, Dr Julia Carroll, for her advice, support and encouragement. I would also like to thank Professor Gordon Brown and Professor Elizabeth Maylor for their comments on the research and their advice on data analysis.

I was also fortunate to receive feedback on my research from many academics outside of Warwick and I would particularly like to thank Usha Goswami, Nicolás Gutiérrez-Palma, Lesly Wade-Woolley and Clare Wood for their questions, comments and criticisms. I am also grateful to Jennifer Thomson and Clare Wood for giving me the opportunity to speak at their various symposia and seminars.

Finally, I would also like to thank Rachel Carter for voicing the auditory stimuli used in Experiments 1a, 1b and 2, Steve Cumberland at Fullrange for assisting with sound recording, and all of the people who kindly gave up their time to participate in the research.

Declaration

I declare that the research presented in this thesis is my own work and has not been submitted for any other degree or qualification.

Terminology and abbreviations

Amplitude rise-time; fundamental frequency

Cross modal fragment priming; lexical decision

DEEdee task; reiterative speech; reiterative syllable substitution

Developmental dyslexia; phonological dyslexia; surface dyslexia

Fragment identification task

Iambic stress; trochaic stress

Mental lexicon

Phoneme; grapheme; morpheme; onset; rime; syllable

Phonological awareness; phonological representation

Prosody; lexical stress; metrical stress; speech rhythm

Segmental phonology; suprasegmental phonology

Spelling-sound correspondences; spelling-stress correspondences

Accuracy (Acc.)

Degrees of freedom (*df*)

Fundamental Frequency (F_0)

Mean (*M*); Standard deviation (*SD*)

Milliseconds (ms.)

Response time (RT)

Phoneme awareness (PA; Phon. Awareness)

Seconds (sec.)

Short-term memory (STM)

Abstract

The relationship between phonemic awareness and literacy ability is well established in the developmental and adult reading literatures. Recent research indicates that awareness of the rhythmic patterns present in spoken language (i.e. prosody) may also be an important predictor of reading ability. Researchers have demonstrated that sensitivity to speech prosody can facilitate speech segmentation and the development of phoneme awareness. Awareness of the rhythmic patterns in spoken words and phrases is also known to play a direct role in phonological decoding, reading comprehension and learning to use punctuation. These findings have the potential to enhance our understanding of typical reading development and inform theories of how poor phonological and auditory skills contribute to dyslexia. This research also helps extend our knowledge of skilled and impaired reading to a wider range of reading materials (e.g. multisyllabic words) and thus raises issues relevant to cognitive models of visual word recognition.

A small number of studies have demonstrated that sensitivity to the prosodic patterns in spoken language is reduced in children with dyslexia. However, there is currently no published research investigating the prosodic processing skills of adults with dyslexia. The precise nature of the prosodic processing deficit associated with dyslexia is also unclear. These gaps in the literature are problematic because phonological processing is multifaceted and the relationship between specific phonological skills and reading ability may change over time.

This thesis presents four cross sectional studies in which adults with dyslexia were compared with control participants matched for age and IQ on various tasks designed to measure prosodic processing. The experiments also contrast the conscious awareness of prosodic structure with the underlying representation of syllabic stress assignment in the mental lexicon and the ability to acquire spelling-sound correspondences for decoding stress assignment in multisyllabic words.

Participants with dyslexia showed reduced awareness of lexical and metrical prosody and these skills were found to be significantly associated with, and predictive of, phoneme awareness and phonological decoding ability (Experiments 1a and 2). In contrast, adults with dyslexia showed normal patterns of stress based priming at magnitudes similar to controls (Experiments 1b and 2). Similar, although somewhat weaker results were also obtained when lexical stress was primed with abstract stress templates rather than real-word stimuli (Experiment 3). Participants with dyslexia also showed normal effects of spelling-stress congruency on lexical decision times for disyllabic words (Experiment 4).

The overall pattern of results strongly suggests 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, or to process information related to prosodic structure in an abstract way. In contrast, the ability of adults with dyslexia to represent lexical stress assignment in the mental lexicon, assemble novel prosodic representations, and learn correspondences between lexical stress assignment and aspects of orthographic structure appears to be intact. Encouragingly, this pattern of results is consistent with recent findings reported in the domain of phonemic processing.

Chapter 1

Theoretical accounts of developmental dyslexia

Overview

The aim of this chapter is to review the empirical evidence supporting various theoretical accounts of developmental dyslexia. It is argued that language based theories currently offer the most comprehensive explanation of reading impairment and that reduced awareness and poor underlying representation of segmental phonology is the most likely candidate for a core deficit in dyslexia. Research findings suggesting a role for impaired speech perception, auditory and visual temporal processing, sluggish attentional shifting, and cerebellar dysfunction are also discussed. Finally, it is suggested that broadening the study of phonological processing in dyslexia to encompass an element of suprasegmental phonology – specifically, prosody (speech rhythm) – may provide new insights into the causes of reading failure.

Developmental dyslexia as a language disorder

Developmental dyslexia is an unexpected and 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). Estimated prevalence rates for developmental dyslexia range between three and ten per cent in the general population (Snowling, 2000) and the condition persists into adulthood where it may continue to cause significant problems, even for academically gifted students in higher education (Hatcher, Snowling, & Griffiths, 2002). Dyslexia has long been of interest to researchers because of its potential consequences for academic achievement (Richardson & Wydell, 2003), self-esteem (Burden, 2008; Ridsdale, 2004), and mental health (Carroll & Iles, 2006). The highly selective impairment of literacy skills in the absence of more general disability also offers a valuable opportunity for researchers to learn about typical and atypical development.

Throughout its history, developmental dyslexia has often been construed as a disorder of visual perception and a number of now discredited visual theories persist as popular misconceptions. Vellutino, Fletcher, Snowling, and Scanlon (2004) cite the examples of optical reversibility theory (Orton, 1925), which suggested that people with dyslexia may perceive mirror images of letters, and spatial confusion theory (Herman, 1959), which suggested that people with dyslexia may fail to perceive printed text in a coherent fashion. Some visual theories of dyslexia, such as the magnocellular deficit theory (Stein & Walsh, 1997), remain popular today and findings of low-level visual impairments in dyslexia continue to emerge (Cornelissen, Richardson, Mason, Fowler, & Stein, 1995; Eden, van Meter, Rumsey, Maisog, Woods, & Zeffiro, 1996). However, since the early 1970s, the dominant theoretical accounts of developmental dyslexia have been language based with a particular focus on the awareness and underlying representation of segmental phonology (i.e. phonemes).

The phonological account of developmental dyslexia (Fowler, 1991; Mattingly, 1972; Snowling, 2000; Stanovich, 1988; 1998; Vellutino, 1977; 1979) recognises that literacy skills build on pre-existing knowledge of spoken language.

Mattingly (1972) argued that learning to read requires conscious awareness of the various phonological units which form words, and that a lack of ‘linguistic awareness’ may be a cause of developmental dyslexia. For readers of alphabetic orthographies such as English, awareness of word structure at the phonemic level is particularly important as written words are decoded via learned correspondences between phonemes and graphemes. Typically developing children display phoneme awareness and a sensitivity to grapheme-phoneme correspondences from the earliest stages of reading instruction (Rack, Hulme, Snowling, & Wightman, 1994) and phonics based teaching has become the primary method of literacy instruction for children in the UK (Rose, 2006; 2009) and elsewhere in Europe (Caravolas, 2005). The phonological account of dyslexia proposes that reading problems arise when people fail to achieve normal levels of phoneme awareness and therefore struggle to learn the grapheme-phoneme correspondences that are required for decoding printed words.

Unlike typically developing children, and skilled adult readers, people with dyslexia experience pervasive problems with multiple aspects of phonological processing. Children and adults with dyslexia are impaired on various measures of phoneme awareness (Bruck, 1992; Hatcher et al., 2002; Snowling, 2000). In contrast, high levels of phoneme blending ability have been associated with early or precocious reading (Olson, Evans, & Keckler, 2006). Problems with phonological processing also manifest themselves in a reduced ability to maintain and manipulate phonological information in short-term memory (Baddeley, Gathercole, & Papagno, 1998; Gathercole & Baddeley, 1990; Pickering, 2006; Smith-Spark & Fisk, 2007), reduced speed and accuracy of rapid naming (Felton & Wood, 1989; Snowling, van

Wagtendonk, & Stafford, 1988), and poor spoken language skills (Catts, 1986; 1989).

In addition to behavioural studies, the results of recent brain imaging research are also consistent with the phonological account of dyslexia. For example, while the neural responses of typically developing children to the speech sounds of their native language can be dampened by the simultaneous visual presentation of an incongruent letter, children with dyslexia show no such effect, thus suggesting weaker neural integration of orthographic and phonological information (Blau, Reithler, van Atteveldt & Seitz et al., 2010). Furthermore, while reading, and while making phonological judgments about printed letter strings, adults with dyslexia show unusually low levels of activation in frontal and temporoparietal regions of the left hemisphere known to be crucially involved in phonological processing and in the integration of phonology and orthography (Blau, van Atteveldt, Ekkebus, Goebel & Blomert, 2009; Goswami, 2008; Price & McCrory, 2005).

The broad and pervasive nature of the phonological processing deficit associated with dyslexia has led to the suggestion 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 (Fowler, 1991; Snowling, 2000). It is proposed that this in turn is responsible for reduced levels of phoneme awareness and a reduced capacity for learning mappings between graphemes and phonemes. The results of twin studies suggest that reading ability and the phonological skills underlying literacy development are highly heritable and therefore it is likely that the widespread phonological processing problems associated with dyslexia are partly influenced by genetic factors (Bishop, 2009; Monaco, 2008; Pennington & Olson, 2005).

Phonological processing and dyslexia: establishing a causal connection

One task which places a particularly high load on phonological processing skills is nonword repetition. This task has been described as a measure of participants' ability to create new phonological representations for novel sound patterns (Beaton, 2004). Typically developing children show a small disadvantage in repeating nonwords compared with both high and low frequency real words, however, in children with dyslexia the discrepancy between real word and nonword repetition is far more pronounced (Snowling, Stackhouse, & Rack, 1986). People with dyslexia also seem to have particular difficulties in reading nonwords aloud (Rack, Snowling, & Olson, 1992). Brown (1997) demonstrated that inadequate phonological representations are a likely cause of this qualitative difference in reading performance by comparing the regular word, irregular word, and nonword reading of two different types of connectionist model. In the first type of model, phonological and orthographic representations were fully segmented (Plaut, McClelland, Seidenberg, & Patterson, 1996), meaning that all phonemes and graphemes were represented individually by distinct processing units. In contrast, the second kind of model used more coarse grained representations in which processing units represented phoneme or grapheme 'triples' (Seidenberg & McClelland, 1989). The latter model showed a pronounced deficit in accurately decoding nonwords relative to both regular and irregular real words, thus resembling the reading/repetition performance of children with dyslexia. In contrast, the model with fully segmented phonological representations produced a pattern of reading performance which more closely resembled typically developing readers.

Computational and connectionist modelling has contributed greatly to the study of typical and atypical reading development. In addition to the study reported by Brown (1997), implementations of the dual route cascaded model (Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001), and a modified version of Seidenberg and McClelland's (1989) triangle model (Harm & Seidenberg, 1999), have successfully demonstrated how the pattern of reading performance seen in developmental dyslexia could arise from impaired phonological representations and a reduced capacity for learning correspondences between graphemes and phonemes.

Intervention studies and longitudinal designs utilising chronological- and reading-age control groups have also indicated a causal connection between phonological processing and literacy ability. Longitudinal data allow researchers to observe literacy development over an extended period of time and establish which of the associated cognitive factors emerge prior to, and form predictive relationships with, reading failure. Intervention studies measure the extent to which an improvement in one set of skills may bring associated benefits in reading performance. As such, longitudinal and intervention studies represent the sternest test of any causal model of developmental dyslexia.

At present, the phonological account of developmental dyslexia is the theory that has received the most validation from longitudinal and intervention studies (Goswami, 2003). Longitudinal studies have consistently found phonological awareness, and in particular phoneme awareness, to be a strong, direct predictor of reading ability across many different alphabetic languages (e.g. Babayiğit & Stainthorp, 2007; Bradley & Bryant, 1983; Furness & Samuelsson, 2009; Hulme, Hatcher, Nation, Brown, Adams, & Stuart, 2002; Hulme, Hatcher, Nation, Lundberg, Olofsson, & Wall, 1980; Nikopoulos, Goulandris, Hulme, & Snowling, 2006) and interventions based on improving phonological skills (Lundberg, Frost, & Peterson, 1988; Torgesen, Alexander, Wagner, Rashotte, Voeller, & Conway et al., 2001), and making explicit links between phonological knowledge and written text (Hatcher, Hulme, & Ellis, 1994), have been shown to have a positive effect on reading performance. Torgesen (2005) evaluated several different phonological interventions for poor readers and attempted to quantify the gains in literacy ability achieved by the children who took part in them. Data from thirteen separate intervention studies were included in the analyses. Per hour of instruction, these interventions yielded average increases of approximately .3 standard deviations in phonemic decoding scores and .2 standard deviations in word reading and reading comprehension scores.

Is impaired phonological processing a core deficit in dyslexia?

Despite the widespread acceptance that impaired phonological processing is the proximal cause of reading difficulties in dyslexia, it is unclear whether it constitutes a core deficit. In order to be considered a core deficit, the phonological processing impairment would need to be the crucial causal factor in all cases of developmental dyslexia and be sufficient to cause reading problems in the absence of any other contributing factors. The ability of the phonological impairment to meet these requirements is challenged firstly by cases of developmental dyslexia in which impaired phonological processing appears to play a diminished etiological role, and secondly, by a variety of research findings indicating that, in at least some cases of dyslexia, a phonological processing impairment may itself be a consequence of more fundamental perceptual and cognitive deficits.

As noted above, one of the principal manifestations of the phonological processing impairment observed in dyslexia is a relative inability to read and repeat nonwords (Rack et al., 1992; Snowling et al., 1986). However, a sub-type of developmental dyslexia, known as surface dyslexia, is characterised by a pattern of impairment in which people have particular difficulty reading irregular words while their nonword reading is relatively spared. Irregular words (e.g. *yacht; colonel; pint*) are so-called because they violate grapheme-phoneme conversion rules. Attempting to decode irregular words using grapheme-phoneme conversion rules produces regularisation errors in which an irregular word is given an incorrect but phonemically regular pronunciation. Therefore, in order to read these words correctly, a reader must activate a word form in the phonological lexicon directly from the orthographic input (Castles & Coltheart, 1993; Coltheart, 1978) or via the word's meaning (Coltheart et al., 2001; Seidenberg & McClelland, 1989). The dual route model of reading (Coltheart, 1978) proposes that nonword reading and irregular word reading are achieved by two dissociable reading processes; the lexical procedure for reading irregular words and the sub-lexical procedure for decoding nonwords.

Adults and children with surface dyslexia are often impaired relative to chronological-age controls in both irregular word and nonword reading, with the deficit for irregular words being more severe (Milne, Nicholson, & Corballis, 2003; Stanovich, 1998; Stanovich, Siegel, & Gottardo, 1997). However, cases also exist where participants' nonword reading scores fall within the normal range and only irregular word reading is significantly impaired (Castles & Coltheart, 1993; Manis, Seidenberg, Doi, McBride-Chang, & Petersen, 1997). In response to these observations, researchers have proposed that while the classical form of developmental dyslexia is characterised by severe and pervasive phonological processing problems, the surface pattern of dyslexic symptoms is the result of a much milder phonological impairment acting in conjunction with additional cognitive factors, such as visual or semantic processing deficits, or environmental factors, such as insufficient print exposure and poor teaching (Manis et al., 1996; Snowling, 1987; Stanovich, 1998; Stanovich, Siegel, & Gottardo, 1997). The possibility that environmental factors play a greater role in surface dyslexia is supported by the results of a twin study indicating lower heritability of surface dyslexia than phonological dyslexia (Castles, Datta, Gayan, & Olson, 1999). Other researchers have gone further and argued that the primary causes of surface dyslexia are non-phonological in nature. For example, it has been argued that people with the surface form of developmental dyslexia have a specific impairment of orthographic processing arising from selective damage to the lexical reading procedure specified in the dual route model (Castles & Coltheart, 1993; Coltheart & Jackson, 2003). The surface form of dyslexia has also been conceptualised as a general delay in reading development (Harm & Seidenberg, 1999). However, regardless of whether surface dyslexia is seen as a result of mild phonological impairment acting in conjunction with other risk factors, a selective impairment of non-phonological processes, or a general delay in literacy development, the existence of people with surface dyslexia indicates that the severity of phonological processing impairments and their role in creating reading problems varies between individuals.

A related issue is the ongoing debate concerning the extent to which phonological processing can be regarded as a unified concept, and whether distinct phonological processes may be differentially impaired in dyslexia (Ramus, 2001). Some researchers argue that phonological processing can be decomposed into various constituent skills. For example, it has been suggested that important differences exist between the higher order processes of phonological awareness and other aspects of phonological processing, such as lexical access and verbal short-term memory (Wagner & Torgesen, 1987). Recent research suggests that the processes involved in the formation of phonological representations can be distinguished from the ability to access those representations for conscious processing (Anthony, Williams, Aghara, Dunkelberger, Novak, & Mukherjee, 2010). The fragmentation of phonological processing in this way raises the possibility that different phonological skills make independent contributions to literacy and may be more or less impaired in different dyslexic samples. Consistent with this possibility, the double-deficit hypothesis (Wolf & Bowers, 1999) proposes that the processing problems of people with dyslexia can be separated into dissociable components of phonological awareness and rapid naming, each of which may contribute to reading failure in a different way. Research has also suggested that highly educated adults with dyslexia may show relatively pure impairments of phonological awareness and phonological retrieval processes while having intact phonological representations (Ramus & Szenkovits, 2008). Like the findings relating to surface dyslexia, these results indicate that different dyslexic samples may display qualitatively and quantitatively different phonological impairments.

The variable nature of the phonological deficit and the observation of the surface dyslexia subtype are examples of the heterogeneity which characterises developmental dyslexia. Further to this, cross sectional and longitudinal studies have successfully linked a number of additional perceptual and cognitive variables to impaired phonological processing and literacy ability. In order for phonological processing to be considered a core deficit in dyslexia, it must be demonstrated that a pure phonological processing impairment can develop, and give rise to reading difficulties, in the absence of other contributory factors. However, researchers have argued that impairments of speech perception (Morais, 2003; Serniclaes, Van Heghe, Mousty, Carré, & Sprenger-Charolles, 2004), auditory temporal processing (Farmer & Klein, 1995; Tallal, 1980), visual temporal processing (Stein & Walsh, 1997), attentional shifting (Hari & Renvall, 2001; Hari, Valta, & Uutela, 1999) and cerebellar function (Nicolson & Fawcett, 1990; 1999; Nicolson, Fawcett, & Dean, 2001) could underlie the phonological processing deficit observed in dyslexia. If this were proven to be the case, these factors could be regarded as root causes of reading impairment.

Speech perception, spoken language skills and developmental dyslexia

Some researchers have argued that the phonological processing problems experienced by people with dyslexia may be the result of a subtle speech perception deficit which causes a blurring of the perceptual boundaries between phonemic categories and undermines the establishment of robust phonological representations and the ability to map phonemes onto graphemes (Serniclaes et al., 2004). Phonological processing problems and reading impairments often occur in the absence of speech perception problems (Joanisse, Manis, Keating, & Seidenberg, 2000; Ramus, Rosen, Dakin, & Day et al., 2003), however, in support of the speech perception deficit theory, a number of cross sectional studies have reported that subgroups of children with dyslexia do experience problems with speech perception. The children identified in these subgroups often have relatively severe problems with phonological processing and literacy.

Several studies have investigated the categorical perception of phonemes in dyslexia (Joanisse et al., 2000; Manis et al., 1997). These studies report that relative to controls, a small proportion of children with dyslexia show unusually shallow categorical perception functions indicating a weaker perceptual boundary between similar sounding phonemes. Children with dyslexia also continue to perceive linguistically irrelevant allophonic variations within phonemic categories long after they have been disregarded by typically developing children (Serniclaes et al., 2004). Cross sectional studies have also demonstrated that relative to chronological- and reading-age controls, some children with dyslexia are impaired in detecting speech in noise (Brady, Shankweiler, & Mann, 1983) and in discriminating word pairs differing by a single phoneme (Adlard & Hazan, 1998). Finally, the results of several longitudinal studies suggest that children who receive a diagnosis of developmental dyslexia have often experienced problems with aspects of speech and language development at a younger age (Catts, 1991a; 1991b; 1993; Gallagher, Frith, & Snowling, 2000).

Findings indicating a role for spoken language problems in dyslexia are not always easy to interpret as it may sometimes be unclear how to separate the skills underlying speech processing from those of phonological awareness, particularly in samples of young children. For example, in a longitudinal study of reading development, Shapiro, Carroll, and Solity (submitted) reported that pre-school measures of phonological ability and speech processing loaded on a single factor which in turn made a unique contribution to reading ability after one year of schooling. The fact that measures of speech processing and phonological ability loaded on the same factor suggests that in early childhood these skills are very closely related and it can be difficult to separate the relative contributions of each variable to literacy performance.

Despite the overlap between certain measures of speech processing, spoken language ability, and phonological awareness, converging lines of research have been able to demonstrate that impaired phoneme perception is not simply a consequence of poor phonological skills or reading failure. Firstly, illiterate adults, unlike some adults with reading problems resulting from dyslexia, possess phoneme perception abilities which are comparable to those of skilled adult readers (Morais, 2003; Serniclaes, Ventura, Morais, & Kolinsky, 2005). Secondly, neurophysiological data has demonstrated that infants at-risk for dyslexia already show attenuated responses to the phonemic contrasts of their native language at only nine weeks of age (van Leeuwen, Been, Kuijpers, Zwarts, Maassen, & van der Leij, 2006). The results of these studies suggest that speech perception problems can develop prior to and independently of phoneme awareness and literacy skills. Therefore, although some impairments of spoken language processing may reflect early manifestations of a core phonological deficit, it is also possible that a relatively pure speech perception deficit could be an underlying cause of impaired phonological processing and literacy development in some cases of dyslexia.

Auditory temporal processing and developmental dyslexia

Auditory temporal processing theory (Farmer & Klein, 1995; Tallal, 1980) proposes that people with dyslexia have a generalised auditory processing deficit which extends beyond linguistic processes such as phonemic categorisation and impairs the perception of all briefly presented or rapidly changing auditory stimuli.

As cues to phoneme identity in continuous speech are brief, overlapping, and transient it is proposed that such a deficit would undermine speech perception and therefore the establishment of phonological representations.

Early evidence in support of this theory came from cross sectional studies in which children with dyslexia were found to be impaired in temporal order judgement for pairs of speech and non-speech sounds separated by short inter-stimulus intervals (Reed, 1989; Tallal, 1980). Longitudinal studies also suggest that measures of auditory temporal processing can account for unique variance in literacy performance. Boets and colleagues (Boets, Ghesquière, van Wieringen, & Wouters, 2007; Boets, Wouters, van Wieringen, & Ghesquière, 2007) reported that small numbers of Dutch children deemed at-risk for dyslexia were significantly impaired on measures of auditory temporal processing such as detecting gaps and frequency modulations in non-speech stimuli. Structural equation modelling performed on these data supported the theory that an auditory temporal processing deficit may undermine speech perception and ultimately phonological awareness and literacy (Boets, 2008; Boets, Wouters, van Wieringen, DeSmedt, & Ghesquière, 2008).

Other researchers have questioned the causal connection between impaired auditory temporal processing, speech perception, and phonological skills (Studdert-Kennedy & Mody, 1995). Cross sectional studies have indicated that children with dyslexia are impaired in making temporal order judgements when the stimuli concerned are similar sounding phonemes, while group differences in performance disappear when the stimuli are dissimilar phonemes (Mody, Studdert-Kennedy, & Brady, 1997; Reed, 1989). It has therefore been suggested that the apparent deficit in temporal order judgment may be another manifestation of impaired speech perception or phonological processing, rather than the result of a more generalised auditory processing impairment (Vellutino & Fletcher, 2005).

The results of reading interventions inspired by auditory temporal processing theory have also been far from promising. Studies suggest that although low-level auditory processing skills may be improved with training, such improvement brings no associated benefits for spoken language skills, phonological awareness or literacy (McArthur, Ellis, Atkinson & Coltheart, 2008; Pokorni, Worthington, & Jamison, 2004). More recently, a meta-analysis of six randomised controlled trials of one such intervention – known commercially as *Fast ForWord* – found no evidence for any significant improvements in participants' word reading, reading comprehension or spoken language skills relative to children allocated to active and/or non-active control groups (Strong, Torgeson, Torgeson & Hulme, 2011).

Visual temporal processing and developmental dyslexia

Magnocellular deficit theory (Stein & Walsh, 1997) extends the notion of a temporal processing impairment to the visual domain and proposes that the magnocellular sub-divisions of the visual and auditory systems are dysfunctional in people with dyslexia. In both visual and auditory processing, magnocells have large receptive fields and high temporal resolution and are associated with the processing of moving or transient stimuli, or the rapid serial processing of static stimuli, such as the individual letters within a written word (Goldstein, 2002). As such, it is argued that while an impairment of the auditory magnocellular system would impair the perception of phonemic cues in speech, an impairment of the visual magnocellular system would interfere with the ability to process printed words and graphemes in quick succession.

In cross sectional studies, adults (Cornelissen et. al., 1995) and children (Eden, et. al., 1996) with dyslexia have been found to be impaired in the perception of visual motion in arrays of dots. Longitudinal data has also shown that a small number of children at-risk for dyslexia show low-level visual impairments which are related to literacy via orthographic awareness (Boets, 2008; Boets et al., 2008). This offers a clear parallel to the theoretical interpretation of findings in the auditory domain.

Despite these findings, at present there is no convincing evidence that interventions aimed at improving visual processing or the visual clarity of written text produce significant and consistent benefits in reading performance. Non-optical, coloured overlays and lenses have been available to English, American, and Australian school pupils with dyslexia – as well as those in many other countries – for a number of years (Hyatt, Stephenson, & Carter, 2009). However, studies which have attempted to evaluate the efficacy of coloured overlays or lenses for improving reading ability have produced extremely variable findings and are often characterised by serious methodological flaws relating to the measurement of reading performance and the selection of appropriate control participants (see Hyatt et al., 2009 for a comprehensive review). Furthermore, it appears that a very substantial number of adults and children with dyslexia do not experience problems with visual processing at all (Boets, 2008; Boets et al., 2008; Ramus et al., 2003). This is clearly indicated by the common finding that people with dyslexia may utilise visual compensatory strategies in learning to read (Hulme & Snowling, 1992).

Attentional shifting and developmental dyslexia

Recently, it has been argued that the visual processing problems experienced by some people with dyslexia may be attributable to the sluggish engagement and disengagement of attention (Hari & Renvall, 2001; Lallier, Thierry, Tainturier, & Donnadieu et al., 2009). It is argued that skilled reading requires the serial application of attention to the graphemes within each word and a deficit in the control of attention would therefore prevent people with dyslexia from segmenting visual words into graphemes and retrieving their corresponding phonological representations (Facoetti, Ruffino, Peru, Paganoni, & Chelazzi, 2008; Vidyasagar & Pammer, 2009).

Some small cross sectional studies have investigated the shifting of visual attention in dyslexia using the attentional blink paradigm. The attentional blink refers to the minimum inter-stimulus interval or stimulus onset asynchrony that is required between two visually presented targets (T1 and T2) before participants can accurately report the identity of the second target on 75% of experimental trials. Results from two studies suggest that relative to chronological age controls, Finnish speaking adults with dyslexia (Hari et al., 1999) and Italian speaking children with dyslexia (Facoetti et al., 2008) show attentional blink durations which are extended by approximately 150ms.

A significant problem with findings from the attentional blink paradigm is that the stimuli used are letters of the alphabet. Furthermore, the attentional blink paradigm requires the rapid serial visual presentation (RSVP) of stimuli meaning that participants have an extremely short space of time in which to encode the letters and retrieve their corresponding phonological labels. As discussed above, due to a pervasive phonological processing deficit, people with dyslexia are impaired in the ability to rapidly retrieve phonological labels from memory (Felton & Wood, 1989; Snowling et al., 1988). Considering the nature of the stimuli and the task demands of the attentional blink paradigm, it seems likely that the task places participants with dyslexia at a fundamental disadvantage relative to controls. In support of this contention, Badcock, Hogben, and Fletcher (2008) reported that no reading group differences in attentional blink duration were observed after controlling for baseline differences in participants' ability to quickly and accurately identify the letter stimuli. Furthermore, an analysis of the accuracy data reported by Facoetti et al. (2008) reveals that the children in their dyslexic sample achieved a maximum accuracy level for T2 identification of just 76%. Moreover, this was achieved with a relatively long T1-T2 onset asynchrony of 1100ms. This result suggests that the task of merely identifying the letter stimuli was quite difficult for these children. Further support can also be gleaned from other RSVP paradigms in which participants are required to identify which of two stimuli appeared in a given position in an array. Research using this kind of task suggests that children with dyslexia are impaired relative to controls when the stimuli used have a phonological label, such as letters or digits, but not when the stimuli are more abstract symbols (Ziegler, Pech-Georgel, Dufau, & Grainger, 2010). All of these findings strongly suggest that the phonological demands of rapidly encoding and retrieving letter/digit names are responsible for the difficulties experienced by people with dyslexia in RSVP paradigms such as the attentional blink.

Another weakness of the literature suggesting a role for visual attention in dyslexia is that correlational analyses investigating the relationship between attentional shifting and literacy are absent from some cross sectional studies (e.g.

Hari et al., 1999) and partial correlations and regression analyses presented in others consistently fail to control for differences in phonological awareness between reading groups (e.g. Lallier et al., 2009; Facoetti et al., 2008). Furthermore, although longitudinal studies indicating a link between low-level visual processing, orthographic representations, and later literacy ability (Boets et al., 2007a; 2007b; 2008) are potentially consistent with the attentional shifting theory, there is currently a lack of longitudinal and intervention data indicating a specific role for attentional shifting in dyslexia (Vidyasagar & Pammer, 2009).

Cerebellar function and developmental dyslexia

Cerebellar deficit theory (Nicolson & Fawcett, 1990; 1999; Nicolson, Fawcett, & Dean, 2001) proposes that cerebellar dysfunction prevents people with dyslexia from automating several of the basic motor skills underlying reading (e.g. articulation and eye movement control) thus leaving fewer cognitive resources available for the effortful process of phonemic decoding. Furthermore, it is argued that the reading skills which are acquired in dyslexia also take longer to become automated and therefore reading remains slow and effortful rather than proceeding fluently.

Cross sectional studies have revealed reading group differences on various measures of cerebellar function. Participants with dyslexia are impaired in executing motor skills (Fawcett, Nicolson, & Dean, 1996), implicit motor learning (Stoodley, Harrison, & Stein, 2006), and in maintaining postural stability while simultaneously performing a distracter task such as backwards counting (Nicolson & Fawcett, 1990). Furthermore, there is a good deal of anecdotal evidence as well as some empirical findings linking dyspraxic symptoms with developmental dyslexia (Bishop, 1990) and several studies report that people with dyslexia may show abnormalities in cerebellar anatomy (Leonard, Eckert, Lombardino, & Oakland et al., 2001) and function (Nicolson, Fawcett, Berry, Jenkins, Dean, & Brooks, 1999).

However, despite these findings, participants' performance on cerebellar tests often fails to predict literacy performance in cross sectional (Ramus et al., 2003) and longitudinal analyses (Shapiro et al., submitted) and the hypothesis that people with dyslexia fail to automate their reading skills is refuted by the finding that participants with dyslexia may read high frequency words as quickly as controls (Snowling, 2000). Also, unlike accounts of dyslexia based around perceptual processing problems, the cerebellar deficit theory is unable to offer a satisfactory account of the phonological processing difficulties which characterise dyslexia (Ramus et al., 2003). Finally, the only intervention study to demonstrate that the repeated practice of exercises intended to strengthen cerebellar function can bring about improvements in literacy performance (Reynolds & Nicolson, 2007; Reynolds, Nicolson, and Hambly, 2003), has been heavily criticised for various methodological and statistical flaws (e.g. McPhillips, 2003; Richards, Moores, Witton, Reddy, & Rippon et al., 2003; Singleton & Morag, 2003; Snowling & Hulme, 2003). In summary, there is currently no proven mechanism by which cerebellar dysfunction could be said to cause literacy problems (Bishop, 2002).

Heterogeneity and developmental dyslexia

Ramus and colleagues (2003) conducted a multiple case study of 16 adults with developmental dyslexia in order to evaluate the various theoretical accounts described above. Participants completed a large battery of tasks including four measures of phonological processing, three measures of basic auditory processing, two measures of speech perception ability, three measures of visual processing, and five measures of cerebellar functioning. The performance of each dyslexic individual in each domain of functioning was compared with data from an age/IQ matched control group. After outliers had been removed from the control group data, a score within the bottom five per cent of the control group distribution was taken as evidence of a processing deficit. Using this criterion, all of the participants in the dyslexic sample were found to be impaired in the domain of phonological processing and five of these participants showed a pure phonological deficit, with no additional difficulties detected by any of the auditory, visual, or cerebellar tasks. Furthermore, overall differences in reading group means were observed for all of the phonological processing tasks and regression analyses conducted with composite phonology, auditory, visual, and cerebellar variables found phonological processing to be by far the strongest predictor of participants' literacy ability.

Following the approach of Ramus et al. (2003), White and colleagues conducted a multiple case study of 23 children with dyslexia and 22 age/IQ matched controls (White, Milne, Rosen, & Hansen et al., 2006). This study utilised five measures of phonological processing and four tasks assessing participants' motor skills. The test battery also included two measures of speech processing, two auditory processing tasks involving non-speech stimuli, and three measures of visual processing. There was a large reading group difference in phonological processing ability and the phonological processing factor was again found to be the strongest predictor of participants' literacy performance. Approximately half of the children with dyslexia (12/23) were impaired in the domain of phonological processing and four of these children showed pure impairments of phonological processing in the absence of other deficits.

Both sets of case studies demonstrate that many people with dyslexia may indeed have a core phonological deficit that cannot be attributed to underlying perceptual problems and reiterate the fact that the phonological deficit is the strongest, most proximal predictor of reading problems in dyslexia. However, as well as confirming the central role of phonological processing problems, the case studies further highlight the substantial heterogeneity which characterises dyslexia and support the contention that additional perceptual, cognitive, and environmental factors may in some cases interact with or exacerbate a phonological processing impairment in causing reading problems (Harm & Seidenberg, 1999; Manis et al., 1996; Snowling, 1987; Stanovich, 1998; Stanovich et al., 1997). The results of the child case studies also confirm that the severity of the phonological deficit itself may vary widely between different dyslexic individuals (Stanovich, 1988; 1998).

In the adult case studies reported by Ramus et al. (2003), a substantial number of participants (10/16) were found to be impaired in the domain of auditory processing. Overall differences in reading group means were reported for the tasks assessing temporal order judgment and sensitivity to frequency modulation and there was a marginal result for one of the speech perception measures (p = .07). Auditory processing ability was also able to account for additional unique variance in literacy performance. Comparatively little evidence was found in support of a visual processing deficit (2/16 participants affected) or a cerebellar deficit (4/16 participants affected) and no significant reading group differences were observed for any of the visual or cerebellar tasks. Visual processing was not a significant predictor of literacy ability and performance on the cerebellar tasks was found to be negatively related to literacy ability.

In the child case studies reported by White et al. (2006), phonological processing deficits were less common (12/23 cases) than in the adult sample (16/16 cases). Several researchers have noted that the specific challenges posed by reading, and the nature of the reading process, may change over time with different cognitive factors being more or less crucial for literacy at different developmental stages (Bowey, 2005). For example, it is possible that certain skills may show a strong relationship with reading in early childhood before being subsumed by the more proximal influence of phonological awareness later in development. The dynamic nature of the longitudinal relationship between literacy and its underlying cognitive skills could therefore account for the lower prevalence of phonological processing problems observed in the childhood dyslexia case studies compared to the adult sample. A relatively large number of the participants in the child case studies (14/23) were also found to be impaired on one or more of the perceptual or motor tasks. Furthermore, six of these participants showed perceptual and/or motor deficits in the absence of a phonological impairment. White et al. (2006) argue that some of these children may have improved their phonological processing skills as a result of remedial reading instruction or that the criterion for identifying a processing deficit (a score in the bottom 5% of the control group distribution) may have led them to underestimate the prevalence of phonological processing problems in the sample. However, the authors do not rule out the possibility that some of their participants may have relatively mild phonological deficits or that their reading difficulties may result from non-phonological factors such as impaired visual processing.

One caveat in interpreting the findings of Ramus and colleagues (2003) is that the participants who took part in their study were university students. It is possible that a sample of well educated adults who may have partly compensated for their reading problems could have led the researchers to underestimate the prevalence and severity of different deficits in the general population of dyslexia sufferers. Despite this reservation however, the results of the Ramus et al. (2003) case studies appear to be consistent with the broader literature in suggesting that phonological processing problems are implicated in a large majority of cases of dyslexia as well as indicating a relatively high prevalence of auditory processing problems with independent links to literacy. Some researchers suggest that the auditory processing problems experienced by these participants may merely exacerbate a core phonological processing deficit (Ramus et al., 2003) while others view them as part of a causal chain in which impaired auditory temporal processing undermines speech perception, phonological awareness, and literacy (Boets et al., 2007a; 2007b; 2008; Serniclaes et al., 2004).

The results of the Ramus et al. (2003) case studies also suggest that a smaller proportion of adults with dyslexia may experience difficulties with aspects of visual perception or cerebellar function. Visual and motor problems were also observed in the child case studies reported by White et al. (2006), occasionally in the absence of a phonological deficit. However, theoretical interpretation of these results is complicated by the fact that the visual deficits observed in these participants did not seem to be temporal in nature or specific to magnocellular processing. In fact, only one of the children with dyslexia studied by White et al. (2006) was impaired in visual motion detection. Ramus et al. (2003) also argue that the auditory processing problems observed in some of their adult case studies were not necessarily specific to temporal auditory processing or speech perception. Any consistent role for perceptual factors or motor skills in causing literacy impairment, even within a very small sub-group of people with dyslexia, is yet to be fully demonstrated and further theoretical development may be necessary to conceptualise the nature of the auditory, visual, and motor problems that are associated with dyslexia (Bishop, 2002; Ramus et al., 2003; Vellutino et al., 2004; White et al., 2006).

Summary: expanding the study of phonological processing in developmental dyslexia

Despite the possibility that other perceptual and cognitive variables may influence the development of reading problems in some individuals, the evidence reviewed in this chapter strongly suggests that reduced awareness and poor underlying representation of the sequences of phonemes within words is the proximal cause of reading impairment and the most likely candidate for a core deficit in developmental dyslexia. Some degree of phonological processing impairment seems to be present in the vast majority, if not all, cases of developmental dyslexia (Snowling, 2000; Stanovich, 1998; Vellutino, 1977; 1979) and, with the possible exception of pure surface dyslexia (Castles & Coltheart, 1993; Coltheart & Jackson, 1998), a phonological processing impairment is sufficient in itself to cause reading problems in the absence of any other deficits (Joanisse et al., 2000; Ramus et al., 2003; White et al., 2006). In contrast, peripheral deficits, such as those involving speech perception and low-level perceptual processes, are not always observed in dyslexia (Boets, 2008; Boets et al., 2007a; 2007b; 2008; Ramus et al., 2003; White et al., 2006) and tend to occur in only the most severe cases (Joanisse et al., 2000;

Manis et al., 1997). Finally, longitudinal and intervention studies have consistently demonstrated developmental and proximal links between phonological skills and literacy ability (Bradley & Bryant, 1983; Hatcher et al., 1994; Hulme et al., 1980; Lundberg et al., 1988) whereas many of the additional deficits associated with dyslexia are not strongly and consistently related to literacy ability in a theoretically interpretable manner (Ramus et al., 2003; Shapiro et al., submitted; Vellutino et al., 2004; Vidyasagar & Pammer, 2009; White et al., 2006).

Arguably the most parsimonious theoretical account of the heterogeneous dyslexia literature is the phonological-core variable-difference (PCVD) model proposed by Stanovich (1988; 1998). The PCVD model views reading ability as a continuous trait influenced by multiple cognitive factors and can conceptualise skilled and impaired reading. The PCVD model proposes that dyslexia is characterised first and foremost by a phonological processing impairment. Although the phonological processing impairment is implicated in virtually all cases of dyslexia, the deficit may vary in severity between individuals. The model also acknowledges that additional problems such as poor spoken language skills or impaired orthographic processing may make their own contributions to reading impairment. Together, the severity of the phonological impairment and the presence or absence of additional deficits determines the extent and the precise nature of each individual's reading problems.

When considering the role of phonological skills in literacy development and dyslexia, it is important to remember that the phoneme constitutes one level of a complex phonological hierarchy. It is possible to segment spoken words and utterances into units of many different sizes, such as the syllable, sub-syllabic units such as the onset and rime, and larger units such as the metrical foot, which may encompass several syllables and even extend across word boundaries (Cruttenden, 1986; Hawkins, 1992). Research suggests that children follow a developmental pattern in which sensitivity to phonological units such as the syllable, onset, and rime, precedes the development of phoneme level skills (Carroll, Snowling, Hulme, & Stevenson, 2003; Goswami, 2002a; Liberman, Shankweiler, Fisher, & Carter, 1974; Treiman & Zukowski, 1991). Sensitivity to the rhythmic patterning or prosody of spoken language is also known to develop very early in infancy and has developmental links with later phonemic knowledge and reading ability (Kuhl, 2004). In contrast, a conscious awareness of phonemes appears to share a reciprocal relationship with literacy ability and begins to emerge only when formal literacy instruction commences and children are explicitly directed towards the phoneme as a level of phonological structure (Duncan, Seymour, & Hill, 1997; 2000; Gombert, 1992; Goswami, 2002a; Seymour & Duncan, 1997). These findings suggest that, although the phoneme is the key phonological unit in early reading acquisition (Duncan et al., 1997; 2000; Hulme et al., 2002; Seymour & Duncan, 1997), children possess knowledge of other phonological units which could also influence reading development (Carroll et al., 2003; Treiman & Zukowski, 1991).

Research suggests that the phonemic knowledge and phonological decoding skills underlying literacy develop earlier in children reading shallow orthographies with consistent relationships between spelling and sound (Caravolas, 2005). Exploiting knowledge of larger phonological units, such as the onset and rime, may be particularly helpful in reading languages with deep orthographies, such as English, where large numbers of words contain irregular mappings between phonemes and graphemes (Goswami, 2000; 2002a; 2002b; Goswami, Ziegler, Dalton, & Schneider, 2003). The potential for larger phonological units to influence reading within a given language would also be expected to increase with the complexity of reading materials. For example, as older children and adults are faced with the task of reading multisyllabic words, knowledge of morphology, syllable structure, and the rules governing syllabic stress assignment become crucially involved in decoding written words (Duncan & Seymour, 2003). Understanding the contribution of these additional levels of phonological knowledge to literacy development may therefore enrich our understanding of the reading problems experienced by people with dyslexia over the lifespan. The next chapter discusses the recent hypothesis that sensitivity to one particular level of phonological structure – prosody (speech rhythm) – may have substantial implications for literacy development.

Chapter 2

Prosody, reading ability and developmental dyslexia

Overview

The initial aim of this chapter is to introduce the concept of prosody (speech rhythm). Based on a diverse range of findings it is suggested that sensitivity to this level of phonological structure may have significant implications for reading development. The existing evidence in support of this hypothesis is then discussed and evaluated. It is argued that sensitivity to the prosodic patterns in speech can influence literacy performance indirectly, through facilitating vocabulary growth, and the development of phonological awareness, and that in older children and adults, conscious awareness of prosody has a direct relationship with phonological decoding ability that is independent of phoneme awareness. It is suggested that the role played by prosodic processing skills in impaired literacy development can be understood within, and make novel contributions to, both phonological and auditory processing accounts of dyslexia. The final sections of the chapter return to the issue of individual differences in the phonological deficits observed across different dyslexic samples and introduce the aims of the current research.

Prosody

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 variations in the assignment of syllabic stress. Unlike emphasis and local changes in intonation, which may occur anywhere within an utterance, the assignment of syllabic stress is highly structured (Buxton, 1983; Cruttenden, 1986). The regularities which result from the systematic assignment of syllabic stress can be exploited in processing spoken and written language (Cutler & Butterfield, 1992; Cutler & Norris, 1988; Kelly, Morris, & Verrekia, 1998). In recent years, researchers have argued that sensitivity to the rhythmic patterns produced by variations in stress assignment across syllables may make a unique contribution to literacy ability (Wade-Woolley & Wood, 2006).

The perception of syllabic stress is associated with systematic 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; Lehiste & Fox, 1992; Liberman, 1960). Hirst (1983) argued that a listener's representations of the prosodic patterns in speech amount to a record of relative changes in these parameters over time. Changes in amplitude and F_0 at the onset of vowels, as well as vowel duration, appear to be particularly important in signalling stress assignment (Buxton, 1983).

Syllables may carry primary, secondary, or tertiary stress, or they may be unstressed (Cruttenden, 1986). The terminology of 'strong' and 'weak' syllables is often used to distinguish syllables which carry some degree of stress and contain a full vowel from those which are unstressed and contain the reduced vowel /ə/ (e.g. Cutler & Butterfield, 1992; Cutler & Carter, 1987), or to distinguish a syllable carrying primary stress from all lesser stressed syllables (e.g. Liberman & Streeter, 1978; Nakatani & Schaffer, 1978). In contrast, other theorists prefer to make more fine-grained distinctions between all levels of syllabic stress (Ladd & Cutler, 1983). In support of this approach, research suggests that adult listeners are able to distinguish between primary and secondary stress in phonemically matched word fragments (Mattys, 2000).

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*)[1]. Specific patterns of lexical stress assignment may occur more or less frequently across different languages. For example, a large majority of English disyllabic words conform to the strong-weak pattern of lexical stress assignment, with primary stress placed on the initial syllable (Cutler & Carter, 1987). In contrast, other European languages, such as Polish, show an opposite bias favouring non-initial stress assignment in disyllables (Kuhl, 2004). Within languages, word length is an important factor in determining lexical stress assignment. An analysis of the items in the CELEX database (Baayen, Piepenbrock, & Gulikers, 1995) indicates that the strong bias towards first syllable stress observed for English disyllabic words diminishes as word length increases, with assignment of primary stress to penultimate and antepenultimate syllables becoming increasingly common (P. Monaghan, private communication, September 22, 2009). The more complex relationships between lexical stress assignment and aspects of orthography, morphology, and grammar are discussed in more detail later in the chapter.

In addition to the lexical stress patterns occurring within words, systematic variation in syllabic stress assignment also produces a metrical stress pattern or

[1] Throughout this manuscript, acute accents placed over vowels (e.g. ó á) indicate the location of primary stress. Grave accents may also be used to indicate the location of secondary stress where necessary (e.g. ò à).

speech rhythm over the course of an entire utterance. In stress-timed languages such as English, German, and Dutch, speech is organised into a series of metrical feet each headed by a syllable carrying primary stress. Although individual syllables may vary in length depending on their level of stress, each foot takes an approximately equal amount of time to articulate thus giving the speech stream a regular rhythm in which strong syllables appear to be evenly spaced (Buxton, 1983).

There are a number of reasons to suspect that sensitivity to the syllabic stress patterns in spoken language may have implications for literacy. Firstly, by facilitating efficient segmentation of the speech stream at word boundaries, prosodic cues assist the learning of new words and, in turn, the segmentation of words into the sub-lexical units required for literacy (Cutler & Butterfield, 1992; Cutler & Norris, 1988; Jusczyk, 1999; Kuhl, 2004). Furthermore, the location of primary stress in spoken English can be lexically contrastive (e.g. *trústy* vs. *trustée*) or help to resolve other ambiguities, such as those arising between compound nouns and noun phrases (*hótdog* vs. *hot dóg*).

As well as assisting children in segmenting new words and sub-lexical units from the speech stream, prosodic skills may also have the potential to influence reading ability directly. Lexical stress assignment appears to be encoded in the mature phonological representations of adults (Cooper, Cutler, & Wales, 2002; Lindfield, Wingfield, & Goodglass, 1999; Soto-Faraco, Sebastián-Gallés, & Cutler, 2001; van Donselaar, Koster, & Cutler, 2005) as well as the developing phonological representations of children (Curtin, 2010; Curtin, Mintz, & Christiansen, 2005). Furthermore, lexical prosody interacts with orthographic structure (Kelly et al., 1998), morphological structure (Rastle & Coltheart, 2000), and grammatical category information (Arciuli & Cupples, 2006; Kelly & Bock, 1988), to affect naming and lexical decision times for visually presented words as well as stress assignment in nonword reading. A relationship has also been observed between the regularity of lexical stress assignment and word frequency (Arciuli & Cupples, 2006; Colombo, 1992; Rastle & Coltheart, 2000) which mimics findings reported at the phonemic level (Seidenberg, Waters, Barnes, & Tannenhaus, 1984). Finally, research has also suggested that skilled adult readers activate prosodic information during visual word recognition (Ashby & Martin, 2008; Ferrand, Segui, & Humphreys, 1997) and while reading connected text (Ashby, 2006; 2010; Ashby & Clifton, 2005; Been & Clifton, 2011).

In light of these findings it is perhaps surprising that prosody has, until recently, received little attention in the context of reading development (Wade-Woolley & Wood, 2006). This is partly because in the wider literature, successful cognitive and computational models of reading have been almost exclusively developed and tested according to data obtained using monosyllabic words. Only relatively recently have efforts been made to characterise the processes underlying multisyllabic word reading and lexical stress assignment (Arciuli, Monaghan, & Ševa, 2010; Chateau & Jared, 2003; Perry, Ziegler, & Zorzi, 2010; Rastle & Coltheart, 2000; Ševa, Monaghan, & Arciuli, 2009; Yap & Balota, 2009).

Prosody, speech segmentation and language learning

In English, a large proportion of polysyllabic words are stressed on their initial syllable. An analysis of the MRC Psycholinguistic Database (Coltheart, 1981; Wilson, 1988) conducted by Cutler and Carter (1987) suggested that after accounting for word frequency in everyday speech, approximately 90% of content words in spoken British English begin with a stressed initial syllable. Based on this observation it was argued that a speech segmentation strategy in which all stressed syllables were treated as word onsets – the metrical segmentation strategy – would lead to the accurate detection of most word boundaries (Cutler, 1990; Grosjean & Gee, 1987). More recently, the degree of stress applied to each syllable has become an increasingly important concept for stress based models of speech segmentation and it has been hypothesised that only syllables carrying primary lexical stress are treated as word onsets (Mattys, 2000).

Cutler and Butterfield (1992) analysed a corpus of spontaneous and induced speech perception errors and categorised them according to whether they may have arisen from the application of the metrical segmentation strategy. Errors indicating metrical segmentation were those which resulted from the insertion of a word boundary prior to a stressed syllable that was not actually a word onset or the deletion of a word boundary prior to an unstressed syllable which was a word onset. Approximately 64% of spontaneous misperceptions and 75% of laboratory induced misperceptions appeared to arise in this manner.

Further evidence for the use of stress based speech segmentation comes from a word spotting paradigm (Cutler & Norris, 1988) in which participants are asked to detect spoken monosyllabic words embedded in disyllabic nonsense strings. Cutler and Norris reasoned that if participants were utilising a metrical segmentation strategy, a nonsense string in which the first syllable carried primary stress and the second syllable carried secondary stress (e.g. *míntàyve*) would be segmented at the onset of the second syllable. In these circumstances the target word (*mint*) would have to be assembled across the resulting boundary in the speech stream. In contrast, a trochaic nonsense string in which the first syllable carried primary stress and the second syllable was unstressed (e.g. *míntesh*) would not be segmented in this way and thus the target word would be easier to detect. The results were consistent with this prediction as participants were able to detect the presence of a real word significantly faster when it was embedded in a nonsense string with a trochaic pattern of stress assignment and an unstressed second syllable.

Speech segmentation abilities appear to emerge very early in development (Jusczyk & Aslin, 1995; Kuhl, 2004). For example, Jusczyk and Aslin (1995) familiarised seven-and-a-half month old North American infants with a series of monosyllabic English words before presenting them in passages of continuous speech. Participants showed significantly longer listening times for passages containing the previously encountered words than for passages containing novel words thus suggesting an ability to segment the previously encountered words from the speech stream. Furthermore, by the age of nine months, infants appear to show a strong listening preference for the dominant stress pattern of their native language. As described above, a large majority of words encountered in everyday spoken English are stressed on their initial syllable (Cutler & Carter, 1987). In accordance with this, Jusczyk, Cutler, and Redanz (1993) found that nine month old North American infants showed significantly longer listening times for words with a trochaic stress pattern compared to those with the less frequently encountered iambic stress pattern. In another study, Jusczyk, Houston, and Newsome (1999) familiarised seven-and-a-half month old North American infants with a series of trochaic and iambic disyllabic words before presenting the same words in passages of fluent speech. Participants again showed significantly longer listening times to passages containing previously encountered words relative to passages containing novel words, however, this finding only applied to words with a trochaic pattern of stress assignment. This result suggests that prosodic cues, and in particular a bias towards assuming word initial syllables carry primary stress, were the dominant factor in these infants' speech segmentation attempts. North American infants as young as seven months have also been shown to use something approximating a metrical segmentation strategy to segment artificial languages composed of nonsense strings (Curtin et al., 2005).

Prosodic patterns appear to exert their greatest influence in guiding the speech segmentation attempts of infants (Jusczyk, 1999; Jusczyk et. al., 1999) before becoming less influential in adulthood (Mattys, White, & Melhorn, 2005; Shukla, Nespor, & Mehler, 2007). Adults and children also utilise other cues to facilitate speech segmentation such as the transitional probabilities which exist between pairs of syllables, the legality of different phoneme sequences (i.e. phonotactic rules), and the allophonic variations in phoneme articulation which occur across different linguistic contexts (Gomez & Gerken, 2000; Jusczyk, 1999; Kuhl, 2004; Mattys et al., 2005; Saffran, 2003; Saffran, Aslin, & Newport, 1996; Saffran, Johnson, Aslin, & Newport, 1999; Saffran, Newport, & Aslin, 1996; Thiessen & Saffran, 2003). In infancy and adulthood these different sources of information appear to interact with prosodic cues in guiding speech segmentation (Curtin et al., 2005; Mattys, et al., 2005; Shukla, et al., 2007; Thiessen & Saffran, 2003).

Prosody and phonological representations

Although the extent to which lexical prosody is represented in the mental lexicon has been a subject for debate, evidence from a number of paradigms now suggests that lexical stress patterns are encoded in the mature phonological representations of adults and the developing phonological representations of children. Furthermore, such findings have been replicated across a number of different alphabetic languages. In a recent study (Curtin, 2010), Canadian infants (mean age fourteen months) learned nonword labels for two objects (e.g. *object x = bédoka; object y = tipégu*). During a later test phase, infants were presented with previously learned label-object pairings as well as novel label-object pairings in which previously encountered labels and objects were mismatched (e.g. *object x = tipégu; object y = bédoka*). In a third trial type, infants were presented with previously learned pairings in which the stress pattern of the label had been changed (e.g. *object x = bedóka; object y = típegu*). As indexed by mean looking times, infants treated these label-object pairs in the same way as the completely novel pairs. These findings indicate that infants encoded the stress pattern of the object labels in their phonological representations and phonemically identical labels with contrasting patterns of stress assignment were treated as phonologically distinct items.

Word level prosodic representations have also been studied using the lexical gating paradigm (Grosjean, 1980; 1996) in which participants are required to identify spoken words based on fragments referred to as onset gates. The dependent variable in the gating paradigm is the mean onset gate size required for correct identification of a set of spoken target words. Lindfield et al. (1999) presented participants with an initial onset gate comprising the first 50ms of a target word and the gate was subsequently increased by a further 50ms following each incorrect identification attempt. In one experimental condition, the researchers followed the standard lexical gating procedure and asked participants to identify target words based on the onset gates alone. In a second condition, the participants heard the onset gate followed by a burst of white noise which continued for the remainder of the word's duration, thus providing additional information about the length of the word. Finally, in a third condition, following the onset gate participants heard the remainder of the word through a low-pass filter. This conveyed the prosodic structure of the word without providing any additional segmental information. Participants required significantly shorter onset gates in order to identify target words when they received additional information about prosodic structure compared to word onsets alone or onsets plus duration information. These results suggest that word level prosody is encoded in the phonological representations stored the mental lexicon and that participants are able to utilise this information to facilitate spoken word identification. Mattys (2000) provided further evidence in support of this claim by demonstrating that participants are also skilled in distinguishing between fragments of spoken words which differ only in stress assignment.

Further evidence that phonological representations encode information relating to word level prosody comes from a cross modal fragment priming paradigm developed by Soto-Faraco and colleagues (2001). Performance on this task indicates that participants can also utilise lexical stress information in spoken primes to facilitate the identification of visually presented target words. The paradigm was initially developed with Spanish participants (Soto-Faraco et al., 2001) and findings have since been replicated with English (Cooper, et al., 2002) and Dutch speakers (van Donselaar, et al., 2005). During the task participants were required to respond to visually presented target words preceded by three types of spoken prime. In the stress congruent prime condition, the spoken prime was the first two syllables of the target word (e.g. *ádmir/al* → *ADMIRAL*)[2]. In contrast, in the stress incongruent prime condition, the spoken prime was the first two syllables of a word that shared

[2] Underlining and / symbols indicate the portion of the word included in the spoken prime.

segmental phonology with the target while differing in stress assignment (e.g. <u>*àdmir*</u>*/átion* → *ADMIRAL*). Participants in all three reported studies were significantly faster to respond to the target word in the stress congruent condition relative to a control condition in which the spoken prime was the first two syllables of a word phonologically unrelated to the target (e.g. <u>*mosquí*</u>*/to* → *ADMIRAL*). However, Cooper et al. (2002) observed that English speakers were no faster to respond to the target in the stress incongruent condition than in the control condition. Despite the continued overlap in segmental phonology, the conflicting prosodic structures of the prime and target ensured that no priming effects were observed in the stress incongruent condition.

Conflicting patterns of lexical stress assignment between primes and target words were found to have an even stronger effect on the response times of Spanish and Dutch speakers. Soto-Faraco et al. (2001) and van Donselaar et al. (2005) both reported inhibition effects in which participants were slower to respond in the incongruent condition relative to the control condition. Together the results from the cross modal fragment priming paradigm indicate that lexical stress is encoded in the phonological representations of Spanish, Dutch, and English speakers and that participants are able to utilise information about lexical stress assignment to facilitate the identification of visually presented words.

Cooper et al. (2002) concluded that the larger impact of lexical stress incongruence on the response times of non-English speakers may reflect differences in phonological structure between English and other languages. Specifically, they argued that vowel reduction in unstressed syllables offers English listeners a valuable segmental (i.e. phonemic) cue to word identity. In contrast, Spanish is a syllable-timed language in which all syllables (stressed and unstressed) contain full vowels and do not vary in overall duration. Vowel reduction also occurs less frequently in Dutch than in English, despite the fact that both are stress-timed languages. Therefore, in Spanish and Dutch, stress assignment is more often a uniquely contrastive feature between words than in English.

English also differs from other languages in that lexical stress is not explicitly marked in written text. In contrast, stressed vowels in Spanish orthography are often indicated by an acute accent (Gutiérrez-Palma & Palma-Reyes, 2008) and stress is also marked explicitly in other languages such as Greek (Protopapas, 2006). Gutiérrez-Palma and Palma-Reyes (2008) found that Spanish speaking adults produced faster lexical decision times for visually presented target words when lexical stress was correctly marked in a masked visual prime (e.g. *técla → TECLA*) than when the stress mark was misplaced (*teclá → TECLA*). Once again, these results suggest that word level prosody is represented in the mental lexicon and may be utilised to facilitate visual word identification.

It is clearly not possible to conduct directly analogous experiments with English participants, however, Wade-Woolley and Akaoka (2006) conducted a visual masked priming experiment with adult readers of English in which visual primes encoded syllabic stress assignment using upper and lower case font. As in the cross modal priming paradigm described above (Cooper et al., 2002) the primes were word fragments. Once again, participants' response times were significantly faster when lexical stress was accurately indicated by the prime (e.g. *PEtu → PETULANT; peTU → PETUNIA*) than when the prime indicated the incorrect stress pattern (*peTU → PETULANT; PEtu → PETUNIA*). Furthermore, the magnitude of the stress priming effect was found to correlate significantly with word and nonword reading ability.

Decoding lexical stress

Although English orthography does not contain any explicit notation for signalling stress assignment, there are a number of cues available to the reader that reliably indicate the location of primary stress within a word. Interestingly, even in languages where stress placement is explicitly marked, the use of stress marks can be slow to develop and children and adults continue to utilise other sources of information in assigning stress (Protopapas, 2006; Protopapas & Gerakaki, 2009; Protopapas, Gerakaki, & Alexandri, 2006; 2007).

Kelly (2004) focussed on word onsets in disyllabic English words and reported a systematic relationship between the number of consonants in word onset position and the likelihood of trochaic stress assignment. In a corpus of 6,862 words drawn from the MRC Psycholinguistic Database (Coltheart, 1981; Wilson, 1988), the proportion of words with trochaic stress assignment was found to be .35 for onsets containing no consonants, .69 for onsets containing one consonant, .83 for onsets containing two consonants and .98 for onsets containing three consonants. Furthermore, this relationship continued to emerge for all consonants in repeated analyses controlling for word frequency, grammatical class, morphemic structure, and consonant-vowel patterns post onset. Finally, Kelly (2004) also demonstrated that words with consonant clusters at the onset of the second syllable were twice as likely to have an iambic pattern of stress assignment as words with single consonants at the onset of the second syllable.

Similar relationships between orthography and stress assignment have been reported for word endings. Kelly et al. (1998) reported that certain word endings such as -*ette*, -*que* and -*umb* were strongly predictive of iambic stress assignment, noting that word endings associated with iambic stress assignment often contain more letters than is necessary to encode the phoneme(s) that they represent. For example, the phoneme /m/ at the end of the word *succúmb* could be adequately represented with the word ending *-um* rather than *-umb*. Therefore, as with onset length and trochaic stress assignment, it seems that the length of a word ending may be a strong cue to iambic stress assignment. Kelly et al. (1998) argued that special cases of this may be the presence of silent letters in word endings (as in the example of *succúmb*, above) and letter doubling. For example, words ending with the phoneme /u/ could be represented orthographically as *-u* or *-oo*. Kelly et al. noted that words ending with the orthographically longer *-oo* are more likely to receive iambic stress (e.g. *tabóo*) while words ending with the orthographically shorter *-u* receive trochaic stress (e.g. *zébu*).

Crucially, data from naming, lexical decision and nonword pronunciation studies indicate that English speakers are sensitive to the correspondences between orthographic patterns and lexical stress assignment and utilise them to decode the stress patterns of written words. Kelly et al. (1998) contrasted words whose orthography accurately predicted their stress pattern (e.g. the iambic *cassétte* and the trochaic *péllet*) with those whose orthography did not accurately predict their stress pattern (e.g. the iambic *cadét* and the trochaic *pálette*). They found that naming and lexical decision times were significantly shorter for words whose orthography accurately predicted their stress assignment (i.e. participants responded faster to *cassétte* than to *cadét* and faster to *péllet* than to *pálette*). Arciuli and Cupples (2006) exploited the fact that iambic stress assignment is more common in verbs and trochaic stress more common in nouns to conduct a similar experiment. In this experiment the researchers measured participants' responses to words that conformed to this pattern (i.e. trochaic nouns and iambic verbs) and those which violated this pattern (i.e. iambic nouns and trochaic verbs). The former were labelled as typically stressed words and the latter as atypically stressed words. Arciuli and Cupples (2006) found that in both naming and lexical decision participants made significantly more errors in response to atypically stressed words, however, the same effects were not observed in participant's response times.

Research utilising a nonword pronunciation paradigm (Smith & Baker, 1976) found that nonwords with a double letter ending (e.g. *nuvitt*) were more likely to be pronounced with iambic stress than corresponding nonwords ending with a single letter (e.g. *nuvit*). More recently, Kelly (2004) reported analogous findings for word onsets, finding that participants were more likely to assign trochaic stress to a nonword beginning with a consonant cluster (e.g. *plonveen*) than to a corresponding nonword beginning with a single consonant (e.g. *ponveen*). It was also found that nonwords embedded in sentences were more likely to be pronounced with trochaic stress when they appeared in a noun context (Kelly & Bock, 1988; Smith, Baker, & Groat, 1982). Similarly, Arciuli and Cupples (2006) reported that participants were more likely to assign trochaic stress to nonwords with noun endings and iambic stress to nonwords with verb endings.

Behavioural experiments have also been supported by a small number of computational and connectionist models which are able to assign stress to words and nonwords. A recent study reported an implementation of a connectionist model of word reading that achieved high levels of accuracy in assigning stress to disyllabic words on the basis of orthographic cues (Ševa et al., 2009). The model was tested with a set of approximately 2,500 words taken from the CELEX database (Baayen et al., 1995). By utilising learned mappings between the orthographic patterns discussed above, and their corresponding patterns of lexical stress assignment, the model assigned primary lexical stress correctly to 97% of trochaic stress words and 77% of iambic stress words. More recent developments in the connectionist modelling of multisyllabic word reading have captured changes in the importance of specific orthographic cues to stress position over the course of reading development (Arciuli et al., 2010) and demonstrated how an extension of the learning procedure for mapping graphemes to phonemes can allow a model to learn mappings between graphemes and stress assignment (Perry et al., 2010). Prior to the development of connectionist models which learn mappings between orthographic representations and stress assignment, Rastle and Coltheart (2000) described an extension of the dual route cascaded model in which lexical stress assignment in disyllables was largely determined by morphological structure. This model was able to successfully simulate stress assignment in word and nonword reading by utilising correspondences between patterns of stress assignment and specific affixes. However, the model's reliance on morphemes rather than more general orthographic cues places limits on flexibility and the ability to generalise to non-morphemic stimuli (Arciuli et al., 2010; Perry et al., 2010).

Finally, there is also evidence to suggest that decoding of lexical stress assignment may be influenced by word frequency. Colombo (1992) reported an interaction between stress regularity and word frequency in naming times for trisyllabic Italian words. Low-frequency items with primary stress on the penultimate syllable (the dominant pattern of stress assignment for trisyllabic Italian words) were named significantly faster than low-frequency words with an irregular pattern of stress assignment. In contrast, the effect of stress regularity was not observed for high-frequency words. Researchers have struggled to replicate these findings for English disyllabic words when stress regularity has been defined according to the dominant trochaic pattern (Brown, Lupker, & Colombo, 1994; Monsell, Doyle, & Haggard, 1989; Rastle & Coltheart, 2000). However, when stress regularity has been defined according to the predictability of stress assignment from grammatical class, orthographic structure, or morphological structure, frequency-regularity interactions have been produced (Arciuli & Cupples, 2006; Kelly et al., 1998; Rastle & Coltheart, 2000). This interaction between word frequency and stress regularity mimics the interaction between word frequency and spelling to sound regularity at the phonemic level (Seidenberg et al., 1984).

Together these findings suggest that there are reliable cues to lexical stress assignment in English orthography, morphology, and grammar. Furthermore, skilled readers appear to learn correspondences between lexical stress assignment, orthographic structure, morphological structure, and grammatical class and apply this knowledge in order to decode the lexical stress patterns of written words and nonwords. This process is analogous to the application of grapheme-phoneme correspondences in decoding segmental phonology and the extent to which stress assignment can be accurately predicted from orthography, grammatical class, and morphological structure clearly influences the speed with which written words can be identified.

Prosody and visual word recognition in skilled adult readers

A number of studies have utilised subliminal visual primes in an attempt to demonstrate the online activation of prosodic representations during skilled reading. In the masked syllable priming paradigm participants are required to respond to visually presented target words preceded by masked visual primes. Some of the targets have initial syllables with a consonant-vowel (CV) structure (e.g. *demóte*) and others have initial syllables with a consonant-vowel-consonant (CVC) structure (e.g. *bálcony*). In the syllable congruent prime condition, the prime is the initial syllable of the target word (e.g. *de* → *DEMOTE; bal* → *BALCONY*). In the syllable incongruent prime condition, in the case of CV targets, the prime is the initial syllable of the target word plus one additional letter (e.g. *dem* → *DEMOTE)* and, in the case of CVC targets, the prime is the initial syllable of the target minus a letter (e.g. *ba* → *BALCONY*). Ferrand et al. (1997) found that English speakers were fastest to name CV and CVC target words when they were preceded by syllable congruent primes. In contrast, participants were no faster to name words preceded by syllable incongruent primes than when they were preceded by a neutral prime (e.g. *%%%%%%* → *DEMOTE*). Furthermore, these results were only observed for words with clear syllable boundaries. Naming times for words containing ambisyllabic consonants (e.g. *bálance*) were not affected by the prime manipulation.

Using a modified version of the masked syllable priming task in conjunction with eye movement recording, Ashby and Martin (2008) were also able to observe syllable priming effects in lexical decision times. In their paradigm, participants initially fixated on one side of the screen whilst the prime was presented parafoveally on the other. Participants then made a saccade to the other side of the screen during which the target word appeared in place of the prime. Using this procedure Ashby and Martin (2008) reported significantly faster lexical decision times for CV and CVC target words preceded by syllable congruent as opposed to syllable incongruent primes. In a similar eye movement paradigm Ashby (2006) presented participants with syllable congruent or syllable incongruent parafoveal primes as they silently read sentences. Fixation durations for low-frequency CV and CVC target words within the sentences were significantly shorter when they were preceded by syllable congruent as opposed to syllable incongruent primes. More recently, the syllable congruency of a masked visual prime has also been shown to influence the magnitude of an ERP component elicited at an early stage of the word recognition process (Ashby, 2010).

Although a number of studies utilising a variety of methodologies have provided convergent evidence for the role of prosody in skilled reading, the interpretation of syllable priming effects is not necessarily straight forward. Firstly, it should be noted that these findings do not directly suggest that lexical stress information is activated during reading, just the suprasegmental units to which lexical stress may be applied (i.e. syllables). Secondly, it is possible that syllable priming effects may in fact be explained by vowel priming. For example, the CV target word *pílot* contains the long vowel /aɪ/ in the first syllable. In the syllable congruent condition (*pi* → *PILOT*) the vowel is still likely to be encoded as /aɪ/. However, in the syllable incongruent condition (*pil* → *PILOT*) the vowel is more likely to be encoded as /ɪ/. This potential difference in vowel identity across prime conditions would result in faster responses in the syllable congruent condition. Finally, other researchers have been unable to replicate the syllable priming effect reported by Ferrand et al. (1997). Schiller (1998; 1999) has reported that naming latencies of English and Dutch speakers become shorter for both CV and CVC target words as the phonological/orthographic overlap between the prime and target increases (i.e. participants respond faster to both types of target following a CVC prime). These findings contradict those of Ferrand et al. (1997) for CV targets and suggest that the findings of those authors for CVC targets may be attributable to an orthographic or phonological priming effect.

Despite these doubts concerning the validity of the syllable priming effect, research conducted using other paradigms has indicated that information regarding metrical and lexical stress may indeed be activated online during silent reading. Ashby and Clifton (2005) recorded eye movement data as participants read short sentences and found that words containing two stressed syllables elicited longer gaze durations and more fixations than words matched for length (number of letters) and frequency but containing one stressed syllable. More recently, Been and Clifton (2011) recorded eye movement data as participants read a series of limericks. These researchers found that participants experienced more difficulty reading when the lexical stress of a critical word contrasted with the overall metrical structure of the limerick.

The significance of stress patterns

Taken together, the findings reviewed so far in this chapter suggest that prosody may be highly relevant to the study of literacy development and reading impairment. Firstly, prosodic cues appear to guide speech segmentation in infancy and may therefore be fundamental to word learning, the discovery of sub-lexical units, and the establishment of early phonological representations. Secondly, information about word level prosody appears to form an integral part of the phonological representations stored in the mental lexicon and has the power to influence the identification of spoken and written words. Furthermore, behavioural studies and computational simulations have demonstrated that lexical stress assignment is a necessary step in the reading of multisyllabic words and that lexical stress may be decoded in a similar fashion to, and influenced by some of the same factors as, phonemic structure. Finally, there is limited evidence to suggest that representations of lexical and metrical prosody, as well as the linguistic units to which stress is applied – syllables – are directly involved in skilled silent reading. The remainder of the chapter aims to evaluate recent findings which suggest a link between prosodic processing skills, normal literacy development, and the reading problems experienced by people with dyslexia.

Prosodic processing skills and typical reading development

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 gódfather → dee déedeedee*). 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, 2007; 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*.

Wells et al. (2004) noted that many of the youngest children in their sample (mean age 5 years and six months) were highly competent in making use of prosody to phrase their speech and indicate focus and affect. This suggests that by the time formal literacy instruction commences, children already have well developed prosodic processing skills. 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. For example, in a sample of typically developing Australian children aged between eight and ten years, performance on both the DEEdee task and the compound noun/noun list discrimination task was found to account for significant, unique variance in word reading after controlling for phonological awareness and sensitivity to rhythm in non-speech stimuli (Whalley & Hansen, 2006). Performance on the DEEdee task also accounted for significant, unique variance in reading comprehension. In a more recent study conducted with typically developing Canadian children aged between eight and thirteen years (Clin, Wade-Woolley, & Heggie, 2009), performance on the DEEdee task and the similar rhythmic matching task (Wood & Terrell, 1998) accounted for significant, unique variance in reading ability after controlling for phonological and morphological awareness. The dependent variable in this analysis was a reading composite encompassing word, nonword, and passage reading as well as comprehension. Finally, performance on the rhythmic matching task, as well as the ability to identify the syllable carrying primary lexical stress within words, has also been associated with the ability to use punctuation correctly in phrasing connected text (Gutiérrez-Palma, Defior, & Calet, 2010; Wade-Woolley & Kotanko, 2010).

A relationship between prosodic skills and reading ability has also been observed in samples of Spanish speaking children aged between six and eight years (Gutiérrez-Palma & Palma-Reyes, 2007; Gutiérrez-Palma, Raya-García, & Palma-Reyes, 2009). These studies utilised a sequence repetition task (Dupoux, Peperkamp, & Sebastián-Gallés, 2001) in which participants learned to press different keys on a computer keyboard in response to two phonemically identical, disyllabic nonwords with contrasting patterns of stress assignment (*mípa = z*; *mipá = m*). Participants then heard a number of two-, three-, and four-item sequences and were required to respond with the correct sequence of key presses on the keyboard (e.g. *mípa, mipá, mipá = z, m, m*). Performance on this task was significantly related to nonword reading scores (Gutiérrez-Palma & Palma-Reyes, 2007) and accounted for significant, unique variance in text reading ability after controlling for phonological awareness (Gutiérrez-Palma et al., 2009). Performance on the sequence repetition task was also related to children's ability to correctly assign lexical stress to pseudowords which suggests that an awareness of prosody may facilitate the learning of rules which govern stress assignment in reading (Gutiérrez-Palma et al., 2009).

Other tasks have also been used to study the connection between normal literacy development and prosodic sensitivity. These tasks differ from the DEEdee task, compound noun/noun phrase discrimination task and sequence repetition task in that they address the processing of prosody exclusively at the level of single words. Wood (2006) developed the mispronunciations task in which participants hear a mispronunciation of a familiar word such as *sófa* and are then required to identify the word by selecting a corresponding object from a doll's house. The mispronunciation can be produced by altering segmental (e.g. *sófa* → *sífa*) or prosodic (*sófa* → *sofá*) features of the word's sound pattern. In studies conducted with English children aged between five and seven years, researchers have found that mispronunciations which are produced by altering the stress pattern of the target word are the most difficult for participants to correct (Holliman, Wood, & Sheehy, 2008a; Wood, 2006). Performance in this condition of the mispronunciations task has also been shown to account for significant, unique variance in phonological awareness (Goodman et al., 2010) and, after controlling for phoneme and rhyme awareness, can explain significant, unique variance in word reading, nonword reading (Holliman et al., 2008a), and spelling ability (Wood, 2006). Performance on a modified version of the mispronunciations task has been found to correlate significantly with phonological awareness and predict significant, unique variance in word reading ability after controlling for age, phoneme awareness, rhyme awareness, vocabulary, verbal short-term memory, and sensitivity to non-speech rhythm (Holliman, Wood, & Sheehy, 2010a).

Another paradigm which highlights the connection between normal literacy development and sensitivity to lexical prosody is the derived word production task (Jarmulowicz, 2006). This task utilises the distinction between rhythmic suffixes such as *–ity*, which alter the lexical stress of the root word (e.g. *áctive* → *actívity*), and neutral suffixes such as -*ness*, which allow the root word to retain its original lexical stress pattern (e.g. *háppy* → *háppiness*). In studies with typically developing

North American children aged eight and nine years, production of words with derivational suffixes was found to be less accurate for rhythmic suffixes than neutral suffixes (Jarmulowicz, 2006; Jarmulowicz, Taran, & Hay, 2007). Jarmulowicz et al. (2007) also reported that performance in derived word production accounted for significant, unique variance in nonword reading after controlling for phonological awareness. Participants in the study reported by Clin et al. (2009) also found derivations harder to produce when they involved altering the lexical stress of the root word. Furthermore, in hierarchical regression analyses, performance in producing stress altering derivations but not neutral derivations accounted for significant, unique variance in reading ability after controlling for phonological awareness and sensitivity to metrical prosody.

Together these findings suggest that sensitivity to prosody may contribute to the development of various literacy skills independently of phoneme awareness. Furthermore, Clin et al. (2009) reported that measures of metrical prosodic sensitivity (the DEEdee task) and lexical prosodic sensitivity (derived word production) could both account for significant, unique variance in the same reading composite. This suggests that sensitivity to word and sentence level prosody may have separate links to reading ability. Studies in which sensitivity to metrical and lexical prosody have been analysed separately have so far suggested that sensitivity to metrical prosody may be of primary importance in the development of advanced reading skills involving connected text (Goodman et al., 2007) whereas sensitivity to lexical prosody may be more important in the development of phonological awareness (Goodman et al., 2010) and spelling ability (Wood & Joshi, 2007). This is consistent with the observation that performance on the DEEdee task, which requires awareness of metrical prosody, accounts for unique variance in children's reading comprehension scores but is not always significantly related to phonological decoding ability as measured by nonword reading (Whalley & Hansen, 2006). In contrast, measures of lexical prosodic processing such as derived word production and the mispronunciations task have been shown to account for unique variance in nonword reading (Holliman et al., 2008a; Jarmulowicz et al., 2007).

A caveat in interpreting these findings is that it is sometimes unclear which level of prosodic processing a particular language task is measuring. For example, the compound noun/noun phrase discrimination task and the DEEdee task have respectively been utilised as measures of lexical and metrical prosodic sensitivity (Whalley & Hansen, 2006). However, other authors have viewed the compound noun/noun phrase discrimination task as a measure of metrical prosody (Goodman et al., 2007; 2010). As noun phrases and noun lists encompass multiple words, and many DEEdee stimuli correspond to single words (e.g. *aláddin* → *deedéedee*), these language tasks arguably contain elements of both metrical and lexical prosody. Therefore, some of the language tasks described above may not be well suited to drawing links between specific prosodic skills and specific aspects of literacy.

There is currently a shortage of longitudinal data investigating the relationship between sensitivity to speech prosody and later reading ability. However, Holliman, Wood, & Sheehy (2010b) recently reported that the performance of six year old children (n = 102) in the stress reversal condition of the revised mispronunciations task 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. Performance on the mispronunciations task at age six also continued to correlate significantly with measures of phonological awareness taken at age seven.

Two further longitudinal studies have been conducted in which sensitivity to rhythm was assessed using non-speech stimuli (David, Wade-Woolley, Kirby, & Smithrim, 2007; Dellatolas, Watier, Le Normand, Lubart, & Chevrie-Muller, 2009). A recent study reported by Dellatolas et al. (2009) utilised a rhythm reproduction task (Stambak, 1951) in which children were required to reproduce a series of rhythmic patterns by tapping a pencil on a table top. Performance on this task during kindergarten (n = 1028, mean age five years and seven months) was found to be significantly related to a composite reading score including measures of word reading, nonword reading, and sentence comprehension obtained nearly two years later (n = 695, mean age seven years and five months). Performance in rhythm reproduction was also a predictor of reading delay (defined as the lowest eight per cent of reading scores in the sample) at the second time point. Unfortunately, the conclusions that can be drawn from this study are extremely limited as the researchers did not control for the children’s IQ, phoneme and rhyme awareness, or vocabulary in their regression analyses. Instead the control variables were socio-economic status, geographical location of school, oral repetition of words, sentences, and digits, and a measure of visual processing speed.

David et al. (2007) utilised the rhythmic competency analysis test (Weikart, 1989) in which children are asked to perform a series of movements (e.g. simultaneous tapping of left and right hands, alternate tapping of left and right hands, and marching on the spot) in time to music. Performance on the rhythmic sensitivity task administered at time point one (n = 53, mean age six years and four months) correlated significantly with composite measures of phonological awareness and rapid naming obtained at the same time point. Holliman et al. (2010a) also reported significant correlations between performance on two non-speech rhythm tasks and phonological awareness in their sample of six year old English speaking children. These findings are also consistent with data from Spanish speaking pre-school children (Defior, Calet, Nigro, Gutiérrez-Palma, & Onochie, 2010) and suggest that sensitivity to rhythm in non-speech stimuli is closely associated with literacy related skills in young children. Performance on the rhythm task used by David et al. was also significantly correlated with word and nonword reading scores obtained at four further time points taken at one year intervals. However, hierarchical regression analyses revealed that after controlling for phonological awareness, rhythmic processing was only a significant predictor of nonword reading at time point five. On the basis of these findings, David et al. argue that only as children get older and begin to read multisyllabic words and connected text does a direct relationship begin to emerge between rhythmic processing and reading. Prior to this it is suggested that sensitivity to speech and non-speech rhythm may influence literacy indirectly by facilitating the development of phonological awareness.

An interesting question for future research is the relative importance of speech and non-speech rhythm in reading development. Studies have found links between non-speech rhythm and phonological awareness in young children and demonstrated that non-speech rhythm can make unique contributions to word and nonword reading (David et al., 1997; Defior et al., 2010; Holliman et al., 2010a). However, although the contribution of speech rhythm to reading ability remains after controlling for that of non-speech rhythm (Holliman et al., 2010a; Whalley & Hansen, 2006) the reverse pattern has not been demonstrated. At present, it seems reasonable to assume that general rhythmic processing may be significant in early phonological development but the processing of speech rhythm in particular may be more closely related to later reading performance.

Prosodic processing skills and developmental dyslexia

In addition to studies conducted with typically developing children, cross sectional studies have suggested that children with reading problems may be impaired relative to chronological-age controls on several measures of prosodic processing ability, for example, the rhythmic matching task (Wood & Terrell, 1998). During the rhythmic matching task participants hear a number of low-pass filtered sentences. The effect of low-pass filtering is similar to that of the reiterative syllable substitution used in the DEEdee task in that original phonemic features are removed from an utterance while prosodic structure is left intact. Participants are required to match each of the low-pass filtered sentences to one of two naturally spoken sentences on the basis of a shared metrical prosodic structure. 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.

Children with dyslexia also appear to have difficulty processing prosody at the word level. For example, ten year old children at-risk of dyslexia are reported to be significantly impaired relative to chronological-age controls in the stress reversal condition of the mispronunciations task (Holliman, Wood, & Sheehy, 2008b). Furthermore, an analysis of the factors influencing nonword repetition performance in Dutch speaking children indicated that stress irregularity had a stronger negative effect on the performance of children at-risk for dyslexia than of chronological-age controls (deBree, Wijnen, & Zonneveld, 2006).

All of these studies reported significant differences between participants with reading problems and chronological-age controls. However, the performance of children with dyslexia is similar to that of younger, reading-age controls (Goswami et al., 2009). This suggests that prosodic processing abilities may be delayed in children with dyslexia rather than fundamentally or qualitatively impaired. Surprisingly, there have been very few cross sectional studies investigating the prosodic processing skills of adults with dyslexia. However, the small amount of research that does exist suggests that relative to chronological-age controls, people with dyslexia may continue to show impairments of prosodic processing throughout the lifespan. Kitzen (2001) found that relative to controls matched for chronological-age, educational level, and socio-economic status, North American college students and graduates with self-reported histories of reading impairment were significantly impaired on both the DEEdee task and the compound noun/noun phrase discrimination task. Furthermore, logistic regression analysis found performance on the DEEdee task to be the most significant predictor of reading group membership in a four-predictor model which also contained measures of phonological awareness and rapid naming.

Studies of children and adults with dyslexia are consistent with data from typically developing children in suggesting that prosodic processing skills, and in particular a conscious awareness of syllabic stress patterns, may have direct links with reading ability which are independent of phoneme awareness. A different but closely related line of research has focussed on the ability of adults and children with dyslexia to perceive variations along the acoustic dimensions of the speech signal which convey information regarding syllabic stress assignment. As noted above, systematic changes in amplitude, duration and F_0 are perceived as differences in loudness, length, and pitch between syllables and these differences underlie the perception of syllabic stress (Fry, 1955; 1958; Lehiste & Fox, 1992; Liberman, 1960). Some researchers have argued that changes in amplitude, particularly amplitude envelope onsets or rise-times, may be particularly significant in signalling stress assignment and facilitating speech segmentation (Goswami, Thomson, Richardson, & Stainthorp et al., 2002). In spoken syllables, amplitude rise-times correspond to the period between the syllable onset and the amplitude peak of the vowel. Therefore, rise-time perception may be important for the perception of stressed vowels as well as the segmentation of syllables into onset/rime units. A number of experimental paradigms have been utilised to study participants' sensitivity to temporal variations in the acoustic properties of the speech signal which convey syllabic stress information. Goswami and colleagues (2002) designed the beat perception task to assess participants' sensitivity to the perceptual beats associated with different amplitude rise-times. As rise-times increase (i.e. the change in amplitude between syllable onset and vowel occurs more slowly), beats become softer and increasingly difficult to detect before stimuli are eventually perceived as continuous sounds with no beat at all. During the beat detection task, participants are presented with a number of non-speech stimuli drawn from a continuum in which rise-time is varied systematically in a series of steps between a minimum value of 15ms and a maximum value of 300ms. Participants are asked to categorise each sound according to whether or not it contains a beat. In addition to the original beat perception paradigm, tasks have also been utilised in which participants are presented with pairs of non-speech sounds and asked to use rise-time, duration, intensity, or frequency information to discriminate between the stimuli or match one of the sounds to a sample stimulus.

Goswami et al. (2002) found that children with dyslexia (mean age nine years) were significantly impaired relative to chronological-age controls in the beat perception task. Furthermore, performance on this task accounted for significant, unique variance in measures of phonological awareness, verbal short-term memory, rapid naming, word reading, nonword repetition, and spelling ability after controlling for age, IQ, and vocabulary. Relative to chronological-age controls, eight and nine year old children with dyslexia are also impaired in distinguishing pairs of non-speech stimuli on the basis of differences in amplitude rise-time and sound duration and significant predictive relationships have been reported between rise-time and duration discrimination and various measures of phonological processing (Richardson, Thomson, Scott, & Goswami, 2004). Performance on the rise-time and duration discrimination tasks is also able to account for significant, unique variance in word reading, nonword reading, and spelling after controlling for age, IQ, and vocabulary (Richardson et al., 2004). More recently, performance in rise-time discrimination has been related to children’s performance in a verbal-visual associate learning paradigm in which spoken nonwords are paired with abstract shapes presented visually on a computer screen, a task which is analogous to the process of forming novel phonological representations (Thomson & Goswami, 2010). Performance in rise-time and frequency discrimination has also been found to account for unique variance in DEEdee task performance after controlling for age and IQ suggesting a direct link between the processing of prosody's acoustic correlates and conscious awareness of prosodic structure (Goswami et al., 2009).

Converging findings have also been reported for samples of English speaking adults with dyslexia and studies conducted with Finnish speaking participants have suggested that rise-time processing may be impaired in dyslexia across different alphabetic orthographies. In comparison with age/IQ matched controls, students with dyslexia studying at UK universities are found to be impaired in the beat detection 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 also 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 and phonological awareness, which are in turn strong predictors of literacy ability. Finally, a study of Finnish speaking children with reading impairments (mean age nine years) found that the ability to discriminate between non-speech sounds on the basis of amplitude rise-times was significantly related to a measure of phoneme perception which was in turn related to spelling ability (Hämäläinen, Leppänen, Eklund, & Thomson et al., 2009). Finnish speaking adults with dyslexia are also impaired relative to controls in rise-time perception with individual differences on measures of rise-time processing accounting for unique variance in phonological ability (Hämäläinen, Leppänen, Torppa, Muller, & Lyytinen, 2003).

The results of these experiments are consistent with studies of prosodic cues to speech segmentation (Cutler & Butterfield, 1992; Cutler & Norris, 1988; Jusczyk, 1999; Kuhl, 2004) in suggesting that sensitivity to prosody may also influence literacy via the development of phonemic and prosodic awareness. It has been argued that reduced sensitivity to the prosodic cues in the speech signal may impair the ability to segment sub-lexical units such as syllables, onsets, and rimes from the speech stream and that such a deficit may ultimately undermine the development of phoneme level phonological representations, phonological awareness, and literacy skills (Foxton, Talcott, Witton, Brace, McIntyre, & Griffiths, 2003; Goswami, et al., 2002; Richardson, et al., 2004).

Interpreting the prosodic processing deficit in developmental dyslexia

The evidence reviewed in the second half of this chapter suggests that prosodic processing skills may be an important factor in normal literacy development and that an impairment of prosodic processing may contribute to the reading problems of people with dyslexia. There currently appear to be two separate mechanisms via which sensitivity to prosody may influence literacy ability; a distal, indirect, early-onset mechanism and a proximal, direct, late-onset mechanism.

Studies investigating the role of prosodic cues in speech segmentation suggest that prosodic processing skills may influence literacy indirectly by facilitating the segmentation of words and sub-lexical units from the speech stream. Given the fact that children are sensitive to, and make use of prosodic cues to speech segmentation from an early age (Juscyzk, 1999; Kuhl, 2004), this mechanism is likely to be active from a very early stage of development. It follows from this that reduced sensitivity to the prosodic cues in speech would be expected to impair the development of the phonological representations and phonological awareness skills required for reading (Goswami et al., 2002; Richardson et al., 2004; Thomson & Goswami, 2010). Furthermore, as lexical stress information seems to form an integral part of word level phonological representations (Curtin, 2010; Cooper et al., 2002), reduced sensitivity to the prosodic patterns in speech would also result in lower quality representations of lexical stress in the mental lexicon and poor prosodic awareness skills (Goswami et al., 2009). It has also been suggested that the role of prosody in speech segmentation and spoken word recognition may be a driving force in vocabulary growth which in turn creates pressure for further segmentation of phonological representations as well as allowing children to discover morphological relations between words (Holliman et al., 2010a; Wood, Wade-Woolley, & Holliman, 2009). Finally, longitudinal data have also suggested a close relationship between sensitivity to non-speech rhythm and phonological skills in children who are just beginning to learn to read (David et al., 2007; Holliman et al., 2010a). Ultimately, reduced sensitivity to the prosodic patterns in speech as well as rhythm in non-speech stimuli could both contribute to impaired literacy development in people with dyslexia. These findings are clearly relevant to auditory and speech processing accounts of developmental dyslexia as they argue for a progression from low-level auditory processing deficits, to impaired speech perception, to low quality phonological representations and reduced awareness of segmental phonology. However, they extend current auditory accounts of dyslexia by placing the proposed deficit at the level of rhythmic processing rather than the rapid processing of phonemic cues, and by arguing for a more global impairment of phonological processing affecting the representation and awareness of both segmental and suprasegmental phonology.

In addition to this indirect or distal relationship between prosodic processing and literacy, studies utilising various language tasks 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 (e.g. Clin et al., 2009; Gutiérrez-Palma et al., 2010; Gutiérrez-Palma et al., 2009; Gutiérrez-Palma & Palma-Reyes, 2008; Holliman et al., 2008a; 2010a; 2010b; Jarmulowicz et al. 2007; Kitzen, 2001; Whalley & Hansen, 2006; Wade-Woolley & Kotanko, 2010; Wood, 2006). As conscious awareness of suprasegmental units develops reciprocally with literacy (Duncan, Seymour, & Hill, 2000; Gombert, 1992; Seymour & Duncan, 1997), direct links between prosody and literacy may only begin to emerge later in development (David et al., 2007), perhaps in response to children encountering written multisyllabic words and connected text for the first time. A number of researchers have speculated on how awareness of prosody may exert a direct influence on reading ability. Firstly, decoding lexical stress assignment is a necessary step in reading multisyllabic words and awareness of stress assignment could clearly facilitate this process. For example, it has been suggested that awareness of the prosodic patterns in speech may help Spanish speaking children to learn the rules for assigning stress to written words and that reduced stress awareness may impede this process (Gutiérrez-Palma-Palma et al., 2009). In a similar vein, it is possible that reduced awareness of prosody in dyslexia may undermine the learning of the correspondences between phonology and variables such as orthography, morphology, and grammatical class that can be used to assign lexical stress in English words. Such a process would be analogous to the way in which poor phonemic awareness impedes the learning of grapheme-phoneme correspondences. Recent analyses of the errors made by Spanish and English speaking children in decoding multisyllabic words suggest that awareness of syllabic stress is significantly correlated with the ability to assign lexical stress correctly but not with the accuracy of phonemic decoding (Gutiérrez-Palma, 2010; Heggie, Wade-Woolley, & Briand, 2010). This suggests that stress awareness may make a specific contribution to decoding by facilitating correct stress assignment in multisyllabic word reading. There are also instances in which stress assignment may be lexically contrastive, for example, in distinguishing between the English words *trústy* and *trustée*. Awareness of syllabic stress assignment could clearly facilitate word identification in these instances. Although it is rare for syllabic stress to be a uniquely contrastive feature in English (Cutler, 1986), prosodic differences, in conjunction with differences in vowel identity, often make phonologically similar items easier to distinguish (e.g. *récord; recórd*). It has also been argued that an awareness of syllabic stress assignment could assist decoding in other ways. For example, it has been suggested that the ability to manipulate prosody and apply stress selectively at any point in a word may help children to decode the less clearly articulated phonemes in unstressed syllables or that knowledge of syllabic stress assignment could help convey information about aspects of segmental phonology such as vowel reduction (Holliman et al., 2008a; 2010a; Wood et al., 2010). Finally, recent research suggests that awareness of lexical and metrical prosody may directly influence other important literacy skills, such as reading comprehension (Whalley &

Hansen, 2006), and the ability to use and understand punctuation as a way of phrasing written text (Gutiérrez-Palma et al., 2010; Wade-Woolley & Kotanko, 2010). These findings clearly have the potential to expand the phonological account of developmental dyslexia into the domain of suprasegmental phonology and provide additional information about the problems experienced by people with dyslexia across the lifespan and across a wider range of reading materials. Ultimately, a better understanding of the relationship between prosodic skills and reading may help researchers develop interventions that yield larger gains in reading ability than are possible through phoneme level training alone.

Despite these promising findings the precise nature of the prosodic processing deficit in dyslexia remains unclear. As described above, it may be possible for impaired prosodic processing to exert a proximal, direct influence on reading performance, or influence literacy development indirectly via phonological awareness, morphological awareness, or vocabulary size. Given the individual differences in the severity and nature of phonological deficits across different dyslexic samples (Stanovich, 1988; 1998; Wolf & Bowers, 1999), it is possible that different people with dyslexia may also experience different types of prosodic processing problems, and these may impact their literacy performance as well as other phonological skills in a variety of different ways.

Some people with dyslexia may be expected to show a far reaching, fundamental impairment of prosodic processing affecting the perception of prosodic cues in speech, the underlying representation of stress assignment, and the conscious awareness of prosodic structure. Findings from perceptual tasks demonstrating that people with dyslexia fail to perceive the changes in amplitude, frequency, and duration which signal syllabic stress in speech are consistent with this suggestion (e.g. Foxton et al., 2003; Goswami et al., 2002; Hämäläinen et al., 2003; 2009; Pasquini et al., 2007; Richardson et al., 2004; Thomson et al., 2006; Witton et al., 2002). In contrast however, other samples of dyslexic individuals may show more limited difficulties with specific aspects of prosodic processing. According to the criteria described by Gombert (1992), several of the language tasks that have been used to compare prosodic processing across reading groups – the DEEdee task, the compound noun/noun phrase discrimination task, the mispronunciations task and the rhythmic matching task – are metalinguistic in nature. Firstly, the tasks require participants to reflect on their knowledge of prosody in a conscious, effortful way and secondly, participants are often required to focus their attention on a single aspect of linguistic form at the partial or total expense of meaning. It could therefore be argued that the observed deficit in prosodic processing reflects a relative inability to consciously reflect upon and apply stored knowledge of prosody while underlying representations of lexical and metrical stress patterns remain intact.

At the phonemic level, a phonological deficit in which the conscious awareness of phonemic structure is impaired despite intact underlying representations has already been observed in a series of experiments by Ramus and Szenkovits (2008). Despite being impaired on conventional measures of phonological awareness, a sample of French speaking adults with dyslexia were found to show phonological similarity effects of equal magnitude to age/IQ matched controls in the context of nonword repetition and nonword discrimination tasks. Furthermore, adults with dyslexia were also found to show normal repetition priming effects in a subliminal auditory priming paradigm. Ramus and Szenkovits suggest that the phonological processing difficulties of adults with dyslexia may result from specific problems in accessing phonological representations during tasks which require the conscious awareness or manipulation of phonemes (e.g. Spoonerisms, phoneme deletion), speeded retrieval of phonological forms (e.g. rapid automatised naming), or maintenance of phonological information in verbal short-term memory (e.g. serial nonword repetition). These findings raise the possibility that a similar pattern of impairment may be observed at the suprasegmental level, at least in samples of well educated adults with dyslexia. In support of this possibility, Dickie, Ota, and Clark (2007) reported that a sample of British university students with developmental dyslexia were able to perceive simple stress contrasts similar to those used in the compound noun/noun phrase discrimination task, but were significantly impaired relative to age/IQ matched controls on tasks which required the conscious manipulation of stress assignment across syllables.

Summary and research aims

Research from a variety of paradigms and theoretical backgrounds has indicated that impaired perception, representation, and awareness of prosody may have substantial implications for reading ability. Recent research findings have provided strong support for this hypothesis, suggesting that prosodic skills may influence literacy indirectly via phonological awareness as well as exerting a direct influence on aspects of phonological decoding and the phrasing of connected text. Although research has demonstrated that people with dyslexia are impaired on various measures of prosodic processing, the precise nature of this impairment, and thus its relationship with literacy, is not yet fully understood. Findings from the study of phonemic processing in dyslexia suggest that there may be substantial heterogeneity in both the severity and the qualitative nature of the prosodic processing deficit across different dyslexic samples.

The experiments reported here aim to understand the precise nature of the prosodic processing problems experienced by one group of people with dyslexia; adults in higher education. Cross modal priming and lexical decision paradigms are utilised alongside more conventional measures of prosodic processing such as the DEEdee task in order to contrast the underlying representation and decoding of syllabic stress assignment with the processes of conscious prosodic awareness. This represents a novel methodological approach to studying prosodic processing in dyslexia. Given the findings of Ramus and Szenkovits (2008) in the domain of phonemic processing, it was tentatively hypothesised that adult participants with developmental dyslexia would show a selective impairment affecting the conscious awareness of syllabic stress assignment while underlying representations remained intact. The first experiment, reported in the next chapter, utilised the DEEdee task in an attempt to replicate findings of a deficit in syllabic stress awareness previously observed in samples of children with dyslexia (Goswami et al., 2009; Wood & Terrell) as well as adults with self-reported histories of reading problems (Kitzen, 2001). The experiment also aimed to investigate the relationship between syllabic stress awareness, literacy, and phonological skills in a sample of adults with dyslexia.

Chapter 3

Syllabic stress awareness and phonological decoding in skilled adult readers and adults with developmental dyslexia

Overview

The experiment described in this chapter investigated conscious awareness of prosody in a sample of adults with developmental dyslexia and age/IQ matched controls. Participants with dyslexia were significantly impaired on a task requiring conscious awareness of lexical and metrical stress assignment (the DEEdee task, Kitzen 2001). Performance on this task accounted for significant, unique variance in phoneme awareness as well as two separate measures of speeded phonological decoding ability (nonword reading and nonsense passage reading). It is argued that adults with dyslexia have difficulty with tasks requiring conscious awareness of prosody and that prosodic skills influence reading ability directly, via their role in decoding multisyllabic words and punctuating text, as well as indirectly, via their relationship with phoneme awareness.

Experiment 1a

Research conducted with typically developing children (Clin et al., 2009; Holliman et al., 2008a; 2010a; Jarmulowicz et al., 2007; Whalley & Hansen, 2006) and children with dyslexia (Goswami et al., 2009; Thomson & Goswami, 2010; Wood & Terrell, 1998) has demonstrated that conscious awareness of prosody has direct links with literacy ability as well as reading related skills such as phoneme awareness, rhyme awareness and verbal-visual associate learning. Given these findings it is perhaps surprising that there are currently no published studies investigating prosodic awareness in adults with dyslexia. In conjunction with the existing studies of prosodic skills and reading ability in childhood, a cross-sectional study of adult readers would allow researchers to observe change or stability in these relationships over the course of development.

In a study of North American college students and graduates, Kitzen (2001) reported that participants with reading problems were significantly impaired on two measures of prosodic awareness; the DEEdee task and the compound noun/noun phrase discrimination task. Furthermore, logistic regression analysis found performance on the DEEdee task to be the most significant predictor of reading group membership in a four-predictor model which also contained measures of phonological awareness and rapid naming. However, this study is unsatisfactory as the students who participated had not received formal diagnoses of developmental dyslexia and were recruited on the basis of self-reported reading problems.

The DEEdee task itself has also been the subject of criticism. During the task, participants are required to match a spoken DEEdee stimulus to one of three length-matched response options on the basis of shared prosodic structure (e.g. *the gódfather → dee déedeedee*). Therefore, in order to complete the DEEdee task successfully, participants must consciously compare and contrast the prosody of several different words and phrases. Generating the prosodic structures for each response option, while simultaneously maintaining a representation of the DEEdee stimulus, before finally conducting the necessary comparisons clearly places a large load on verbal short-term memory. Furthermore, due to the fact that the response options are presented to participants visually, the task also contains substantial inherent reading demands. As a result, participants' reading ability, phonemic awareness and vocabulary knowledge could all contribute to performance on the DEEdee task and the correlations between DEEdee task performance and reading ability may be explained in terms of the phonological and memory demands that are common to both.

The current experiment aimed to build on the original study conducted by Kitzen (2001). The DEEdee task was utilised to investigate conscious awareness of syllabic stress assignment in skilled adult readers and adults with reading problems. However, unlike in Kitzen's study, all of the participants with reading problems had received formal diagnoses of developmental dyslexia. Furthermore, in order to control for the possible contributions of phonemic awareness, vocabulary knowledge and reading ability to the DEEdee task, measures of these variables were also included and controlled statistically during hierarchical regression analyses. Reading ability was also covaried when examining reading group differences in DEEdee task performance.

Based on previous research conducted with typically developing children (Clin et al., 2009; Whalley & Hansen, 2006) and children with reading problems (Goswami et al., 2009; Wood & Terrell, 1998), as well as Kitzen's (2001) unpublished findings relating to adults with self-reported histories of reading problems, it was hypothesised that adults with dyslexia would show impaired awareness of syllabic stress assignment in comparison with age/IQ matched controls. It was also predicted that performance on the DEEdee task would account for significant, unique variance in literacy ability after controlling for the influence of

IQ, phoneme awareness, verbal short-term memory, vocabulary, and the reading demands of the DEEdee task itself.

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 (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 (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 Wechsler Abbreviated Scale of Intelligence (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 with feedback. 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 (RT). Response times were measured from the onset of the response options.

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, a cross modal priming task (Experiment 1b, next chapter), phoneme reversal, digit span, vocabulary, and the IQ subscales. During the DEEdee 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 are provided in Table 1 (page 77). 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. There were no significant reading group differences in age, verbal IQ, performance IQ or vocabulary.

Table 1.

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

Measure	Dyslexia	Age/IQ Control	*t* (78)	sig.	*d*
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	$p = .003$	0.70
Nonword Reading	89.66 (12.72)	102.79 (11.41)	4.82	$p < .001$	1.09
Passages (sec.)	31.03 (11.49)	21.92 (3.85)	4.33	$p < .001$	1.15
Phon. Awareness	9.59 (3.40)	11.48 (3.55)	2.37	$p = .020$	0.54
Verbal STM	15.53 (2.79)	17.40 (2.17)	3.35	$p = .001$	0.77

All participants scored above chance on the DEEdee task (Table 2, page 78). However, control participants were significantly more accurate and significantly faster to respond than participants with dyslexia. In order to control for the reading demands of the DEEdee task, the comparisons of reading group means reported in Table 2 were repeated as ANCOVA analyses with TOWRE word reading scores entered as a covariate. The significant effect of reading group on DEEdee task accuracy (F (1, 77) = 8.41, p = .005) and DEEdee task response time (F (1, 77) =

13.07, $p = .001$) remained after controlling for differences in reading ability between groups.

Table 2.

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

Measure	Dyslexia	Age/IQ Control	*t* (78)	sig.	*d*
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

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, page 79). 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. 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.

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 control = 46, df dyslexic = 30)

A hierarchical regression analysis was conducted using phoneme awareness as a dependent variable. Age, verbal IQ, performance IQ, vocabulary, and verbal short-term memory were entered as predictors at step 1 followed by DEEdee task accuracy and DEEdee task response time at step 2. The full model was able to account for 38.4% of the variance in phoneme awareness (F (7, 72) = 6.43, $p < .001$, $R^2 = .384$). When entered at step 2, DEEdee task performance accounted for a unique 11.5% of the variance in phoneme awareness (F (2, 72) = 6.74, $p = .002$, $\Delta R^2 = .115$). DEEdee task accuracy was a significant predictor of phoneme awareness (t (72) = 2.33, $p = .022$, $\beta = .277$) and there was a marginal result for DEEdee task response time (t (72) = 1.91, $p = .060$, $\beta = -.207$).

Further 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 correlations between DEEdee task accuracy and word reading and between DEEdee task response time and word reading were non-significant within 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 and DEEdee task response time at step 2. In order to ensure that any unique contribution of the DEEdee task was due to the influence of syllabic stress awareness and not the reading demands associated with the task, TOWRE word reading was also entered at step 1 in both analyses.

The full model was able to account for 74.4% of the variance in nonword reading (F (9, 70) = 22.58, $p < .001$, $R^2 = .744$) and 55.8% of the variance in nonsense passage reading (F (9, 70) = 9.83, $p = .001$, $R^2 = .558$). When entered at step 2, DEEdee task performance accounted for a unique 5.7% of the variance in nonword reading (F (2, 70) = 7.78, p = .001, ΔR^2 = .057) and a unique 6.9% of the variance in nonsense passage reading (F (2, 70) = 5.48, p = .006, ΔR^2 = .069). DEEdee task accuracy (t (70) = 2.80, p = .007, β = .229) and DEEdee task response time (t (70) = 2.05, p = .044, β = -.150) were both significant predictors of nonword reading. DEEdee task response time was also a significant predictor of nonsense passage reading (t (70) = 3.29, p = .002, β = .315) whereas DEEdee task accuracy was not (t < 1).

Discussion

This experiment utilised the DEEdee task to investigate conscious awareness of prosody in a sample of adults with developmental dyslexia. Relative to age/IQ matched controls, participants with dyslexia were significantly less accurate and significantly slower to respond during the DEEdee task. Furthermore, these differences remain even after controlling for differences in word reading ability between the groups. These results demonstrate for the first time that adults with developmental dyslexia are impaired in the ability to consciously reflect upon and apply their knowledge of lexical and metrical prosody. This is significant theoretically, as it confirms that reading group differences in prosodic processing ability persist beyond childhood and that prosodic skills continue to influence reading performance in samples of adult readers.

Performance on the DEEdee task was correlated with a number of literacy and literacy related skills within both reading groups and accounted for significant, unique variance in phoneme awareness. The association between phoneme awareness and DEEdee task performance indicates that there is a close relationship between these skills and that awareness of prosodic structure may be one of many phonological skills which underlie reading ability. Such an interpretation is supported by the fact that prosody appears to be integral to phonological representations themselves (Cooper et al., 2002; Curtin, 2010; Curtin et al., 2005). Researchers have argued for some time that the notion of phonological awareness, and the range of phonological skills that are thought to influence reading ability, should be extended to include knowledge of prosodic structure (Wade-Woolley & Wood, 2006). As sensitivity to rhythmic structure and phonological units such as onsets, rimes, and syllables, develops prior to phoneme level skills (Carroll et al., 2003; Treiman & Zukowski, 1991), it is also reasonable to suggest that the close relationship between stress awareness and phoneme awareness reflects this developmental trajectory. The contribution of prosodic skills to the development of phoneme level knowledge has been proposed by a number of researchers (Foxton et al., 2003; Goswami et al., 2002; Richardson et al., 2004) and represents an indirect influence of prosodic skills on literacy development.

Finally, 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. These results are consistent with earlier studies of typically developing children (Clin et al., 2009; Holliman et al., 2008a; 2010a; Jarmulowicz et al., 2007; Whalley & Hansen, 2006) and children with dyslexia (Goswami et al., 2009; Wood & Terrell, 1998), in suggesting that conscious awareness of syllabic stress assignment also makes a direct, unique contribution to reading ability that is independent of phoneme awareness. This direct relationship with reading ability may reflect the fact that prosodic knowledge is specifically useful in decoding multisyllabic words (Gutiérrez-Palma, 2010; Heggie et al., 2010), learning the linguistic rules and correspondences governing stress assignment (Gutiérrez-Palma et al., 2009) and in facilitating processes operating at the sentence level, such as phrasing and applying punctuation in connected text (Gutiérrez-Palma et al., 2010; Wade-Woolley & Kotanko, 2010). It has also been suggested that knowledge of prosodic structure may be a source of phonemic information during decoding, such as determining the location of a reduced vowel (Holliman et al., 2008a; Wood et al., 2009). It is these specific applications of prosodic knowledge that may account for its independent contribution to literacy beyond phoneme awareness.

Summary

The results of this study suggest that a subgroup of people with dyslexia – adults with experience of higher education – show reduced awareness of lexical and metrical prosody and that syllabic stress awareness is significantly associated with, and predictive of, phoneme awareness and phonological decoding ability. These findings are consistent with the suggestion that prosodic skills influence reading ability directly, via their role in decoding multisyllabic words and punctuating text, as well as indirectly, via their relationship with phoneme awareness.

The experiments reported in the following chapter attempt to extend these findings by introducing a contrast between the conscious awareness of prosody and the underlying representation of syllabic stress assignment. The aim of this is to better understand the nature of the prosodic processing problems associated with dyslexia.

Chapter 4

Representations of lexical stress in skilled adult readers and adults with developmental dyslexia

Overview

The experiments reported in this chapter utilised the cross modal fragment priming paradigm (Cooper et al., 2002; Soto-Faraco et al., 2001; van Donselaar et al., 2005) to investigate the mental representation of lexical stress assignment in two samples of adults with developmental dyslexia and age/IQ matched controls. Participants with dyslexia showed normal patterns of stress based priming in both experiments and the magnitudes of the observed priming effects were comparable across reading groups. In contrast, adults with dyslexia were again found to be impaired on a task requiring conscious awareness of syllabic stress assignment (the fragment identification task, Mattys, 2000). It is argued that adults with dyslexia may have a specific impairment affecting the conscious awareness of syllabic stress assignment while underlying representations remain intact. Parallels are drawn between these results and similar findings reported at the phonemic level (Ramus & Szenkovits, 2008). Possible reasons for the selective impairment of phonemic and prosodic awareness and the implications of these findings for theories of dyslexia and models of visual word recognition are discussed.

Experiment 1b

The results reported in Experiment 1a suggest that adults with developmental dyslexia are impaired in the ability to consciously reflect upon patterns of lexical and metrical stress assignment and that conscious awareness of prosodic structure is significantly associated with phonemic processing and literacy ability in adulthood. However, as discussed in Chapter 1, many researchers have argued that phonological processing consists of more than phonological awareness and can in fact be decomposed into various constituent skills (Wagner & Torgesen, 1987). This raises the possibility that different phonological skills may make independent contributions to reading ability and may be more or less impaired in different dyslexic individuals (Ramus, 2001; Wolf & Bowers, 1999). Recent research has drawn a contrast between the quality of the underlying phonological representations used for reading and the processes involved in accessing and reflecting upon this knowledge of phonological structure (Anthony et al., 2010; Ramus & Szenkovits, 2008). In the context of phonemic processing, recent findings have suggested that highly educated adults with dyslexia show relatively pure impairments of phonological awareness and phonological retrieval processes while having intact phonological representations (Ramus & Szenkovits, 2008). Despite these findings concerning the phoneme level skills of people with dyslexia, there are currently no published studies which aim to contrast the different aspects of prosodic processing. As a result, the exact nature of the prosodic processing deficit associated with dyslexia is unknown. A better understanding of the type of prosodic skills that are impaired in dyslexia would help inform theories of how prosodic processing influences literacy development.

Experiment 1b utilised the cross modal fragment priming paradigm (Cooper et al., 2002; Soto-Faraco et al., 2001; van Donselaar et al., 2005) to assess the ability of adults with developmental dyslexia to accurately represent the lexical prosody of words stored in the mental lexicon. As described in Chapter 2, during the cross modal fragment priming 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. *<u>ádmir</u>/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. *<u>àdmir</u>/átion* → *ADMIRAL*). Priming effects are measured in each of these conditions relative to a control condition in which the spoken prime is the first two syllables of a word phonologically unrelated to the target (e.g. *<u>mosquí</u>/to* → *ADMIRAL*). It was predicted that control participants would respond significantly faster in the stress congruent prime condition relative to the control condition while showing no evidence of a priming effect in the stress incongruent condition. This pattern of responding has been observed previously in skilled adult readers of English, Spanish and Dutch (Cooper et al., 2002; Soto-Faraco et al., 2001; van Donselaar et al., 2005).

The absence of a priming effect in the stress incongruent prime condition, despite the continued overlap in the segmental phonology of the prime and target word, can be attributed to the contrast in their patterns of lexical stress assignment. Therefore, it was reasoned that if participants with dyslexia represent lexical prosody less clearly than controls, they would be expected to show evidence of a priming effect for both stress congruent and stress incongruent primes. 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.

In conjunction with the evidence of a stress awareness deficit reported in Experiment 1a, similar patterns and magnitudes of priming across the two reading groups could be taken as evidence for a specific impairment of prosodic awareness in adults with dyslexia. This would raise the possibility of extending the findings of Ramus and Szenkovits (2008) from the domain of phonemic processing to another level of the phonological hierarchy. In contrast, differences in either the pattern or magnitude of priming observed across the reading groups 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 and procedure

Sample characteristics and significance tests for the matching and literacy measures are presented in Table 1 (page 77). In addition to the cross modal fragment priming task, participants completed the matching, literacy and DEEdee tasks as previously described (pages 73-76).

Measures

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 coincide 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 variables were the mean response time for lexical decision (correct trials only) and percentage error rate 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).

Results

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.

A 2 (reading group) by 3 (prime condition) repeated measures ANOVA was conducted on participants' lexical decision times (Figure 1, page 91)[3]. The main effect of reading group was significant by subjects and by items (F_1 (1, 76) = 35.64, p < .001, d = 1.30; F_2 (1, 47) = 363.28, p < .001, η_p^2 = .885) reflecting the fact that control participants were faster to respond than participants with dyslexia across all prime conditions. The main effect of prime condition was also significant by subjects and by items (F_1 (2, 152) = 13.96, p < .001, η_p^2 = .155; F_2 (2, 94) = 12.34, p < .001, η_p^2 = .208). Post hoc paired samples t-tests with Bonferroni corrections applied for multiple comparisons revealed that, overall, participants were significantly faster to

[3] Error bars in all figures represent one standard error of the mean

respond in the stress congruent condition compared to the control condition (t_1 (77) = 5.28, p < .001, η_p^2 = .266; t_2 (95) = 4.75, p < .001, η_p^2 = .332) and the stress incongruent condition (t_1 (77) = 3.74, p = .001, η_p^2 = .153; t_2 (95) = 4.45, p < .001 , η_p^2 = .291). There was no significant difference in response time between the stress incongruent condition and the control condition (t_1 (77) = 1.04, p = .910, ns; t_2 < 1, ns). Finally, the interaction between reading group and prime condition failed to reach significance in either the subjects or the items analysis (F_1 and F_2 < 1, ns) indicating that participants in both reading groups showed the same pattern of priming effects across the three conditions.

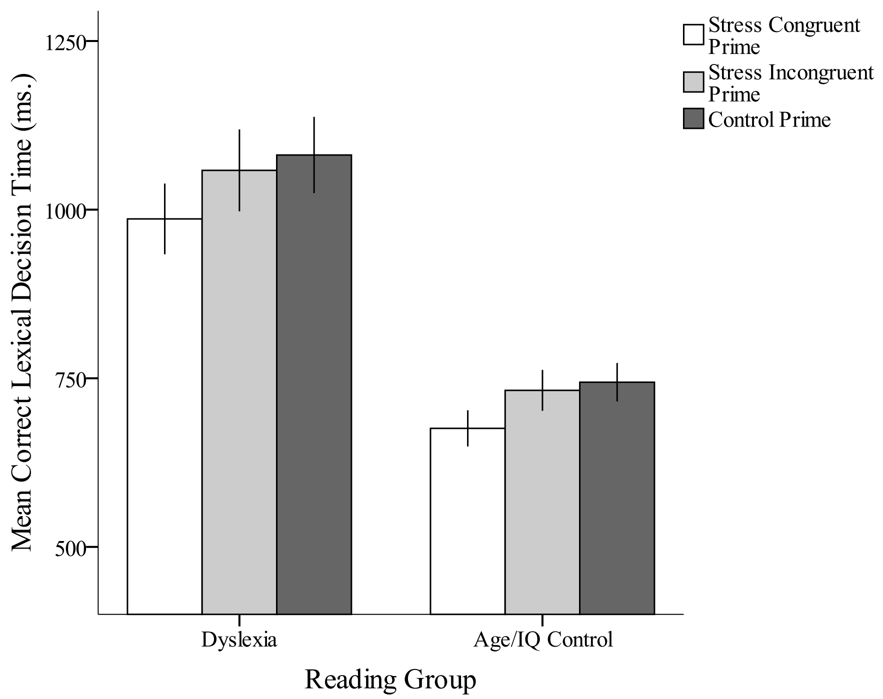

Figure 1. Mean correct lexical decision time by reading group and prime condition

Priming effect magnitudes were calculated for the stress congruent and stress incongruent conditions relative to the control condition (Figure 2, page 92). In order to control for the main effect of reading group in the response time data, effect magnitudes were calculated by taking the mean difference in response time between the pair of prime conditions and dividing by the mean response time in the control condition. Independent samples t-tests revealed that neither of the priming effects differed significantly in magnitude between reading groups ($t < 1$ in both cases). Furthermore, participants with dyslexia (t (29) = 2.16, $p = .039$, $\eta_p^2 = .139$) and controls (t (47) = 3.98, $p < .001$, $\eta_p^2 = .252$) both showed significantly more priming in the stress congruent condition compared to the stress incongruent condition.

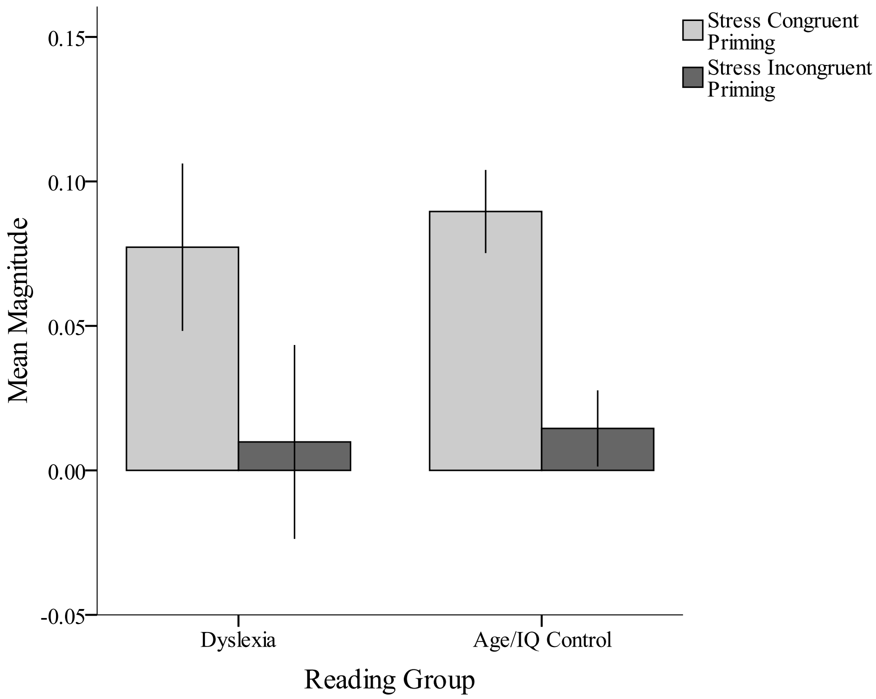

Figure 2. Mean priming effect magnitudes by reading group

A 2 (reading group) by 3 (prime condition) repeated measures ANOVA was also conducted on the error data (Figure 3, page 93). The main effect of reading group was significant by subjects and by items (F_1 (1, 76) = 6.57, p = .012, d = .46; F_2 (1, 47) = 14.62, p < .001, η_p^2 = .237) indicating that control participants had a lower overall error rate than participants with dyslexia. The main effect of prime condition was significant by items and a marginal result was obtained in the subjects analysis (F_1 (2, 152) = 3.00, p =.053, η_p^2 = .038; F_2 (2, 94) = 4.66, p = .012, η_p^2 = .090).

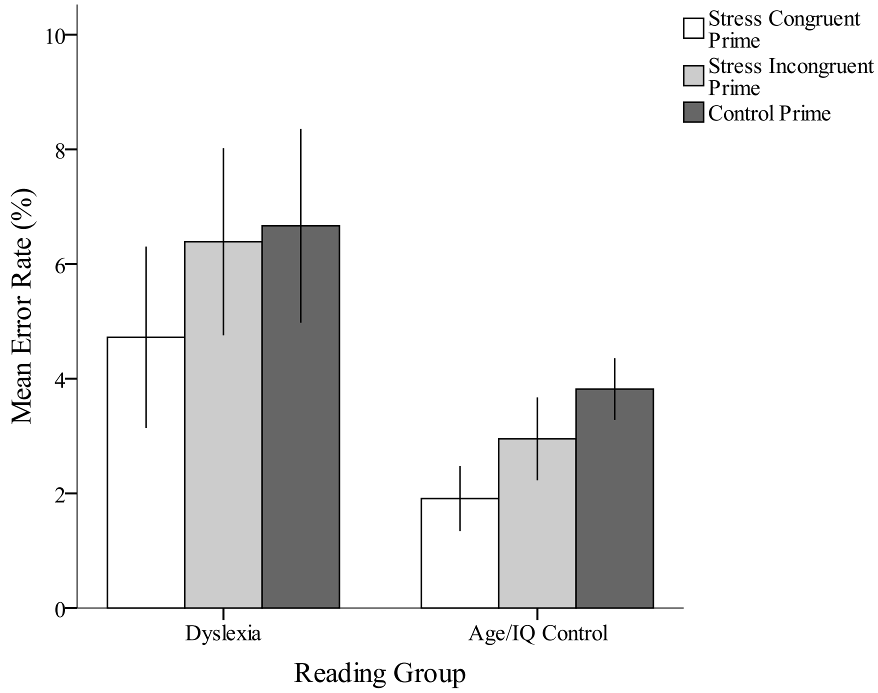

Figure 3. Mean percentage error rate by reading group and prime condition

Post hoc paired samples t-tests with Bonferroni corrections applied for multiple comparisons revealed that, overall, participants made fewer errors in the stress congruent condition compared to the control condition (t_1 (77) = 2.57, p = .036, η_p^2 = .079; t_2 (95) = 3.45, p = .002, η_p^2 = .181). There was no significant difference in error rates between the stress congruent and stress incongruent conditions (t_1 (77) = 1.84,

p = .211, ns; t_2 (95) = 1.83, p = .210, ns) or between the stress incongruent condition and the control condition (t_1 and $t_2 < 1$). The interaction between reading group and prime condition again failed to reach significance in either the subjects or the items analysis (F_1 and $F_2 < 1$, ns).

As noted previously (page 73), participants with dyslexia were included in the sample regardless of their overall degree of reading impairment. The purpose of this was to capture some of the natural variability and heterogeneity in reading ability and avoid drawing artificial comparisons between highly skilled readers on the one hand and very impaired readers on the other. A potential difficulty with this approach is that the consequent overlap in reading ability between groups may have obscured reading-related differences in priming performance and increased the likelihood of a negative result. In order to address this, further analyses were conducted in which reading ability was treated as a continuous – rather than categorical – variable. If the non-significant group*prime interactions obtained in the ANOVA analyses are valid, and different levels of reading ability are not associated with different patterns or magnitudes of priming, a continuous measure of word reading ability should also fail to predict the critical priming effect magnitudes in a regression analysis.

Regression analyses were conducted in which reading ability – as measured by TOWRE word reading scores – was used to predict the magnitudes of the critical stress congruent and stress incongruent priming effects. Analyses conducted on the response time data indicated that word reading ability was not a significant predictor of the stress congruent (R^2 = .004, p = .605, β = -.059) or stress incongruent (R^2 = .002, p = .706, β = -.043) priming effects. Similar results were also obtained for the stress congruent (R^2 = .001, p = .819, β = -.026) and stress incongruent (R^2 = .002, p = .682, β = -.047) priming effects observed in the error data.

Discussion

This experiment utilised the cross modal fragment priming paradigm to investigate the ability of adults with dyslexia to represent the lexical stress patterns of words stored in the mental lexicon. In contrast to their impaired performance on the DEEdee task, observed in Experiment 1a, participants with dyslexia showed the same pattern of priming effects as age/IQ matched controls. The lexical decision responses of participants in both reading groups were faster and more accurate in the stress congruent condition compared to the control and stress incongruent conditions with little or no difference observed between the control and stress incongruent conditions. Furthermore, the magnitudes of the priming effects were not significantly different across the reading groups once overall differences in response time had been taken into account. This suggests that adults with developmental dyslexia accurately represent lexical stress in the mental lexicon and, at the representational level, are able to distinguish between words with overlapping segmental phonology on the basis of differences in lexical stress assignment.

An alternative explanation for these results stems from the variable level of reading impairment in the dyslexic sample. It is possible that the consequent overlap in reading ability between the dyslexic and control groups may have obscured reading-related differences in priming performance and increased the chances of a negative result. However, this possibility is refuted by the fact that a continuous measure of word reading ability also failed to predict the magnitudes of the critical priming effects in a series of regression analyses conducted across the entire sample of participants.

Ramus and Szenkovits (2008) have argued that the reading problems of adults with dyslexia may result from specific difficulties in accessing phonological representations rather than the quality of the representations themselves. The main effect of reading group observed in the response time data, particularly in the context of the non-significant interaction between reading group and prime condition, offers some support for this suggestion. This pattern of results indicates that while the nature of the underlying representations may be similar in both reading groups, participants with dyslexia are nevertheless processing information relating to syllabic stress assignment less efficiently than controls. One obvious source of the difference in overall response time between the reading groups is the lower reading ability of the participants with dyslexia. As a result of this, participants with dyslexia would naturally be slower to decode the target strings and generate their lexical decision responses. However, it is also possible that the spoken primes take longer to activate potential lexical candidates in the dyslexic group, or that competition between lexical candidates is resolved more slowly. As a result of this, priming effects are observed at much longer latencies than in the control group. Overall, the results obtained from the priming task are consistent with the suggestion that, despite having intact phonological representations, participants with dyslexia may be less efficient in accessing these representations and using them to compare different stimuli according to a specific aspect of their phonological structure.

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. This interpretation would be consistent with previous findings reported in the domain of phonemic processing where French speaking adults with dyslexia have been shown to perform normally in subliminal auditory priming, and to show effects of phonological similarity in online phonological processing tasks, despite also having reduced levels of phoneme awareness (Ramus & Szenkovits, 2008). Unpublished findings have also suggested that English speaking adults with dyslexia are impaired on tasks requiring the conscious manipulation of syllabic stress despite accurately perceiving contrasts between compound nouns and phonemically matched noun phrases (Dickie et al., 2007). Together these results suggest that the literacy problems associated with dyslexia in adulthood may arise from specific problems in accessing and manipulating stored knowledge of segmental and suprasegmental phonology rather than deficiencies in the underlying representations involved in reading.

When considering the results reported in Experiments 1a and 1b 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 differences in task performance observed in

Experiments 1a and 1b. It would also be useful to investigate whether stress based priming effects can be observed across a wider range of stimuli, such as items that share morphological and semantic attributes in addition to overlapping segmental phonology. 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, general processing demands, 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 were chosen in order to control for the possible influence of reading demands, verbal short-term memory load, differences in the level of prosody addressed, and item specific effects on participants' responding. The tasks utilised in the experiment 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. As before, participants were required to respond to visually presented target words preceded by three types of spoken prime. In the stress congruent prime condition, the prime was the first two syllables of the target word (e.g. *<u>prósec</u>/utor* → *PROSECUTOR*). In contrast, in the stress incongruent prime condition, the prime was the first two syllables of a word that shared segmental phonology with the target but differed in stress assignment (e.g. *<u>pròsec</u>/útion* → *PROSECUTOR*). Finally, in the control condition, the prime was the first two syllables of a phonologically unrelated word (e.g. *<u>accél</u>/erate* → *PROSECUTOR*).

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 experiments, 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 Experiments 1a and 1b, would strongly suggest a selective impairment of conscious prosodic awareness in adults with dyslexia. Finally, due to the increased semantic and morphological relatedness within the pairs of experimental primes, it was also hypothesised that a small semantic or morphologically based priming effect may be observed in the stress incongruent prime condition.

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

Matching and literacy. Participants completed the Similarities and Matrix Reasoning subscales of the Wechsler Abbreviated Scale of Intelligence (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 Test of Word Reading Efficiency (Torgesen et al., 1999). These tasks were administered and scored as described in Experiment 1a (pages 73-74).

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 with feedback prior to beginning the task.

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 explicit 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 (RT). 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. This task adopted the same format as in Experiment 1b. 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. 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 48 experimental primes also served as target words. 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). Primes were presented at the end of non-constraining carrier sentences (e.g. *Hank asked his wife to say <u>prósec</u>*) 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 D.

A total of 8 presentation orders were constructed and 2 participants with dyslexia and 3 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 variables were the mean response time for lexical decision (correct trials only) and percentage error rate 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 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 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 a notable but statistically non-significant ($p = .109$) difference in age between the reading groups. 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 31 years.

Table 5.

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

Measure	Dyslexia	Age/IQ Control	t (38)	sig.	d
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

Five participants with dyslexia and one control participant were equal to or below chance on the fragment identification task (Table 6, page 106). Overall, participants with dyslexia were significantly less accurate than controls. Participants with dyslexia were also slower to respond than controls, although, after correcting for unequal variances, this result failed to reach significance.

Table 6.

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

Measure	Dyslexia	Age/IQ Control	*t* (38)	sig.	*d*
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

As the primary purpose of this study was to contrast performance in the two experimental tasks, and the sample size was smaller than in the previous experiment, large scale correlational analyses were not conducted. However, partial correlations – controlling for age, verbal IQ and performance IQ – were calculated 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 ($r = -.454$, $p = .005$).

As in Experiment 1b, participants were excluded from the priming analyses if their overall percentage error rate exceeded 25%. The longest 5% of response times registered by each participant in each prime condition were also removed from the data. These procedures ensured that participant exclusions were minimised and that the overall response time of each individual participant was taken into account when removing outliers. In total, one participant with dyslexia was excluded due to a high overall error rate (26%).

A 2 (reading group) by 3 (prime condition) repeated measures ANOVA was conducted on participants' lexical decision times (Figure 4). The main effect of reading group was significant by subjects and by items (F_1 (1, 37) = 10.79, p = .002, d = .27; F_2 (1, 47) = 301.11, p < .001, η_p^2 = .865) reflecting the fact that participants with dyslexia responded more slowly than controls across all prime conditions. The main effect of prime condition was also significant by subjects and by items (F_1 (2, 74) = 15.05, p < .001, η_p^2 = .289; F_2 (2, 94) = 6.34, p = .003, η_p^2 = .119).

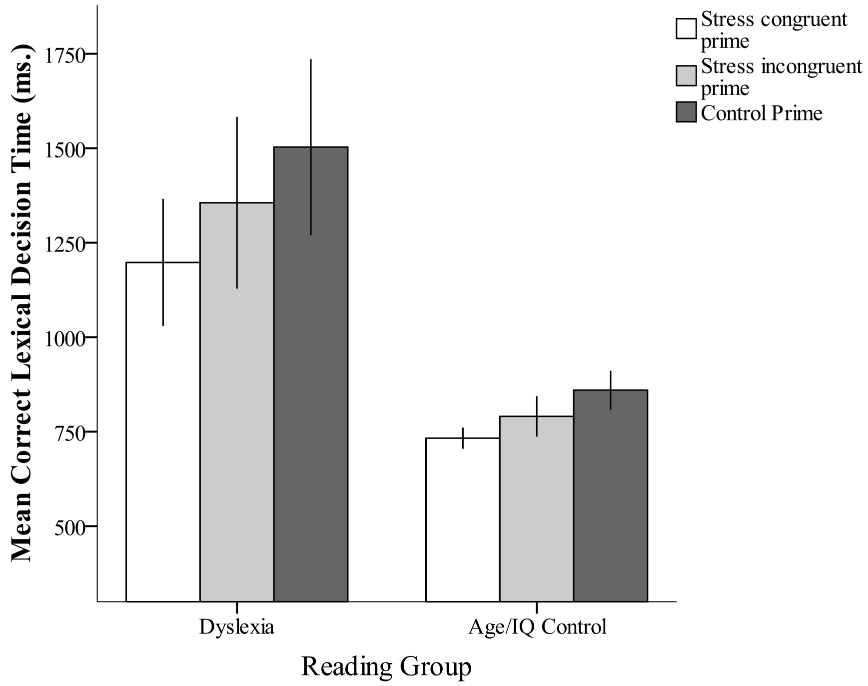

Figure 4. Mean correct lexical decision time by reading group and prime condition

Post hoc paired samples t-tests with Bonferroni corrections applied for multiple comparisons revealed that, overall, participants were significantly faster to respond in the stress congruent condition compared to the control condition (t_1 (38) = 4.39, p < .001, η_p^2 = .337; t_2 (95) = 3.98, p < .001, η_p^2 = .230). As anticipated, due to the increased semantic and morphological relatedness of the primes in Experiment 2, a significant priming effect was also observed in the stress incongruent condition. However, this effect was weaker than the stress congruent priming and only appeared in the subjects analysis (t_1 (38) = 4.36, p < .001, η_p^2 = .333; t_2 (95) = 1.63, p = .320, ns). There was no significant difference in response time between the stress congruent condition and the stress incongruent condition (t_1 (38) = 2.10, p = .126, ns; t_2 (95) = 2.06, p = .126, ns). Finally, the interaction between reading group and prime condition failed to reach significance in either the subjects or the items analysis (F_1 (2, 74) = 2.57, p = .104, ns; F_2 (2, 94) = 1.60, p = .207, ns) indicating that participants in both reading groups showed the same pattern of priming performance across the three conditions.

Priming effect magnitudes (Figure 5, page 109) were calculated for the stress congruent and stress incongruent conditions relative to the control condition as described in Experiment 1b (page 92). Independent samples t-tests revealed that neither of the effect magnitudes differed significantly between reading groups (t < 1 in both cases). Both reading groups showed a non-significant trend in which more priming was observed in the stress congruent condition compared to the stress incongruent condition.

As predicted, due to the increased morphological and semantic relatedness of the primes, more priming was observed in the stress incongruent condition than had been the case in Experiment 1b (Figure 2, page 92). As a result, the differences in effect magnitudes for stress congruent and stress incongruent primes did not reach significance in either the dyslexic (t (14) = 1.34, p = .201, ns) or the control group (t (23) = 1.33, p = .196, ns). When the data from the two reading groups were pooled, the difference in magnitude between the stress congruent and stress incongruent priming effects marginally failed to reach significance (t (38) = 1.91, p = .063, ns).

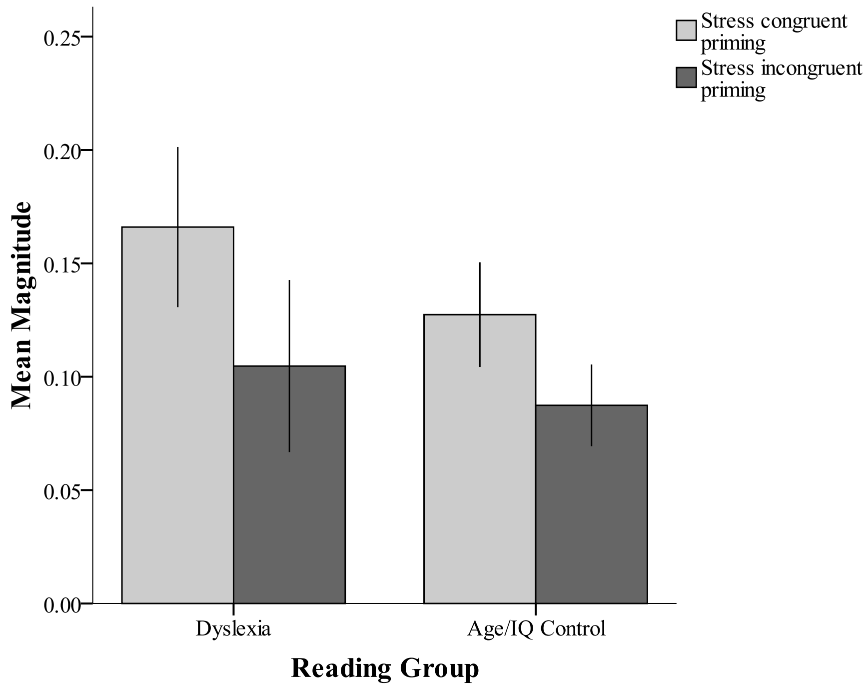

Figure 5. Mean priming effect magnitudes by reading group

A 2 (reading group) by 3 (prime condition) repeated measures ANOVA was also conducted on the error data (Figure 6, page 110). The main effect of prime condition was significant by subjects and by items (F_1 (2, 74) = 6.25, p =.003, η_p^2 = .145; F_2 (2, 94) = 5.00, p = .009, η_p^2 = .096). Post hoc paired samples t-tests with Bonferroni corrections applied for multiple comparisons revealed that, overall, participants made significantly fewer errors in the stress congruent condition compared to the control condition (t_1 (38) = 3.99, p = .001, η_p^2 = .296; t_2 (95) = 3.05, p = .009, η_p^2 = .167). Participants also made significantly fewer errors in the stress incongruent condition compared to the control condition (t_1 (38) = 2.75, p = .028, η_p^2 = .166; t_2 (95) = 2.48, p = .045, η_p^2 = .107). No significant differences were found between the stress congruent condition and the stress incongruent condition (t_1 and t_2 < 1).

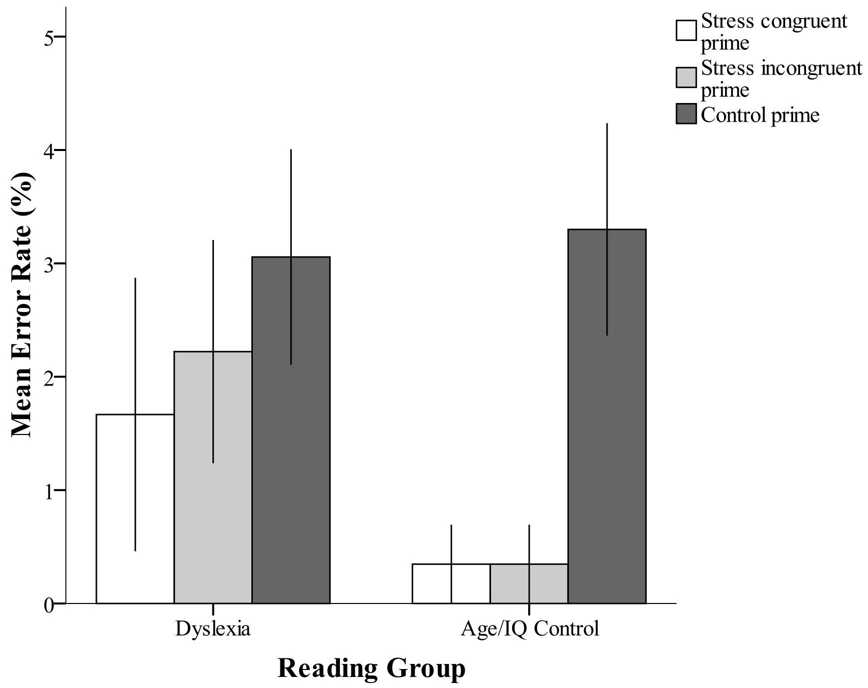

Figure 6. Mean percentage error rate by reading group and prime condition

The main effect of reading group (F_1 (1, 37) = 1.40, p = .244, ns; F_2 (1, 47) = 2.13, p = .151, ns) and the interaction between reading group and prime condition (F_1 (2, 74) = 1.35, p = .265, ns; F_2 (2, 94) = 1.09, p = .342, ns) failed to reach significance in either the subjects or the items analysis.

Regression analyses were again conducted across the entire sample to ensure that reading-related differences in priming performance had not been obscured by the variable level of reading impairment amongst the dyslexic participants and the overlap in reading ability between the two groups. Once again, TOWRE word reading scores failed to predict the magnitude of the stress congruent (RT: R^2 = .021, p = .378, β = -.145; Errors: R^2 = .066, p = .289, β = .257) and stress incongruent (RT: R^2 = .005, p = .663, β = .072; Errors: R^2 = .159, p = .091, β = .399) priming effects either in the response time data or the error data.

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, general processing demands, the specific items used as stimuli and the level of prosody addressed. The experiment also investigated priming effects resulting from the manipulation of lexical stress in a novel set of stimuli.

The cross modal fragment priming paradigm was used to assess participants' ability to accurately encode lexical stress information in phonological representations stored in the mental lexicon. As in Experiment 1b, participants in both reading groups showed an identical pattern of priming effects across the three experimental conditions as well as comparable priming effect magnitudes. Overall, participants showed significant priming effects in the stress congruent and stress incongruent prime conditions with a non-significant trend in which the stress congruent priming effect was greater in magnitude than the stress incongruent priming effect. These results were again supported by regression analyses in which a continuous measure of reading ability failed to predict the magnitudes of the critical priming effects in either the response time or the error data.

The priming data reported in this experiment and in Experiment 1b are consistent with findings from previous priming studies (Cooper et al., 2002; Soto-Faraco et al., 2001; van Donselaar, 2005), as well as research conducted using other paradigms (e.g. Curtin, 2010; Curtin et al., 2005; Lindfield et al., 1999), in suggesting that information concerning lexical stress assignment forms an integral part of readers' phonological representations. They also support the contention that, perhaps surprisingly, these representations may be equally well specified in skilled adult readers and adults with dyslexia. In the case of prosodic structure, adults with dyslexia appear to accurately represent lexical stress assignment in the mental lexicon and draw stress based distinctions between different words. Finally, a main effect of reading group was again observed in the response time data. This main effect, observed in the context of the non-significant interaction between reading group and prime condition, suggests that despite having intact phonological representations, participants with dyslexia may be less efficient in accessing these representations and using them to compare different stimuli according to a specific aspect of their phonological structure. Such an interpretation would be consistent with the position of Ramus and Szenkovits, who have argued that the reading problems associated with dyslexia result from specific problems in accessing phonological representations, rather than the quality of the representations themselves.

The priming task used in this experiment differed from that in Experiment 1b in that the pairs of words used as experimental primes were derived from a common root, and as a result, in addition to the shared segmental phonology in the first two syllables, there was a substantial semantic and morphological overlap between the stress congruent and stress incongruent primes. For this reason, substantially more priming was observed for the stress incongruent primes than in Experiment 1b. This result is interesting for two reasons. Firstly, as the pattern and magnitude of priming was similar across reading groups, this result suggests that the semantic and morphological relations between words, as well as their segmental and suprasegmental phonology, are well preserved in the mental lexicon of adults with dyslexia. Secondly, the fact that participants continued to show a trend for larger priming effects in the stress congruent condition compared to the stress incongruent condition, suggests that the stress based distinctions between words are sufficiently strong to distinguish pairs of items that are extremely closely related on several linguistic dimensions. It is this type of word pair, in which many details of segmental phonology, semantics, and morphology are shared, that information pertaining to lexical stress assignment may prove most useful in assisting reading.

Participants with dyslexia again experienced difficulties with a task that required conscious awareness of lexical stress assignment; the fragment identification task (Mattys, 2000). Five participants with dyslexia scored below chance on this task and there was a large overall difference in accuracy between the reading groups. These results are consistent with the findings reported in Experiment 1a in which participants with dyslexia were found to be significantly impaired on the DEEdee task and together they extend earlier findings of a prosodic awareness deficit in samples of children with reading problems (Goswami et al., 2009; Wood & Terrell, 1998). Performance on the fragment identification task was also significantly correlated with word and nonword reading ability. This finding is also consistent with the results of Experiment 1a, in which the DEEdee task was found to be strongly related to reading ability and phoneme awareness. Finally, these results add to a larger body of research discussing the role of prosodic skills in typical reading development (e.g. Clin et al., 2009; Holliman et al., 2008a; 2010a; Jarmulowicz et al., 2007; Whalley & Hansen, 2006) by demonstrating that conscious awareness of lexical and metrical prosody continues to be significantly related to reading ability and reading related skills in adulthood.

The overall pattern of performance observed across Experiments 1 and 2 strongly suggests that adults with dyslexia show a selective impairment affecting tasks that require conscious awareness of metrical and lexical prosody while underlying representations of syllabic stress assignment remain intact. The fact that the experimental tasks used in Experiment 2 shared the same stimuli, addressed the same level of prosodic structure, and imposed similar demands on reading and verbal short-term memory rule out these factors as potential reasons for the observed difference in performance. Furthermore, converging findings have also been reported in the domain of phonemic processing (Ramus & Szenkovits, 2008). Together these results suggest that the literacy problems associated with dyslexia in adulthood may arise from specific problems in accessing and manipulating stored knowledge of segmental and suprasegmental phonology rather than deficiencies in the underlying representations involved in reading. If this is indeed the case, existing models of word reading (e.g. Coltheart et al., 2001; Harm & Seidenberg, 1999) may have to be adapted in order to place greater emphasis on the effortful processes involved in reading in addition to the robustness of phonological representations and the passive learning of statistical correspondences between phonological and orthographic units.

The claim that adults with dyslexia may accurately represent suprasegmental phonology appears to be inconsistent with the finding that English speaking adults with dyslexia are impaired relative to age/IQ matched controls in the beat perception task devised by Goswami and colleagues (2002) and in discriminating non-speech stimuli on the basis of amplitude rise-time, duration and frequency (Pasquini et al., 2007; Thomson et al., 2006; Witton et al., 2002). Similar findings have also been reported across different orthographies (e.g. Hämäläinen et al., 2003). These findings would seem to imply a more fundamental impairment of prosodic processing in dyslexia. Researchers have argued that people with dyslexia may fail to perceive and accurately encode the rhythmic structure of spoken language and that this in turn compromises the development of phonological representations (Goswami et al., 2002; Richardson et al., 2004). However, an analysis of the processing demands associated with these perceptual tasks suggests that they share many features with tasks that have been used to measure awareness of prosodic structure in linguistic stimuli. For example, participants may be asked to listen to multiple stimuli and match one of them to a sample stimulus or to discriminate between two stimuli on the basis of a particular acoustic dimension. Therefore, rather than reflecting a fundamental deficit in the perception and encoding of prosodic structure, the reading group differences observed on these tasks may in fact result from dyslexic participants' relative inability to consciously compare and contrast the different auditory stimuli. In short, it has been assumed that because these tasks utilise non-speech stimuli they must therefore be addressing low-level auditory processes; this is not necessarily the case.

It may be parsimonious to attribute the reading difficulties of adults with dyslexia to problems with higher level phonological processes involved in accessing and manipulating phonological information rather than an all encompassing multi-level phonological deficit such as that proposed recently by Goswami (2011). However, in order to substantiate this, it must be explained why adults with dyslexia should show reduced access to, and awareness of, representations that are themselves intact. Ramus and Szenkovits (2008) argue that a selective impairment affecting the ability to access mental representations in phonological processing, as well as in low-level visual and auditory tasks, may fully account for the phonological problems associated with dyslexia, as well as the related sensory and cognitive deficits described in Chapter 1, across the full course of development. However, another possibility lies in the nature of the samples studied. The adults included in the current experiments, as well as those of Ramus and Szenkovits, are students in higher education. It is likely that these participants have received substantial amounts of additional reading tuition and phonological training and also that their IQ and educational level have allowed them to compensate for some of their difficulties. These factors may help compensate for some aspects of the individual's phonological processing problems, such as the ability to 'hear' differences between speech sounds and form robust representations of the sequences of phonemes within words, but fail to significantly improve other processes, such as the speed at which phonological information can be accessed or the ease with which phonological information can be consciously manipulated. It is possible that a broad phonological deficit may prove to be appropriate for describing younger or less well educated groups of dyslexic people but such a theory may be overly general for understanding the reading problems of university students. Studies of phonological processing provide support for this suggestion by revealing that phonological processing is multifaceted (Wagner & Torgesen, 1987), different aspects of phonological processing have independent links with specific literacy skills (Wolf & Bowers, 1999), different dyslexic individuals may show quantitatively and qualitatively different phonological deficits (Castles & Coltheart, 1993; Stanovich, 1988; 1998), and the types of phonological difficulties observed, and their relationship with reading, may differ over the course of development, particularly in cases where individuals have received remedial reading instruction (Bowey, 2005; Goswami, 2003).

Summary

The experiments reported in this chapter assessed the ability of adults with dyslexia to accurately represent lexical stress assignment in the mental lexicon and contrasted this ability with their conscious awareness of prosodic structure. Both experiments demonstrated that adults with dyslexia show normal patterns of stress based priming and that priming effects achieve similar magnitudes to those of control participants. In contrast, participants were found to be impaired on tasks requiring conscious awareness of prosodic structure. The second experiment ruled out the possibility that these apparent differences in performance may be the result of inconsistencies in the processing demands of the experimental tasks. Overall, the results strongly suggest that educated adults with dyslexia show a selective impairment of prosodic awareness similar to that reported at the level of phonemic processing by Ramus and Szenkovits (2008). Those authors have suggested that that a selective impairment affecting the ability to access mental representations in phonological processing, as well as in low-level visual and auditory tasks, may fully account for the phonological problems associated with dyslexia as well as the related sensory and cognitive deficits described in Chapter 1. However, it is also possible that this selective impairment results from changes in individuals' phonological skills over the course of development, particularly in response to high levels of remedial reading instruction and educational attainment. Experiment 3, reported in the following chapter, further investigates the dissociation between prosodic awareness and the underlying representation of syllabic stress in dyslexia by attempting to prime lexical stress using abstract stress templates (DEEdee stimuli) in place of spoken word fragments.

Chapter 5

Reading group differences in the priming of lexical stress with abstract (DEEdee) stress templates

Overview

The experiment reported in this chapter utilised a novel cross modal priming paradigm to investigate the processing of lexical stress information in a sample of adults with developmental dyslexia and age/IQ matched controls. In place of the real-word fragments used previously, this paradigm attempted to prime lexical stress using abstract stress templates in the form of DEEdee stimuli. Both groups of participants showed marginally faster response times following stress congruent DEEdee primes in comparison to stress incongruent DEEdee primes. However, overall, the main effect of prime condition was marginally non-significant. It is tentatively concluded that the results of the experiment are consistent with those of the previous studies in suggesting that the prosodic processing difficulties of adults with dyslexia are specific to tasks that require conscious access to phonological information and the ability to draw explicit comparisons between phonological representations.

Experiment 3

The experiments reported in the previous chapters lead to the conclusion that adults with developmental dyslexia are able to accurately represent the prosody of words stored in the mental lexicon and, at the representational level, are able to draw distinctions between different items on the basis of syllabic stress. Despite this however, the results of Experiments 1 and 2 also suggest that adults with dyslexia continue to experience difficulties with other aspects of prosodic processing, such as accessing prosodic representations, manipulating prosodic information in an abstract way, or consciously comparing and contrasting different stimuli according to a particular aspect of phonological structure.

The experiment reported in this chapter utilised a novel cross modal priming paradigm to further investigate the dissociation between the representation of syllabic stress and the conscious awareness of prosodic structure. During this task, lexical stress was primed using abstract stress templates in the form of DEEdee stimuli. In the stress congruent DEEdee prime condition, the spoken prime was a DEEdee stimulus corresponding to the stress pattern of the target word (*e.g. deedeedéedee* → *EXHIBITION*). In contrast, in the stress incongruent DEEdee prime condition, the spoken prime was a DEEdee stimulus representing a pattern of lexical stress assignment that conflicted with the target word (e.g. *deedéedeedee* → *EXHIBITION*). Priming effects were measured in each of these conditions in relation to a control condition which utilised naturally spoken primes (e.g. *philósopher* → *EXHIBITION*). Finally, a repetition prime condition (e.g. *exhibítion* → *EXHIBITION*) was also included.

The use of abstract stress templates crucially altered the nature of the cross modal priming task. Whereas previously lexical stress information had been presented to participants in the context of a real-word prime – albeit a word fragment – participants were now required to extract this information from a DEEdee stimulus. In order to achieve this, participants must first form a representation encoding the prosodic structure of the novel, unfamiliar DEEdee prime. It was hypothesised that control participants would be faster to respond in the stress congruent DEEdee prime condition relative to the control condition and the stress incongruent DEEdee prime condition. The specific demands of the DEEdee priming paradigm meant that similar or contrasting patterns of responding amongst participants with dyslexia had the potential to shed further light on the specific types of prosodic processes and specific types of prosodic representations that are associated with reading difficulties in adulthood.

Although adults with dyslexia are known to struggle with DEEdee stimuli in the context of the DEEdee task itself (Table 2, page 78; Kitzen, 2001), it is yet to be established whether this is due to the metalinguistic demands of the task (e.g. consciously contrasting several phonological representations) or an inability to form prosodic representations of novel stimuli and extract lexical stress information from the DEEdee items. The current experiment addresses this question by utilising DEEdee stimuli in the context of an implicit, preconscious phonological processing task. If participants with dyslexia were to show a comparable pattern of DEEdee priming to controls this would add support to the suggestion that the prosodic processing deficit in dyslexia is specific to tasks requiring conscious access to phonological information.

In contrast, while it is possible that adults with dyslexia may come to form robust representations of lexical stress assignment in real words over time (Experiments 1b and 2) – particularly in response to remedial instruction or because of compensatory factors such as IQ and educational level – it is equally possible that the same participants may continue to struggle when asked to form new prosodic representations for novel or unfamiliar items such as DEEdee stimuli. Failure of dyslexic participants to show a priming advantage for stress congruent over stress incongruent DEEdee stimuli could indicate a problem with this aspect of phonological processing. Such a finding would also indicate that, unlike the representations stored in the mental lexicon, the prosodic representations assembled online during a linguistic task may be impaired in dyslexia.

Method

Participants

Participants were 36 students enrolled on undergraduate and postgraduate courses at a large university in the UK. The sample included 18 students with developmental dyslexia recruited through the university's disability support service (*M* age = 23 years, *SD* = 6.36, 4 males) and 18 age/IQ matched controls (*M* age = 22 years, *SD* = 3.37, 3 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 problems (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

Matching and literacy. Participants completed the Similarities and Matrix Reasoning subscales of the Wechsler Abbreviated Scale of Intelligence (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 Test of Word Reading Efficiency (Torgesen et al., 1999). These tasks were administered and scored as described in Experiment 1a (pages 73-74).

Cross modal DEEdee priming. During the cross modal priming task participants were required to make lexical decision responses (real word or nonword) to visually presented letter strings preceded by spoken real-word and DEEdee primes. The relationship between prime and target was manipulated as a 4-level independent variable (repetition prime, control prime, stress congruent DEEdee prime and stress incongruent DEEdee prime). In the repetition condition the spoken prime and the target word were identical (e.g. *exhibítion → EXHIBITION*). In the control condition the spoken prime was a word that differed from the target in both segmental phonology and lexical stress assignment (e.g. *philósopher → EXHIBITION*). In the stress congruent DEEdee prime condition the spoken prime was a DEEdee stimulus corresponding to the stress pattern of the target word (*e.g. deedeedéedee → EXHIBITION*). Finally, in the stress incongruent DEEdee prime condition, the spoken prime was a DEEdee stimulus corresponding to the stress pattern of the control prime and thus conflicting with the target word (e.g. *deedéedeedee → EXHIBITION*). The current experiment also included two further conditions in which stress congruent and stress incongruent prime words were heard through a low-pass filter. However, this manipulation was unsuccessful and the results relating to these conditions are not discussed.

The design of the experiment emerged from a series of pilot studies utilising a variety of different prime conditions. Priming to the DEEdee stimuli could not be obtained in reference to non-linguistic control conditions (e.g. beeps, tones, white noise) leading to the adoption of the real-word comparison conditions described above. Greater variation in the primes (i.e. a larger number of different prime conditions) appeared to help elicit priming to the DEEdee primes, perhaps because a larger number and variety of control primes increased the number of intervening trials between experimental primes and prevented participants from confusing similar sounding DEEdee stimuli. As these manipulations represented stages in the development of the methodology, rather than theoretically significant hypotheses, the results are excluded from the thesis.

A total of 15 target words were selected for use in the experiment. The target words contained either 3 or 4 syllables and they were selected so that 5 different lexical stress patterns were equally represented; strong-weak-weak (e.g. *díagram*), weak-strong-weak (e.g. *tobácco*), weak-weak-strong (e.g. *entertáin*), weak-weak-strong-weak (e.g. *horizóntal*) and weak-strong-weak-weak (e.g. *apólogy*). Each target word was matched with a control word with contrasting segmental phonology and lexical stress assignment. Repetition and control primes were matched for length (i.e. number of syllables) and Kucera-Francis (1967) written frequency (*M* experimental primes = 21.67 words per million, *M* control primes = 26 words per million) using the MRC Psycholinguistic Database (Coltheart, 1981; Wilson, 1988).

All primes were spoken by a male native speaker of British English. The DEEdee primes were created using the reiterative syllable substitution technique

(Liberman & Streeter, 1978; Nakatani and Schaffer, 1978) in which each syllable of a spoken word is replaced with the nonsense syllable *dee*. The effect of this is to remove the original phonemic content of the utterance while retaining its prosodic structure (e.g. *psychólogy* → *deedéedeedee*). In order for the DEEdee primes to mimic natural speech as closely as possible, the speaker was shown each of the target words 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. Each prime was recorded as a separate sound file and trimmed using the speech analysis software PRAAT (Boersma, 2001). A full list of the stimuli used in the task is provided in Appendix E.

Participants saw all 15 target words once in each of the 6 prime conditions giving a total of 90 experimental trials per participant. The experimental trials were spread across 6 blocks with prime condition counterbalanced across blocks (i.e. each target word appeared once in each block, each time in a different prime condition). There were also 15 filler items with nonword targets which were repeated in every block giving a total of 30 trials per block and 180 trials in all. The sequence of the blocks was counterbalanced with 3 control participants and 3 participants with dyslexia assigned to one of 6 different presentation orders.

Each trial began with a row of asterisks displayed on the screen for 3450ms. The asterisks remained on screen while participants listened to the spoken prime. Following the prime, and an ISI of 500ms, the asterisks were replaced with the target in upper case type. The dependent variables were the mean response time for lexical decision (correct trials only) and percentage error rate 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 approximately 40 minutes and gave informed consent before beginning any of the tasks. The literacy measures were administered first followed by the cross modal DEEdee priming task and the IQ subscales. During the cross modal DEEdee 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. 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 are provided in Table 7 (page 126). Participants with dyslexia were significantly impaired relative to controls on the measure of nonword reading ability. However, the group difference in word reading ability narrowly failed to reach significance (p = .094). There were no significant reading group differences in age, verbal IQ or performance IQ.

Table 7.

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

Measure	Dyslexia	Age/IQ Control	*t*(34)	sig.	*d*
Age (yrs.)	23.28 (6.36)	22.06 (3.37)	<1	-	-
Verbal IQ	54.39 (6.45)	56.50 (4.44)	1.14	$p = .261$	-
Performance IQ	54.06 (8.19)	55.22 (7.16)	<1	-	-
Word Reading	91.00 (9.68)	96.39 (9.10)	1.72	$p = .094$	0.56
Nonword Reading	89.28 (8.64)	98.28 (9.27)	3.01	$p = .005$	0.98

As previously, the longest 5% of response times registered by each participant in each prime condition were removed from the data. This ensured that the overall response time of each individual participant was taken into account when removing outliers. All of the participants had overall error rates below the 25% percent criterion used in the previous experiments and therefore all of the participants were included in the priming analyses (*M* dyslexic group = 2.96, *M* control group = 1.45). Unsurprisingly, participants in both reading groups were significantly faster to respond following a repetition prime than in all other prime conditions. Therefore, the analyses focus on response times in the stress congruent DEEdee condition, the stress incongruent DEEdee condition and the control condition.

Response time data from the cross modal priming task are displayed in Figure 7 (page 127). Data from the critical stress congruent and stress incongruent DEEdee conditions were entered into a 2 (prime) by 2 (reading group) repeated measures ANOVA. The main effect of group was significant by subjects and by items (F_1 (1, 34) = 7.42, p = .010, d = .89; F_2 (1, 14) = 77.42, p < .001, η_p^2 = .847) indicating that control participants were significantly faster to respond than participants with dyslexia. Control participants showed a small advantage for the stress congruent DEEdee primes over the stress incongruent DEEdee primes (*M* difference (subjects) = 26.82ms; *M* difference (items) = 23.38ms). Participants with dyslexia also responded more quickly in the stress congruent condition compared to the stress incongruent condition (*M* difference (subjects) = 12.8ms, *M* difference (items) = 22.76ms). However, the main effect of prime condition failed to reach significance in the subjects analysis and only a marginal result was obtained in the items analysis F_1 (1, 34) = 2.90, p =.098, ns; F_2 (1, 14) = 4.50, p = .053, ns). The critical interaction between reading group and prime condition was not significant in the subjects or the items analysis (F_1 and F_2 < 1).

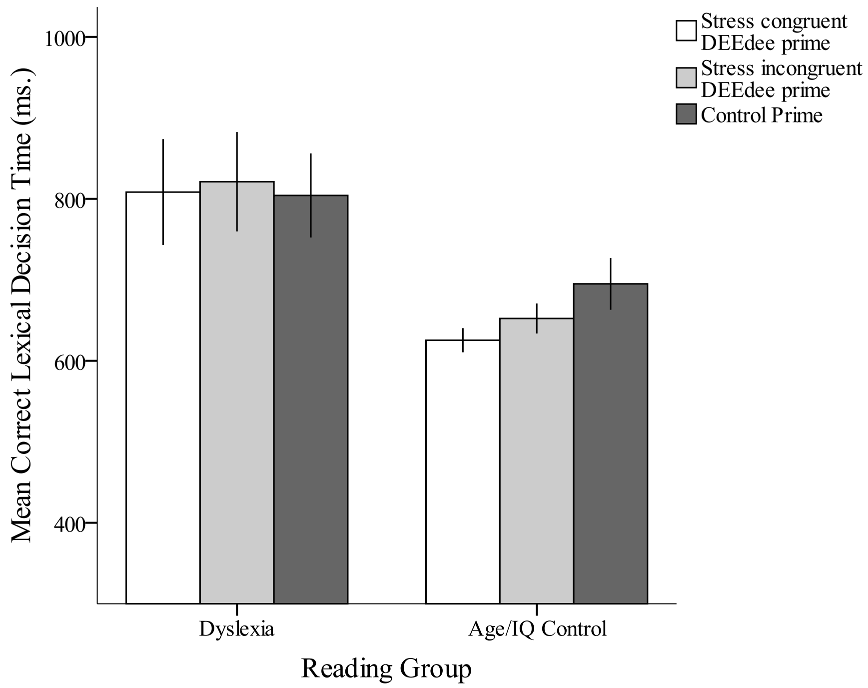

Figure 7. Mean correct lexical decision time by reading group and prime condition

An identical 2x2 repeated measures ANOVA conducted on the error data for the stress congruent and stress incongruent DEEdee conditions (Figure 8) produced no significant main effects or interactions (F_1 and $F_2 < 1$ in all cases).

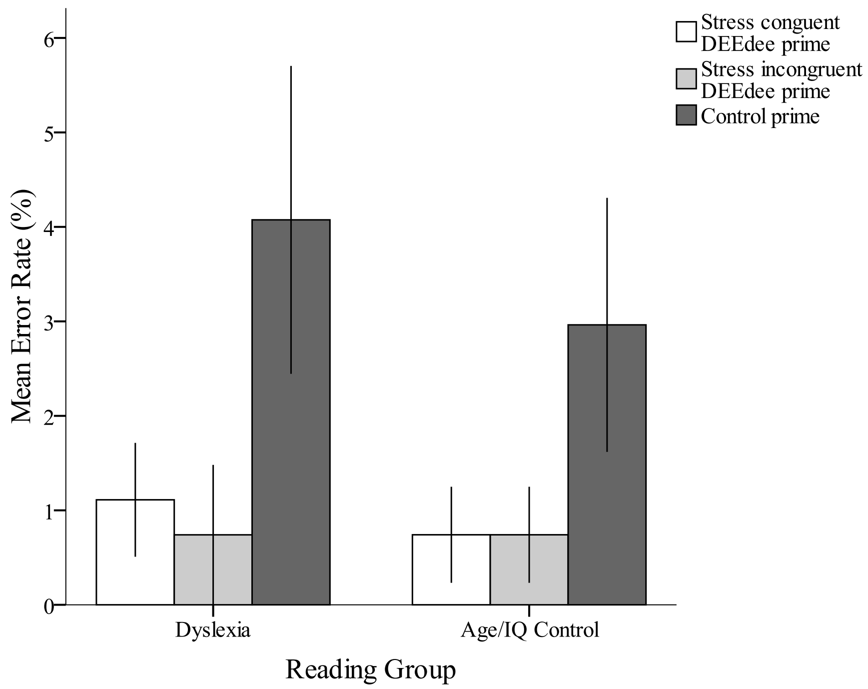

Figure 8. Mean percentage error rate by reading group and prime condition

As in the previous experiments, regression analyses were conducted across the entire sample to ensure that the absence of the critical interaction was not due to an overlap in reading ability between the two groups of participants. This was particularly important in this instance as the mean difference in word reading ability had not reached significance (Table 7, page 126). Using the method described in Experiment 1b (page 92), priming effects – measured relative to the control condition – were calculated for the stress congruent and stress incongruent primes. The priming effects observed in the response time data are displayed in Figure 9 (page 129). TOWRE word reading ability failed to account for any significant variance in the magnitude of stress congruent (RT: R^2 = .003, p = .741, β = .057; Errors: R^2 = .022, p = .384, β = -.150) or stress incongruent priming (RT: R^2 = .008, p = .868, β = .087; Errors: R^2 = .019, p = .418, β = -.139). Priming effects were also calculated for the stress congruent DEEdee primes relative to the stress incongruent DEEdee primes in order to mirror the structure of the 2x2 ANOVA. Once again, word reading ability was not a significant predictor of priming performance (RT: R^2 = .001, p = .862, β = -.030; Errors: R^2 = .009, p = .583, β = -.095).

Although the 2x2 ANOVA and the regression analyses discussed above were consistent with the results of the previous experiments, the priming effect magnitudes presented in Figure 9 revealed an interesting difference between these priming data and those previously reported.

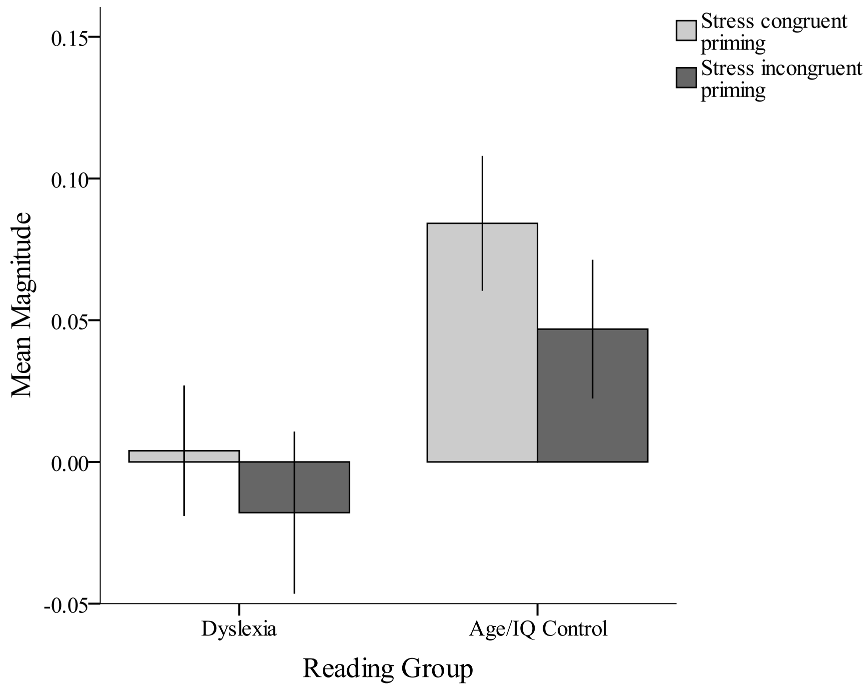

Figure 9. Mean priming effect magnitudes by reading group

Specifically, they suggested that participants with dyslexia had shown little or no priming to the DEEdee stimuli in relation to the real-word control condition. In contrast, the control participants had shown priming effect magnitudes that were comparable to those observed in Experiment 1 (page 92) and Experiment 2 (page 109). An independent samples t-test confirmed that control participants showed significantly more priming in the stress congruent DEEdee condition than participants with dyslexia (t (34) = 2.42, p = .021, d = .79). The magnitude of the stress incongruent priming effect did not differ significantly between groups (t (34) = 1.72, p = .095, ns). These results also suggested that, unlike participants with dyslexia, control participants had shown significantly more priming to the stress congruent DEEdee primes than to the stress incongruent DEEdee primes. A paired samples t-test confirmed that control participants showed significantly more priming in the stress congruent DEEdee condition than in the stress incongruent DEEdee condition (t (17) = 3.23, p = .005, η_p^2 = .384). In contrast, there was no difference in the magnitudes of the stress congruent and stress incongruent priming effects within the dyslexic group ($t < 1$)[4]. Given that both groups of participants showed similar amounts of facilitation for stress congruent DEEdee primes over stress incongruent DEEdee primes, it seems unlikely that these results relate to differences in stress sensitivity. A potential explanation involving semantic inhibition is put forward in the discussion.

[4] A reading group (dyslexia, age/IQ control) by prime condition (stress congruent DEEdee, stress incongruent DEEdee, real-word control) repeated measures ANOVA included in an earlier draft of the thesis also revealed a significant interaction (F_1 (2, 68) = 3.62, p =.032, η_p^2 = .096; F_2 (2, 28) = 5.52, p = .010, η_p^2 = .283). Post hoc t-tests with Bonferroni corrections applied for multiple comparisons indicated that the source of the interaction was a significant difference in response time between the stress congruent DEEdee condition and the control condition (t_1 (17) = 3.30, p = .013, η_p^2 = .390; t_2 (14) = 7.50, p < .001, η_p^2 = .801) and between the stress incongruent DEEdee condition and the control condition (t_1 (17) = 2.16, p = .136, ns; t_2 (14) = 4.73, p = 001, η_p^2 = .615) occurring in the control group.

Discussion

The experiment reported in this chapter introduced a novel cross modal priming paradigm in which abstract stress templates in the form of DEEdee stimuli were used to prime lexical stress. Unsurprisingly, participants with dyslexia were again significantly slower to respond than the control participants across all of the prime conditions. To a certain extent this is likely to reflect differences in reading ability between the groups and the reduced speed at which participants with dyslexia are able to decode the letter strings and generate their lexical decision responses. However, this finding may also indicate less efficient processing of the spoken primes or reduced speed in accessing, activating, and resolving competition between different lexical representations.

The DEEdee priming paradigm utilised in the current experiment differed from the cross modal fragment priming described previously as it placed additional demands on participants' ability to assemble prosodic representations online in response to novel, unfamiliar stimuli. As in the previous priming experiments, the critical interaction between reading group and prime condition failed to reach significance. Participants in both reading groups showed small amounts of facilitation (≈20ms) for the stress congruent DEEdee primes over the stress incongruent DEEdee primes. Regression analyses also confirmed that a continuous measure of reading ability was not significantly associated with different patterns or magnitudes of priming. Disappointingly however, the main effect of prime condition was, at best, marginally non-significant (p = .053 in the items analysis) and therefore it is not possible to make strong claims about the ability of either group to derive lexical stress information from DEEdee stimuli in the context of a priming task.

With this in mind, it is noted that the results of Experiment 3 are broadly consistent with the findings of the previous priming studies in suggesting that the prosodic processing difficulties of adults with dyslexia are specific to tasks that require conscious access to phonological information and the ability to draw explicit comparisons between different phonological representations. None of the priming experiments conducted thus far have suggested that the prosodic representations of adults with dyslexia – either those stored permanently in the mental lexicon or the more transient representations assembled online and held in short-term memory during priming – are of significantly lower quality than those of age/IQ matched controls.

There was, however, one interesting point of difference in the performance of the two reading groups in the DEEdee priming paradigm. Specifically, in addition to the small differences in response time between the stress congruent and stress incongruent DEEdee prime conditions that were observed in both reading groups, control participants – but not dyslexic participants – also showed evidence of priming to the DEEdee stimuli in relation to the real-word control condition. Given that both groups of participants showed similar amounts of facilitation for stress congruent DEEdee primes over stress incongruent DEEdee primes, it seems unlikely that these results relate to differences in stress sensitivity. Instead, it is possible that the semantic incongruity of the real-word control primes may have produced an additional inhibition effect in the control group[5]. This inhibition effect is likely to be responsible for producing the advantage observed for both DEEdee conditions over the real-word control condition amongst control participants. The extent to which the

[5] I would like to thank the external examiner for this suggestion

advantage was greater for the congruent DEEdee stimuli than for the incongruent DEEdee stimuli represents a small additional impact of stress priming.

Furthermore, the absence of such an inhibition effect in the dyslexic group could also be responsible for those participants' apparent lack of priming to the DEEdee stimuli in relation to the real-word controls. The results of several ERP studies now suggest that the process of recognising semantic incongruity in linguistic stimuli is significantly delayed in dyslexic children and dyslexic adults (Jednoróg, Marchewka, Tacikowski, & Grabovska, 2010; Rüsseler, Becker, Johannes, & Münte, 2007; Torkildsen, Swersen, Simonsen, Moen & Lindgren, 2007). It is therefore possible that the relatively brief ISI of 500ms utilised in the current priming task allowed insufficient time for the semantic incongruity to exert an effect on the response times of the participants with dyslexia. As a result of this, the semantic inhibition effect associated with the real-word control primes and the consequent advantage over the control condition for the DEEdee primes was not observed in the dyslexic group.

Phonological processing is multifaceted and different phonological skills may have independent links with literacy and be more or less impaired in different samples of dyslexic individuals (Castles & Coltheart, 1993; Ramus, 2001; Stanovich, 1988; 1998; Wagner & Torgesen, 1987; Wolf & Bowers, 1999). The results of the current experiment are broadly consistent with those of Experiments 1 and 2, as well as previous research conducted in the domain of phonemic processing (Ramus & Szenkovits, 2008), in suggesting that adults with dyslexia have particular problems with tasks requiring conscious access to phonological information.

Summary

This experiment utilised a novel cross modal priming paradigm to investigate the prosodic processing skills of adults with developmental dyslexia. Participants in both reading groups showed a small amount of facilitation for stress congruent versus stress incongruent DEEdee primes. These findings are broadly consistent with the argument advanced in Chapter 4 that adults with dyslexia accurately represent lexical stress assignment but continue to experience difficulties with higher level phonological skills requiring conscious reflection, or the manipulation of phonological structure. They also suggest that prosodic representations assembled online – as well as those stored in the mental lexicon – are intact in adults with dyslexia. However, the non-significant main effect of prime condition urges caution in interpretation. The final experiment, reported in the following chapter, utilised the lexical decision paradigm devised by Kelly et al. (1998) to investigate the ability of adults with dyslexia to learn correspondences between lexical stress patterns and the orthographic structure of printed English words.

Chapter 6

Learning to decode lexical stress in developmental dyslexia

Overview

The experiment reported in this chapter utilised the lexical decision paradigm devised by Kelly et al. (1998) to investigate the sensitivity of adults with developmental dyslexia to the statistical correspondences between patterns of lexical stress assignment and the orthographic structure of printed English words. The lexical decision responses of adults with developmental dyslexia and age/IQ matched controls were significantly faster and significantly more accurate when the orthographic structure of a word gave a reliable indication of its lexical stress pattern. This effect of spelling-stress congruency suggests that adults with dyslexia are able to learn correspondences between lexical stress assignment and orthographic structure and utilise this information to facilitate phonological decoding. It is concluded that the prosodic processing deficit associated with dyslexia in adulthood does not affect the robustness of the prosodic representations used in reading or cause difficulties in acquiring the spelling-sound correspondences used in decoding printed multisyllabic words.

Experiment 4

The phonological theory of developmental dyslexia, and computational models of visual word recognition, have argued that people with dyslexia may fail to accurately represent the phonemic structure of spoken words and that this in turn may impair the ability to learn the statistical correspondences between phonemes and graphemes that are crucial for decoding written words (e.g. Coltheart et al., 2001; Fowler, 1991; Harm & Seidenberg, 1999; Snowling, 2000). An analogous argument can also be made regarding the decoding of suprasegmental phonology. Although English orthography does not contain any explicit notation for signalling lexical stress assignment, there are a number of cues available to the reader that reliably indicate the location of primary lexical stress within a word. The pattern of lexical stress assignment associated with a particular word may be reliably indicated by its grammatical category (Arciuli & Cupples, 2006; Kelly & Bock, 1988; Smith et al., 1982), as well as orthographic (Kelly, 2004; Kelly et al., 1998) and morphological structure (Rastle and Coltheart, 2000). Computational models have indicated that lexical stress can be accurately decoded on the basis of these relationships (Arciuli et al., 2010; Perry et al., 2010; Rastle & Coltheart, 2000; Ševa et al., 2009). Following the logic applied to phonemic decoding, a failure to accurately represent the suprasegmental phonology of spoken words may impair the ability to learn the statistical correspondences that exist between lexical stress assignment and its orthographic, morphological and grammatical correlates, or to learn the rules that govern the use of stress marks in languages such as Spanish (Gutiérrez-Palma et al., 2009). The results of Experiments 1, 2 and 3 suggest that adults with developmental dyslexia accurately represent lexical stress assignment in the mental lexicon and that the prosodic skills which contribute to reading difficulties in adulthood involve the ability to access phonological representations, and to consciously reflect on and manipulate prosodic information. The experiment reported in this chapter investigated whether adults with dyslexia are able to take advantage of their intact prosodic representations and learn the statistical correspondences that exist between lexical stress assignment and the orthographic structure of printed English words.

A study conducted by Kelly (2004) focussed on the relationship between orthographic structure and lexical stress assignment in disyllabic English words and reported a positive relationship between the number of consonants in word onset position and the likelihood of a word receiving a trochaic (strong-weak) pattern of lexical stress assignment. In the same study, Kelly also demonstrated that words with consonant clusters at the onset of the second syllable were twice as likely to have an iambic (weak-strong) pattern of lexical stress assignment as words with single consonants at the onset of the second syllable. A similar relationship between orthographic structure and lexical stress assignment has also been reported for word endings. Kelly et al. (1998) reported that word endings such as *-ette, -que* and *-umb* were strongly predictive of iambic stress assignment, noting that word endings associated with iambic stress assignment often contain more letters than is necessary to encode the phoneme(s) that they represent. For example, the phoneme /m/ at the end of the word *succúmb* could be adequately represented with the word ending *-um* rather than *-umb*. Therefore, as with onset length and trochaic stress assignment, it seems that increasing orthographic length of a word ending may be a strong cue to iambic stress assignment. Crucially, data from naming, lexical decision and nonword pronunciation studies indicate that English speakers are sensitive to the correspondences between lexical stress assignment and orthographic structure and utilise them to decode the stress patterns of written multisyllabic words. Kelly et al. (1998) devised a lexical decision paradigm that contrasted 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' naming and lexical decision times were significantly shorter, and error rates significantly lower, for words whose orthography reliably indicated their stress assignment.

The current experiment utilised the lexical decision paradigm devised by Kelly et al. (1998) to investigate reading group differences in the ability to learn statistical correspondences between lexical stress assignment and orthographic structure. It was predicted that control participants would respond significantly faster and make significantly fewer errors in response to words in which orthographic structure was a reliable indicator of lexical stress assignment. If participants with dyslexia have successfully learned the correspondences between orthographic structure and stress assignment, they too should show this pattern of responding. This pattern of results would suggest that the reading problems of adults with dyslexia cannot be attributed to the robustness of underlying representations or the ability to acquire the correspondences governing spelling-sound conversion. Alternatively, if participants with dyslexia are less able to learn the correspondences between lexical stress assignment and orthographic structure, we would predict a significant interaction between reading group status and orthographic reliability in which participants with dyslexia show a diminished effect of spelling-stress congruency on their lexical decision responses.

Method

Participants

Participants were 37 students enrolled on 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 age/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 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 problems (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

Matching and literacy. Participants completed the Similarities and Matrix Reasoning subscales of the Wechsler Abbreviated Scale of Intelligence (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

Test of Word Reading Efficiency (Torgesen et al., 1999). These tasks were administered and scored as described in Experiment 1a (pages 73-74).

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 the computer screen. 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), reading group status (dyslexia, age/IQ control), and stress assignment (trochaic, iambic).

The stimuli with reliable and unreliable spelling-stress relationships were matched for length (*M* reliable = 6.34 letters, *M* unreliable = 5.94 letters) and Kucera-Francis (1967) written frequency (*M* reliable = 5.47 words per million, *M* unreliable = 6.78 words per million) using the MRC Psycholinguistic Database (Coltheart, 1981; Wilson, 1988). The small differences in length and frequency were statistically non-significant and worked against the hypothesis (i.e. they would be expected to improve performance for the unreliable words relative to the reliable words). 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*).

In addition to the experimental words, 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. A full list of stimuli used in the experiment is provided in Appendix F.

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 for 3450ms. Following this, the cross was replaced in the centre of the screen with the target string. Targets were displayed in 18-point lower case Courier font. The order of the experimental trials was randomised and in order to minimise fatigue and maintain levels of concentration participants were allowed a short break after each block of 48 trials. The dependent variables were mean response time for lexical decision (correct trials only) and percentage error rate recorded for the reliable and unreliable word types. 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 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 are provided in Table 8 (page 143). 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 a marginally 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 (two 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)[6].

Table 8.

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

Measure	Dyslexia	Age/IQ Control	t(35)	sig.	d
Age (yrs.)	23.19 (6.01)	19.67 (2.87)	2.36	p = .043	0.77
Verbal IQ	54.13 (5.44)	52.62 (6.09)	<1	-	-
Performance IQ	52.19 (9.46)	52.24 (8.28)	<1	-	-
Word Reading	89.50 (11.16)	101.29 (10.20)	3.34	p = .002	1.09
Nonword Reading	86.25 (8.79)	101.10 (9.51)	4.86	p < .001	1.58

The response time data from the lexical decision task was trimmed in the same manner as the priming data reported in the previous experiments. The longest 5% of response times registered by each participant in response to each type of target word were removed. This ensured that the overall response time of each individual participant was taken into account when removing outliers. Participants were excluded from the analyses of the lexical decision data 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

[6] ANOVA and regression analyses of the lexical decision data were conducted on the full sample and repeated with the 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. As such, only the analyses conducted on the full sample are reported in the text.

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 10). The main effects of reading group (F_1 (1, 33) = 17.43, p < .001, d = 1.38; F_2 (1, 60) = 201.00, p < .001, η_p^2 = .770) and orthographic reliability (F_1 (1, 33) = 11.46, p = .002, η_p^2 = .258; F_2 (1, 60) = 6.27, p = .015, d = .35) 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.

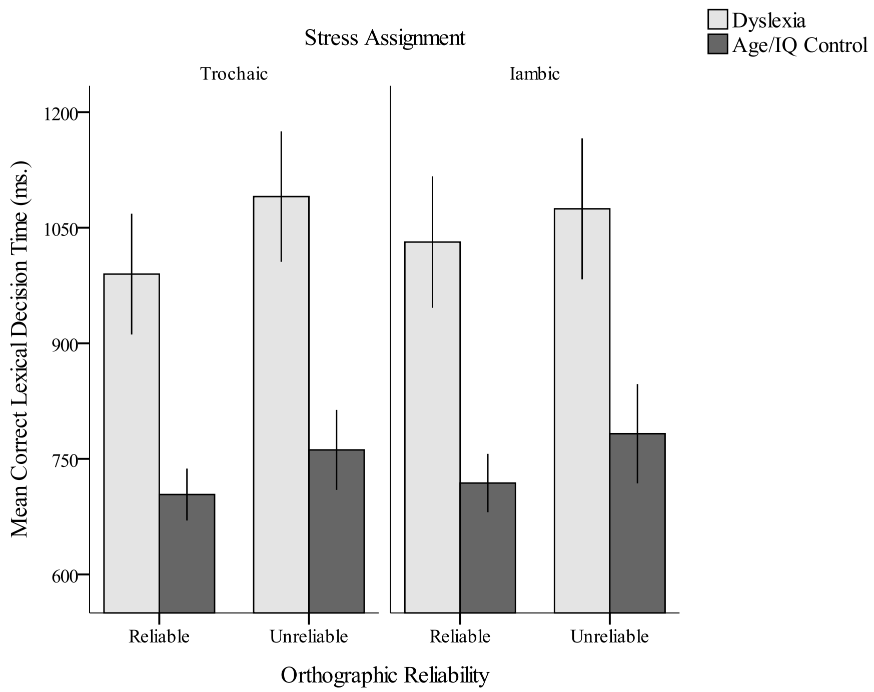

Figure 10. Mean correct lexical decision time by reading group and word type

The main effect of stress failed to reach significance in either the subjects or items analyses (F_1 (1, 33) = 1.40, p = .245, ns; F_2 < 1). Crucially, the interaction between reading group and orthographic reliability also failed to reach significance and there were no other significant two- or three-way interactions (F_1 and F_2 < 1 in all cases).

A 2 (reading group) by 2 (orthographic reliability) by 2 (stress assignment) repeated measures ANOVA was also conducted on the error data (Figure 11). 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; F_2 (1, 60) = 7.42, p = .008, d = .60). 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.

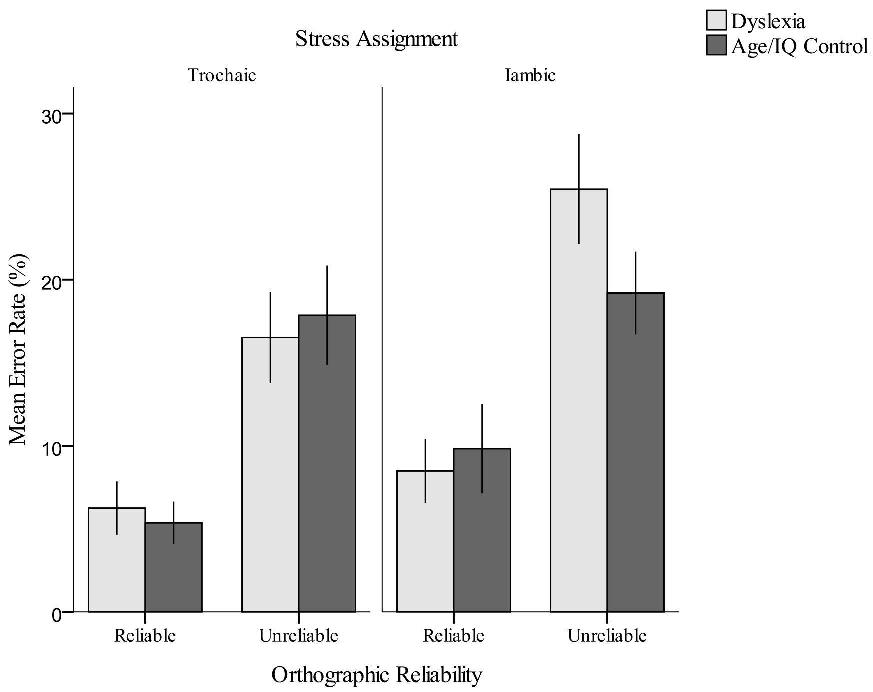

Figure 11. Mean percentage error rate by reading group and word type

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; F_2 < 1). 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; F_2 (1, 60) = 1.56, p = .217, ns), the interaction between reading group and reliability, and all of the other two- and three-way interactions (p > .1 in all cases) failed to reach significance in either the items or subjects analyses.

Regression analyses were conducted to confirm that the absence of the critical interaction between reading group and orthographic reliability was not simply due to an overlap in reading ability between the control and dyslexic groups. For this purpose, the overall difference in response time and error rate between orthographically reliable and orthographically unreliable words was calculated for each participant. TOWRE word reading was not a significant predictor of the orthographic reliability effect observed in the response time data (R^2 = .003, p = .950, β = -.051) or the error data (R^2 = .005, p = .694, β = .070).

Discussion

This experiment utilised the lexical decision paradigm devised by Kelly et al. (1998) to investigate the sensitivity of adults with developmental dyslexia to the statistical correspondences between patterns of lexical stress assignment and the orthographic structure of printed English words. As in the previous experiments there was a main effect of reading group in the response time data. This is likely to result, 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 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. Finally, the main effect of reading group in the response time data could also reflect reduced speed in accessing stored phonological representations.

The main effect of stress assignment generally failed to reach significance. However, there was a significant effect of stress assignment observed in the subject 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. As noted in the introductory chapters, 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 phonological representations hypothesis states that under-specified phonological representations impair the ability of people with dyslexia to acquire the correspondences between phonology and orthography that guide the decoding of printed words (Fowler, 1991; Snowling, 2000). This account of reading failure has also been put forward in the form of computational models of visual word recognition (e.g. Coltheart et al., 2001; Harm & Seidenberg, 1999). Although these models have dealt with the learning of correspondences at the grapheme-phoneme level, a logically analogous argument can be made regarding the ability to acquire correspondences between larger orthographic units such as syllables and elements of suprasegmental phonology such as lexical stress assignment. Having demonstrated that adults with dyslexia represent the prosodic structure of words as accurately as controls (Experiments 1b and 2), it was hypothesised that adults with dyslexia should also be able to acquire the statistical correspondences between lexical stress assignment and orthographic structure. The absence of significant interactions from the response time and error data – most importantly the absence of an interaction between reading group and orthographic reliability – suggests that this is indeed the case. Participants in both reading groups were significantly faster and significantly more accurate to make 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 the orthographic structure was an unreliable predictor of lexical stress assignment. Regression analyses also confirmed that the absence of the critical interaction cannot be attributed to an overlap in reading ability between groups. This suggests that both groups of participants are sensitive to the relationship between orthographic structure and lexical stress assignment and that spelling-stress congruency in disyllabic words exerts a similar effect on the reading of skilled adult readers and adults with dyslexia.

Together with the results of the previous experiments, these findings suggest that one of the primary mechanisms via which phonological processing is thought to impair literacy performance – impaired phonological representations and an inability to learn spelling-sound correspondences – may not account for the reading problems experienced by adults with dyslexia. Instead, researchers should focus on other aspects of phonological processing such as the ability to access phonological representations (Ramus & Szenkovits, 2008) and consciously reflect upon and manipulate phonemic and prosodic information in an abstract way. Existing models of skilled reading may also need to be adapted in order to capture the importance of these aspects of phonological processing in addition to the current focus on the quality of underlying representations and the passive learning of correspondences between orthographic and phonological units.

Finally, it should be reiterated that these claims do not extend beyond the type of sample with which the current experiments have been conducted. Phonological processing is composed of several separable skills, each with unique links to literacy ability, and the relationship between phonological processing and literacy, as well as the phonological strengths and weaknesses of particular individuals, may change over time (Anthony et al., 2010; Bowey, 2005; Goswami, 2003; Ramus, 2001; Ramus & Szenkovits, 2008; Wagner & Torgesen, 1987; Wolf & Bowers, 1999). Factors such as IQ, educational level and experience of remedial instruction may help compensate for some aspects of a phonological deficit, such as the ability to 'hear' differences between speech sounds, form robust phonological representations, and learn mappings between phonological and orthographic units of different sizes. However, these factors may be less helpful in remediating other aspects of the phonological deficit, such as the speed at which phonological information can be accessed, or the ease with which phonological information can be consciously manipulated. Therefore, it is possible that adults with dyslexia, especially those of high educational attainment, may show a relatively specific or narrow phonological deficit that differs quantitatively and qualitatively from that observed in younger or less educated samples. The experiments reported here provide evidence in support of this contention in the context of prosodic processing.

Summary

This experiment utilised the lexical decision paradigm devised by Kelly et al. (1998) to investigate the ability of adults with developmental dyslexia to learn correspondences between an aspect of orthographic structure and lexical stress assignment in disyllabic English words. The results suggest that adults with dyslexia are sensitive to the relationship between stress assignment and orthographic structure and that spelling-stress congruency affects the reading performance of skilled adult readers and adults with dyslexia to a similar degree.

In conjunction with findings reported in earlier chapters, these results strongly suggest that adults with developmental dyslexia do not show a broad, multi-level impairment of prosodic processing ability. Instead, the prosodic processing problems associated with dyslexia in adulthood appear to be limited to tasks requiring participants to access and consciously reflect upon their knowledge of prosodic structure, or to process information related to prosodic structure in an abstract way. In contrast, the ability of adults with dyslexia to represent lexical stress assignment in the mental lexicon and to learn correspondences between lexical stress assignment and aspects of orthographic structure to help decode multisyllabic words appears to be intact.

Chapter 7

General discussion

Overview

The aim of this chapter is to summarise and evaluate the key findings reported in Experiments 1-4 and discuss the nature of the prosodic processing deficit associated with dyslexia in adulthood. Limitations of the current experiments and directions for future research are also discussed. It is argued that a number of distinct phonological skills, operating on phonological units of various grain sizes, may influence reading performance at different stages of development and across different types of reading material. This conclusion has implications for our understanding of skilled and impaired reading in adulthood and raises issues relevant to phonological and auditory accounts of developmental dyslexia as well as cognitive models of visual word recognition.

Summary of key findings

Experiments 1-4 have produced a number of key findings which provide new insight into the relationship between prosodic processing skills and literacy ability and have potential implications for our understanding of impaired and skilled reading in adulthood. Firstly, adults with dyslexia were found to be impaired in the ability to consciously reflect upon their knowledge of lexical and metrical prosody. In Experiment 1a, in comparison with the age/IQ matched controls, participants with dyslexia were significantly less accurate and significantly slower to respond during the DEEdee task. The ANCOVA analyses conducted in Experiment 1a (pages 77-78) address a serious criticism of the DEEdee task – that of inherent reading demands – and confirm that differences in prosodic awareness remain after controlling for differences in reading ability between groups. In Experiment 2, participants with dyslexia were significantly less accurate than controls during the fragment identification task with nearly one third of participants with dyslexia achieving scores below or equal to chance. Together, the findings of Experiment 1a and Experiment 2 are consistent with earlier studies of children with reading difficulties (Goswami et al., 2009; Wood & Terrell, 1999) 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., 2007; 2010).

Conscious awareness of lexical and metrical prosody was 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. 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. These results are consistent with earlier studies of typically developing children (Clin et al., 2009; Holliman et al., 2008a; 2010a; Jarmulowicz et al., 2007; Whalley & Hansen, 2006) and children with dyslexia (Goswami et al., 2009; Wood & Terrell, 1998) in suggesting that conscious awareness of syllabic stress assignment makes a direct, unique contribution to reading ability that is independent of phoneme awareness. It was also observed in Experiment 1a that DEEdee task performance accounted for unique variance in phoneme awareness. This offers support to the contention that prosodic skills also make an indirect contribution to literacy development by facilitating the acquisition of phoneme level knowledge (Foxton et al., 2003; Goswami et al., 2002; Richardson et al., 2004).

The results of the cross modal fragment priming tasks reported in Experiments 1b and 2 suggest that adults with developmental dyslexia accurately represent lexical stress in the mental lexicon and, at the representational level, 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. 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. In Experiment 2, participants with dyslexia also showed effects of morphological relatedness that were comparable to those observed in the control group. These findings contrast sharply with the impaired performance observed in the same samples of participants during the prosodic awareness tasks. The results reported in Experiment 2, in which the priming task was 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.

Although priming was observed to follow a similar pattern and attain a similar magnitude in both reading groups, the latency of the effects was significantly longer in the dyslexic group. The main effect of reading group that emerged consistently in the response time data, taken in the context of the non-significant interaction between reading group and prime condition, suggests that despite having intact phonological representations, participants with dyslexia may be less efficient in accessing these representations and in activating and resolving competition between lexical candidates.

Experiment 3 utilised a novel cross modal priming paradigm in order to prime lexical stress with abstract stress templates in the form of DEEdee stimuli. Overall, the results of this experiment are somewhat weaker than those reported in Experiments 1 and 2 due to the marginally non-significant main effect of prime condition. However, as in the previous priming studies, participants in both reading groups appeared to be similarly affected by the syllabic stress manipulation. Consistent with the data from Experiments 1 and 2, Experiment 3 failed to find any evidence for impaired phonological representations in the dyslexic sample, even though the priming task placed additional demands on participants' ability to assemble novel phonological representations online in response to unfamiliar stimuli. The fact that participants with dyslexia were influenced to a small extent by the stress congruency of the DEEdee primes also suggests that their difficulties with the DEEdee task itself (Experiment 1) are due to the metalinguistic challenges of consciously accessing and contrasting different phonological representations.

Finally, the results of the lexical decision task utilised in Experiment 4 suggest that both groups of participants are equally sensitive to the relationship between orthographic structure and lexical stress assignment and that spelling-stress congruency in disyllabic words exerts a similar effect on the reading of skilled adult readers and adults with dyslexia. Participants in both reading groups were significantly faster and significantly more accurate to make 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 the orthographic structure of the final syllable was an unreliable predictor of lexical stress assignment.

The overall pattern of results obtained in Experiments 1-4 strongly suggests 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, or to process information related to prosodic structure in an abstract way. In contrast, the ability of adults with dyslexia to represent lexical stress assignment in the mental lexicon and to learn correspondences between lexical stress assignment and aspects of orthographic structure appears to be intact.

The prosodic processing deficit in adulthood: implications for phonological and auditory accounts of dyslexia and for reading intervention

The contrast between the conscious awareness of prosodic structure and the underlying representation of syllabic stress observed in the current experiments is relevant to the discussion of individual differences in the phonological deficit which characterises dyslexia. A number of studies have demonstrated that phonological processing is multifaceted and that different skills may have independent links with specific aspects of literacy performance (Anthony et al., 2010; Ramus, 2001; Wagner & Torgesen, 1987; Wolf & Bowers, 1999). Different dyslexic individuals may also show quantitatively and qualitatively different phonological deficits, and the types of phonological difficulties observed, and their relationship with reading, may change during development, particularly in cases where individuals have received remedial reading instruction (Bowey, 2005; Castles & Coltheart, 1993; Goswami, 2003; Stanovich, 1988; 1998). The results of the current experiments would suggest that dyslexic adults with experience of higher education show a deficit in prosodic processing that specifically impairs the ability to access prosodic representations and to consciously reflect upon knowledge of prosodic structure in an abstract way. This interpretation is consistent with the findings reported by Ramus and Szenkovits (2008) in the domain of phonemic processing. Despite being impaired on conventional measures of phoneme awareness, a sample of French speaking adults with dyslexia were found to show phonological similarity effects of equal magnitude to age/IQ matched controls in the context of nonword repetition and nonword discrimination tasks. Adults with dyslexia were also found to show normal repetition priming effects in a subliminal auditory priming paradigm. Therefore, in the context of both phonemic and prosodic processing, adults with dyslexia experience problems with accessing and manipulating phonological information despite appearing to have intact phonological representations.

The findings reported in Experiment 4 suggest that adults with dyslexia are also able to learn the statistical correspondences between patterns of lexical stress assignment and the orthographic structure of word endings. Furthermore, adults with dyslexia are able to exploit spelling-sound relationships at the suprasegmental level in reading disyllabic words in the same way as skilled readers. Converging findings have recently been reported in a study of Italian children with developmental dyslexia (Paizi, Zoccolotti & Burani, 2011). The concept of stress neighbourhoods has been used to define the relationship between orthographic structure and lexical stress assignment in Italian words (Colombo, 1992). 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*). A word's stress neighbourhood is determined by taking all words with matching orthographic structure in the penultimate and final syllables and calculating the proportion of stress friends. Studies of skilled adult readers 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 (Colombo, 1992). Paizi et al. (2011) reported that typically developing children and children with developmental dyslexia (mean age 11 years) were both more accurate in reading low frequency words with larger proportions of stress friends. This finding implies that Italian speaking children with dyslexia are able to learn correspondences between orthographic patterns and lexical stress assignment and that the relationship between spelling patterns and stress assignment influences their reading of trisyllabic words. This result raises the question of whether English children with dyslexia would also show sensitivity to spelling-stress correspondences. At both segmental and suprasegmental levels, Italian has a more consistent orthography than English. For example, there is a clear bias towards penultimate stress assignment in Italian trisyllables (Colombo, 1992). In contrast, an analysis of the items in the CELEX database (Baayen et al., 1995) indicates that although there is a strong bias towards trochaic stress assignment in disyllabic English words (77% of items), in the case of trisyllables, initial stress (50% of items) and penultimate stress (46% of items) are almost equally common (P. Monaghan, private communication, 22 September 2009). The fact that lexical stress assignment appears to be more variable in English than in Italian may mean that the correspondences between spelling patterns and stress assignment are acquired more slowly by English speaking children. Future research may seek to establish the nature of the prosodic processing deficit associated with dyslexia at different stages of development and across different languages.

The findings of the current experiments have at least two implications for the phonological account of developmental dyslexia. Firstly, the observation that people with dyslexia show a persistent and significant deficit in prosodic awareness, and that prosodic processing can account for unique variance in reading ability after controlling for phoneme awareness, suggests that the notion of a core phonological deficit in developmental dyslexia should be broadened to take account of the contributions made by suprasegmental phonology. Researchers first began to argue for a broader definition of phonological awareness a number of years ago (Wade-Woolley & Wood, 2006) and there is now empirical evidence from samples of dyslexic children and adults to justify this suggestion. One finding that has emerged consistently in investigations of typically developing children and children with dyslexia, as well as Experiment 1a, is the relationship between prosodic and phonemic awareness. As sensitivity to rhythmic structure and phonological units such as onsets, rimes, and syllables, develops prior to phoneme level skills (Carroll et al., 2003; Kuhl, 2004; Treiman & Zukowski, 1991), it is reasonable to suggest that the close relationship between stress awareness and phoneme awareness reflects this developmental trajectory. The contribution of prosodic skills to the development of phoneme level knowledge has previously been proposed by a number of researchers (Foxton et al., 2003; Goswami et al., 2002; Richardson et al., 2004). Understanding this indirect link between prosodic skills and literacy ability may therefore 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 adulthood 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. This implies that the type of phonological processes measured by these tasks may be as important for literacy as the type of phonological unit that they address.

The direct link between prosodic skills and reading ability seems to arise from the fact that phonological units of different sizes may be more or less useful in decoding different types of reading material. Prosodic knowledge is likely to be specifically useful in decoding multisyllabic words (Gutiérrez-Palma, 2010; Heggie et al., 2010), learning the linguistic rules and correspondences governing stress assignment (Gutiérrez-Palma et al., 2009) and in facilitating processes operating at the sentence level, such as phrasing and applying punctuation in connected text (Gutiérrez-Palma et al., 2010; Wade-Woolley & Kotanko, 2010). It is these specific applications of prosodic knowledge that can account for its independent contribution to literacy beyond phoneme awareness. Understanding the direct link between prosodic skills and literacy has the potential to provide additional information about the problems experienced by people with dyslexia across the lifespan and across reading materials of differing complexity. This may be particularly useful in helping understand the reading problems of adults with dyslexia as they progress to reading complex material in secondary and higher education. The longitudinal study of rhythmic processing and literacy reported by David et al. (2007) supports this suggestion by demonstrating that a direct link between phonological decoding ability and prosodic processing emerges later in development as children become more experienced readers and begin to encounter more complex reading materials. Furthermore, recent research has suggested that phonemic and prosodic skills make independent contributions to reading and predict different types of reading error (Gutiérrez-Palma, 2010; Heggie et al., 2010). Ultimately, a better understanding of the relationship between prosodic skills and reading may help researchers develop interventions that yield larger gains in reading ability than are possible through phoneme level training alone. Despite the undoubted success of existing phonological interventions in improving children's reading (Hatcher et al., 1994; Torgesen, 2005), the problems associated with dyslexia often persist into adulthood and continue to cause significant academic difficulty (Hatcher et al., 2002) as well as anxiety and embarrassment (Carroll & Iles, 2006; Ridsdale, 2004). Interventions that aimed to improve awareness of stress assignment may be particularly useful in helping older children and adults with dyslexia to decode and assign stress correctly in multisyllabic words (Gutiérrez-Palma et al., 2009) and continue to make gains in reading ability that apply to increasingly complex materials.

In addition to the different types of phonological unit that may contribute to reading problems over the lifespan, the phonological account of dyslexia should also formally acknowledge the different types of phonological processes that may be impaired in samples of dyslexic individuals who differ in age or the severity of reading impairment. The phonological theory of developmental dyslexia, and computational models of visual word recognition, have primarily argued that people with dyslexia fail to accurately represent the phonemic structure of spoken words and that this in turn impairs the ability to learn the statistical correspondences between phonemes and graphemes that are crucial for decoding written words (e.g. Coltheart et al., 2001; Fowler, 1991; Harm & Seidenberg, 1999; Snowling, 2000). However, the results of the current experiments suggest that in adulthood dyslexia is characterised by specific problems with accessing and manipulating phonological information and not by a broad phonological deficit which also affects the perception and underlying representation of phonological structure. In short, these results suggest that one of the primary mechanisms via which phonological processing is thought to impair literacy performance – impaired phonological representations and an inability to learn spelling-sound correspondences – may not fully capture the nature of the reading problems associated with dyslexia in adulthood. The phonological account of dyslexia would be strengthened by a systematic understanding of the types of phonological processes that are impaired in different dyslexic samples. Models of visual word recognition are already being extended to take account of the role of prosodic skills in decoding multisyllabic words. Research has demonstrated that lexical stress assignment is often reliably indicated by factors such as grammatical category, morphological structure and spelling patterns (Arciuli & Cupples, 2006; Kelly, 2004; Kelly & Bock, 1988; Kelly et al., 1998; Rastle and

Coltheart, 2000; Smith et al., 1982) and computational models have indicated that lexical stress can be accurately decoded on the basis of these relationships (Arciuli et al., 2010; Perry et al., 2010; Rastle & Coltheart, 2000; Ševa et al., 2009). Further to this, models of visual word recognition also need to acknowledge a wider range of phonological processes that contribute to skilled and impaired reading in adulthood in addition to the current focus on the robustness of representations and the learning of statistical correspondences between phonological and orthographic units.

It is likely that the educated adult participants who took part in the current experiments have received substantial amounts of additional reading tuition and phonological training and also that their IQ, educational level and experience of reading intervention will have shaped the nature of their individual phonological deficits. It is also possible that certain phonological skills may recover over time or in response to reading experience or intervention. Factors such as IQ, educational level, remedial reading instruction and experience of intervention may help compensate for some phonological processing problems, such as the ability to 'hear' differences between speech sounds and form robust representations of the sequences of phonemes within words, but fail to significantly improve other processes, such as the speed at which phonological information can be accessed or the ease with which phonological information can be consciously manipulated. Such changes in the breadth of the phonological deficit over time would have implications for our understanding of dyslexia in adulthood as well as views on which phonological skills may need to be targeted in order for interventions to bring about continued success for adults with dyslexia. In the future, it will be important to address the question of why certain phonological skills may improve over time while other difficulties persist into adulthood. One answer may be found in the nature of the interventions that are currently available, many of which focus on learning grapheme-phoneme correspondences and improving phoneme awareness (Hatcher et al., 1994). These interventions improve the quality of children's phonological representations and facilitate the acquisition of spelling-sound conversion rules but are less likely to improve other aspects of phonological processing such as the speed with which representations can be accessed.

The suggestion that the phonological deficit associated with dyslexia may, in some instances, narrow in scope during development can also be considered in the theoretical context of so-called Matthew effects. Stanovich (1986) argued that reading impairments will often become more severe over time as the negative experiences and emotions associated with reading failure cause the affected individual to avoid reading altogether. This prevents the individual from improving their reading through practice and also makes it harder for reading problems to be indentified and remediated. In contrast, good readers will seek out opportunities to read and thus continue to improve due to the practice, encouragement and praise that they receive. Certain characteristics of the dyslexic samples studied in the current experiments, such as high IQ, educational level, experience of remedial reading instruction and a supportive school and home environment, could be considered as protective factors operating against the vicious cycle of the Matthew effect.

The results of the current experiments also have implications for theories that emphasise the role of auditory skills in reading development. One example is the auditory temporal processing account of developmental dyslexia (Farmer & Klein, 1995; Tallal, 1980) which argues for a progression from low-level auditory processing deficits, to impaired speech perception, to low quality phonological representations and reduced awareness of segmental and suprasegmental phonology.

Some researchers have argued that a fundamental deficit in processing the acoustic correlates of prosody – for example, amplitude rise-time – may undermine the establishment of phonological representations and produce a broad phonological deficit affecting the representation and awareness of both segmental and suprasegmental phonology (Goswami, 2011; Goswami et al., 2002; Richardson et al., 2004). The observation that adults with dyslexia actually show a rather narrow impairment of prosodic processing seems to be inconsistent with this theory. In fact, the results of the current experiments provide no evidence to suggest that adults with dyslexia display the type of prosodic processing deficit that would be predicted by the rise-time account. One way to account for this discrepancy is to reiterate that different samples of dyslexic individuals show different types of phonological deficit and that the participants in the current experiments may have recovered from, or compensated for, some aspects of their prosodic processing deficit due to factors such as IQ, educational level and reading intervention. Taking this view, other samples of dyslexic individuals, and particularly children or less educated adults, may indeed show a broader impairment of prosodic processing as predicted by the rise-time theory and other auditory processing accounts of developmental dyslexia. However, it may be more parsimonious to attribute the reading difficulties of adults with dyslexia to problems with higher level phonological processes involved in accessing and manipulating phonological information rather than a broad multi-level phonological deficit.

A second possibility stems from an analysis of the demands of the experimental tasks used to study the processing of amplitude and frequency modulations in samples of dyslexic and non-dyslexic adults (Hämäläinen et al., 2003; Pasquini et al., 2007; Thomson et al., 2006; Witton et al., 2002). As noted previously, these paradigms share many features with tasks that have been used to measure awareness of prosodic structure in linguistic stimuli (e.g. the DEEdee task). For example, participants may be asked to listen to multiple stimuli and match one of them to a sample stimulus or to discriminate between two stimuli on the basis of a particular acoustic dimension. Therefore, rather than reflecting a fundamental deficit in the perception and encoding of prosodic structure, the reading group differences observed on these tasks may in fact result from dyslexic participants' relative inability to consciously compare and contrast the different auditory stimuli. It has been assumed that because these tasks utilise non-speech stimuli they must therefore be addressing low-level auditory processes; this is not necessarily the case. It may be possible to interpret impaired performance in rise-time, frequency and duration discrimination as further evidence of a stress awareness deficit.

This point raises a broader issue of the task demands associated with measures of phonological processing ability. Phonological processing constitutes many separate skills and many different phonological units may be involved in reading. The picture is complicated further by the role of more general factors such as verbal short-term memory. Furthermore, in samples of young children it can also be difficult to distinguish between phonological skills and processes of speech perception. Given all of this, it is important that researchers think carefully about the demands associated with specific experimental tasks and attribute any findings or deficits to the correct level of phonological processing.

Limitations and questions for future research

One possible criticism of the current research is that a failure to find significant interactions in the cross modal fragment priming tasks (Chapter 4) and the lexical decision task (Chapter 6) constitutes a null result and therefore these findings are not open to interpretation (anonymous review, *Journal of Memory and Language*, 2010). However, the absence of statistically significant interactions are not null results in the true sense and this assertion ignores the fact that the non-significant interactions arise from near identical, statistically significant main effects of prime condition or word type being observed in both of the reading groups. Therefore, rather than a null result, the absence of an interaction actually represents two, identical, positive results that lead quite naturally to the interpretation and conclusions that are outlined above.

A second potential criticism of the cross modal priming tasks (Chapter 4) is that they may not have been sensitive enough to detect subtle differences in the quality of participants' phonological representations. Contrary to this suggestion, the cross modal fragment priming tasks ask participants to detect extremely subtle differences in stress assignment between pairs of words. The fragments used as primes both carry more stress on the first syllable than the second and the difference between each pair of items lies in the level of stress applied to the initial syllable. In fragments such as *ádmir* (from *ádmiral*), the initial syllable carries primary stress and the second syllable is unstressed, while in fragments such as *àdmir* (from *àdmirátion*), the initial syllable carries secondary stress and the second syllable is unstressed. These are extremely fine distinctions in stress assignment and would be expected to produce differences in priming performance between reading groups if there were even subtle differences in the quality of participants' representations. Subtle group differences in the quality of representations would also be expected to emerge in the effect magnitudes but these are nearly identical across the two reading groups in Experiment 1b and Experiment 2. Furthermore, in Experiment 2, participants with dyslexia were clearly unable to detect the differences between fragments such as *prósec* (from *prósecutor*) and *pròsec* from (from *pròsecútion*) in the context of an identification task. Therefore, the items were sensitive enough to reveal group differences in prosodic processing ability but such differences only emerge when participants are asked to make conscious comparisons or judgments of different stimuli. Finally, when lexical stress was primed using a far coarser relationship between the prime and the target (Experiment 3), striking differences in priming performance emerged.

One limitation of the current experiments that cannot be answered is that they are cross sectional comparisons rather than longitudinal studies. As such, it is only possible to speculate about the changing nature of the prosody-literacy relationship over time and differences in the phonological deficit that may be found between different samples. Future research may aim to investigate exactly how the relationship between prosodic processing and reading changes over time. Some longitudinal studies have already begun making progress towards this goal, for example, in demonstrating an early role for non-speech rhythm in developing phonological skills (David et al., 2007; Defior et al., 2010; Holliman et al., 2010a), the importance of speech rhythm sensitivity in six year old children for later reading ability (Holliman et al., 2010b) and the relatively late emergence of a direct link between rhythmic skills and decoding as children encounter more complex reading materials (David et al., 2007). Given the cross linguistic differences in the distribution and predictability of lexical stress assignment discussed above, it may also be fruitful to investigate differences in the nature of the prosodic processing deficit across different languages.

Another interesting direction for future research would be to establish the role and time course of lexical stress assignment in phonological decoding. In the context of recognising spoken English words, it has been suggested that stress assignment may take place at a relatively late stage and play only a peripheral role in lexical access (Cooper et al., 2002). However, in the context of decoding written words, there are at least two potential advantages to the early decoding of lexical stress assignment. Firstly, information regarding segmental phonology varies systematically with stress assignment in English. For example, decoding the lexical stress pattern of a word provides information about the likely arrangement of reduced and full vowels (Wood et al., 2010). Secondly, in the context of written and spoken word recognition it has been noted that stressed syllables contain more information than unstressed syllables. Altmann (1990) estimated that a stressed syllable contains approximately three times more information regarding the identity of a spoken word than an unstressed syllable. This is attributed to there being more information concerning vowel identity in a stressed syllable and also the extra clarity with which stressed syllables are articulated. In the context of written words, Kelly noted that a strong relationship exists between stress assignment and spelling patterns with stressed syllables often containing more letters and thus more phonemes than unstressed syllables (Kelly, 1998; Kelly et al., 2004). As an example, consider the word *políce*. The initial syllable of this word is unstressed and contains the consonant /p/ and the vowel /o/. This syllable provides relatively little information for reducing the number of lexical candidates that potentially match the target string. In contrast, the second syllable carries primary stress and contains the consonants /l/ and /c/ as well as the vowels /i/ and /e/. The stressed syllable clearly carries more information regarding the identity of the word than the initial, unstressed syllable.

It follows from these observations that if a reader were to assign lexical stress early in the decoding process subsequent phonemic decoding could be strategically focussed on the most informative section of the word. One way to achieve this would be to segment the word into graphemes – /p/ /o/ /l/ /i/ /ce/ – and hypothesise that primary stress should be applied to the vowel preceding the longer grapheme. Phonemic decoding of the graphemes could then begin at the stressed vowel rather than the word onset. Using the MRC Psycholinguistic Database (Coltheart, 1981; Wilson, 1988) it can be demonstrated that only one candidate (*políce*) matches the input ---*íce*. Therefore, once lexical stress has been assigned, the word can be identified by decoding just two graphemes. In contrast, many more candidates (e.g. *poling; polish; polite*) match the input *pol*---. In this instance, a stress driven decoding strategy of assigning lexical stress and focussing phonemic decoding on the stressed syllable arguably helps the reader identify the word more efficiently than a sequential decoding strategy. The same strategy may be particularly useful in decoding words ending with double or silent letters as well as those containing prefixes such as *un*- which are present in a large number of words. Studies seeking to determine the time course of lexical stress decoding in visual word recognition would be extremely interesting and make a valuable contribution to the development of models that describe the reading of multisyllabic words.

Summary and conclusions

The findings of these experiments strongly suggest that adults with developmental dyslexia do not show a broad, multi-level impairment of prosodic processing ability. Instead, the prosodic processing problems associated with dyslexia in adulthood appear to be limited to tasks requiring participants to access and consciously reflect upon their knowledge of prosodic structure, or to process information related to prosodic structure in an abstract way. In contrast, the ability of adults with dyslexia to represent lexical stress assignment in the mental lexicon and to learn correspondences between lexical stress assignment and aspects of orthographic structure to help decode multisyllabic words appears to be intact. Phonological accounts of developmental dyslexia, as well as models of visual word recognition in skilled adult readers, must be adapted in order to fully capture the full range of phonological processes and variety of phonological units which influence reading ability across different individuals and reading materials of varying complexity. This may in the future lead to the development of more comprehensive reading interventions which can build on the gains that are already possible through phoneme level training.

References

Adlard, A., & Hazan, V. (1998). Speech perception in children with specific reading difficulties (dyslexia). *The Quarterly Journal of Experimental Psychology: Human Perception and Performance, 51*, 153-177.

Altmann, G. T. M. (1990). Lexical statistics and cognitive models of speech processing. In G. T. M. Altmann (Ed.), *Cognitive Models of Speech Processing: Psycholinguistic and Computational Perspectives* (pp. 211-235). Cambridge, MA: MIT Press.

Anthony, J. L., Williams, J. M., Aghara, R. G., Dunkelberger, M., Novak, B., & Mukherjee, A. D. (2010). Assessment of individual differences in phonological representation. *Reading and Writing, 23,* 969-994.

Arciuli, J., & Cupples, L. (2006). The processing of lexical stress during visual word recognition: Typicality effects and orthographic correlates. *The Quarterly Journal of Experimental Psychology*, *59,* 920-948.

Arciuli, J., Monaghan, P., & Ševa, N. (2010). Learning to assign lexical stress during reading aloud: Corpus, behavioural, and computational investigations. *Journal of Memory and Language, 63,* 180-196.

Ashby, J. (2006). Prosody in skilled silent reading: Evidence from eye movements. *Journal of Research in Reading, 29,* 318-333.

Ashby, J. (2010). Phonology is fundamental in skilled reading: Evidence from ERPs. *Psychonomic Bulletin and Review, 17*, 95-100.

Ashby, J., & Clifton, C. (2005). The prosodic property of lexical stress affects eye movements during silent reading. *Cognition, 96,* B89-B100.

Ashby, J., & Martin, A. E. (2008). Prosodic phonological representations in early visual word recognition. *Journal of Experimental Psychology: Human Perception and Performance, 34,* 224-236.

Baayen, R. H., Piepenbrock, R., & van Rijn, H. (1995). *The CELEX Lexical Database (CD-ROM)*. Philadelphia, PA: University of Pennsylvania, Linguistic Data Consortium.

Babayiğit, S., & Stainthorp, R. (2007). Pre-literate phonological awareness and early literacy skills in Turkish. *Journal of Research in Reading, 30,* 394-413.

Badcock, N. A., Hogben, J. H., Fletcher, J. F. (2008). No differential attentional blink in dyslexia after controlling for baseline sensitivity. *Vision Research, 48*, 1497-1502.

Baddeley, A. D., Gathercole, S. E., & Papagno, C. (1998). The phonological loop as a language learning device. *Psychological Review, 105,* 158–173.

Baddeley, A.D., & Hitch, G. (1974). Working memory. In G.H. Bower (Ed.), *The psychology of learning and motivation: Advances in research and theory* (pp. 47-89). New York: Academic Press.

Beaton, A. A. (2004). *Dyslexia, reading and the brain: A sourcebook of psychological and biological research*. Hove, England: Psychology Press.

Been, M., & Clifton, C. (2011). Stress matters: Effects of anticipated lexical stress on silent reading. *Journal of Memory and Language*, *64,* 153-170.

Bishop, D. V. M. (1990). Handedness, clumsiness and developmental language disorders. *Neuropsychologia, 28,* 681-690.

Bishop, D. V. M. (2002). Cerebellar abnormalities in developmental dyslexia: Cause, correlate or consequence? *Cortex, 38*, 491-498.

Bishop, D. V. M. (2009). Genes, cognition, and communication: Insights from neurodevelopmental disorders. *Annals of the New York Academy of Sciences, 1156*, 1-8.

Blau, V., Reithler, J., van Atteveldt, N., Seitz, J., Gerretsen, P., Goebel, R., & Blomert, L. (2010). Deviant processing of letters and speech sounds as proximate causes of reading failure: A functional magnetic resonance imaging study of dyslexic children. *Brain, 133,* 868-879.

Blau, V., van Atteveldt, N., Ekkebus, M., Goebel, R., & Blomert, L. (2009). Reduced neural integration of letters and speech sounds links phonological and reading deficits in adult dyslexia. *Current Biology, 19,* 503-508.

Blumstein, S., & Goodglass, H. (1972). The perception of stress as a semantic cue in aphasia. *Journal of Speech and Hearing Research, 15,* 800-806.

Boersma (2001). PRAAT: A system for doing phonetics by computer. *Glot International, 5,* 341-345.

Boets, B. (2008, September). Auditory and visual processing and early literacy development in children at risk for dyslexia. *Paper presented at the Autumn School in Cognitive Neuroscience, University of Oxford UK*.

Boets, B., Ghesquière, P., van Wieringen, A., & Wouters, J. (2007a). Speech perception in preschoolers at family risk for dyslexia: Relations with low-level auditory processing and phonological ability. *Brain and Language, 101*, 19-30.

Boets, B., Wouters, J., van Wieringen, A., DeSmedt, B., & Ghesquière, P. (2008). Modelling relations between sensory processing, speech perception, orthographic and phonological ability, and literacy achievement. *Brain and Language, 106,* 29-40.

Boets, B., Wouters, J., van Wieringen, A., & Ghesquière, P. (2007b). Auditory processing, speech perception and phonological ability in pre-school children at high-risk for dyslexia: A longitudinal study of the auditory temporal processing theory. *Neuropsychologia, 45,* 1608-1620.

Bowey, J. A. (2005). Predicting individual differences in learning to read. In M. J. Snowling & C. Hulme (Eds.), *The science of reading: A handbook* (pp. 155-172). Oxford, England: Blackwell.

Bradley, L. & Bryant, P. (1983). Categorising sounds and learning to read: A causal connection. *Nature, 301*, 419-421.

Brady, S. A., Shankweiler, D., & Mann, V. (1983). Speech perception and memory coding in relation to reading ability. *Journal of Experimental Child Psychology, 35,* 345-367.

Brown, G. D. A. (1997). Connectionism, phonology, reading, and regularity in developmental dyslexia. *Brain and Language, 59,* 207-235.

Brown, P., Lupker, S. J., & Colombo, L. (1994). Interacting sources of information in word naming: A study of individual differences. *Journal of Experimental Psychology: Human Perception and Performance, 20*, 537–554.

Bruck, M. (1992). Persistence of dyslexics' phonological awareness deficits. *Developmental Psychology, 28*, 874-886.

Burden, R. (2008). Is dyslexia necessarily associated with negative feelings of self worth? A review and implications for future research. *Dyslexia: An International Journal of Research and Practice, 14,* 188-196.

Buxton, H. (1983). Temporal predictability in the perception of English speech. In A. Cutler & D. R. Ladd (Eds.), *Prosody: Models and measurements* (pp. 111-121). Berlin, Heidelberg: Springer-Verlag.

Caravolas, M. (2005). The nature and causes of dyslexia in different languages. In M. J. Snowling & C. Hulme (Eds.), *The science of reading: A handbook* (pp. 336-355). Oxford, England: Blackwell.

Carroll, J. M. & Iles, J. E. (2006). An assessment of anxiety levels in dyslexic students in higher education. *British Journal of Educational Psychology, 76*, 651-662.

Carroll, J. M., Snowling, M. J., Hulme, C., & Stevenson, J. (2003). The development of phonological awareness in preschool children. *Developmental Psychology, 39*, 913-923.

Castles, A., & Coltheart, M. (1993). Varieties of developmental dyslexia. *Cognition, 47*, 149-180.

Castles, A., Datta, H., Gayan, J., & Olson, R. K. (1999). Varieties of developmental reading disorder: Genetic and environmental influences. *Journal of Experimental Child Psychology, 72*, 73-94.

Catts, H. (1986). Speech production/phonological deficits in reading-disordered children. *Journal of Learning Disabilities, 19*, 504-508.

Catts, H. (1989). Speech production deficits in developmental dyslexia. *Journal of Speech, Language and Hearing Disorders, 54*, 422-428.

Catts, H. (1991a). Early identification of dyslexia: Evidence from a follow-up study of speech-language impaired children. *Annals of Dyslexia, 41*, 163-177.

Catts, H. (1991b). Early identification of reading disabilities. *Topics in Language Disorders, 12*, 1-16.

Catts, H. (1993). The relationship between speech-language impairment and reading disabilities. *Journal of Speech and Hearing Research, 36*, 948, 958.

Chateau, D., & Jared, D. (2003). Spelling-sound consistency effects in disyllabic word naming. *Journal of Memory and Language, 48*, 255-280.

Clin, E., Wade-Woolley, L., & Heggie, L. (2009). Prosodic sensitivity and morphological awareness in children's reading. *Journal of Experimental Child Psychology, 104*, 197-213.

Colombo, L. (1991). The role of lexical stress in word recognition and pronunciation. *Psychological Research, 53*, 71-79.

Colombo, L. (1992). Lexical stress effect and its interaction with frequency in word pronunciation. *Journal of Experimental Psychology: Human Perception and Performance*, *18*, 987-1003.

Coltheart, M. (1978). Lexical access in simple reading tasks. In G. Underwood (Ed.), *Strategies of information processing* (pp. 151-216). London: Academic Press.

Coltheart, M. (1981). The MRC Psycholinguistic Database. *Quarterly Journal of Experimental Psychology*, *33A*, 497-505.

Coltheart, M., & Jackson, N. (1998). Defining dyslexia. *Child Psychology and Psychiatry Review, 3*, 12-16.

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

Cooper, N., Cutler, A., & Wales, R. (2002). Constraints of lexical stress on lexical access in English: Evidence from native and non-native listeners. *Language and Speech, 45,* 207-228.

Cornelissen, P., Richardson, A., Mason, A., Fowler, S., & Stein, J. (1995). Contrast sensitivity and coherent motion detection measured at photopic luminance levels in dyslexics and controls. *Vision Research, 35,* 1483-1494.

Cruttenden, A. (1986). *Intonation*. Cambridge, England: University Press.

Curtin, S. (2010). Young infants encode lexical stress in newly encountered words. *Journal of Experimental Child Psychology, 105*, 376-385.

Curtin, S., Mintz, T. H., & Christiansen, M. H. (2005). Stress changes the representational landscape: Evidence from word segmentation. *Cognition, 96,* 233-262.

Cutler, A. (1986). Forbear is a homophone: lexical prosody does not constrain lexical access. *Language and Speech, 29*, 201-220.

Cutler, A. (1990). Exploiting prosodic possibilities in speech segmentation. In G. T. M. Altmann (Ed.), *Cognitive Models of Speech Processing: Psycholinguistic and Computational Perspectives* (pp. 105-121). Cambridge, MA: MIT Press.

Cutler, A. & Butterfield, S. (1992). Rhythmic cues to speech segmentation: Evidence from juncture misperception. *Journal of Memory and Language, 31*, 218-236.

Cutler, A. & Carter, D. M. (1987). The predominance of strong initial syllables in the English vocabulary. *Computer Speech and Language, 2*, 133-142.

Cutler, A. & Norris, D. (1988). The role of strong syllables in segmentation for lexical access. *Journal of Experimental Psychology: Human Perception and Performance, 14*, 113-121.

David, D., Wade-Woolley, L., Kirby, J. R., & Smithrim, K. (2007). Rhythm and reading development in school-age children: A longitudinal study. *Journal of Research in Reading, 30*, 169-183.

deBree, E., Wijnen, F., & Zonneveld, W. (2006). Word stress production in three-year-old children at risk of dyslexia. *Journal of Research in Reading, 29*, 304-317.

Defior, S., Calet, N., Nigro, L., Gutiérrez-Palma., N., & Onochie, E. (2010, July). Emergent prosodic skills and literacy development in Spanish preschool children. *Poster presented at the seventeenth annual meeting of the Society for the Scientific Study of Reading, Berlin, Germany*.

Dellatolas, G., Watier, L., Le Normand, M., Lubart, T., & Chevrie-Muller. (2009). Rhythm reproduction in kindergarten, reading performance at second grade and developmental dyslexia theories. *Archives of Clinical Neuropsychology, 24*, 555-563.

Dickie, C., Ota, M., & Clark, A. (2007, August). The phonological deficit in developmental dyslexia: Is there a suprasegmental component? *Paper presented at the sixteenth International Congress of Phonetic Sciences, Saarbrücken, Germany.*

Duncan, L. G., Seymour, P. H. K., & Hill, S. (1997). How important are rhyme and analogy in beginning reading? *Cognition, 63*, 171-208.

Duncan, L. G., Seymour, P. H. K., & Hill, S. (2000). A small-to-large unit progression in metaphonological awareness and reading? *The Quarterly Journal of Experimental Psychology, 53A*, 1081-1104.

Duncan, L. G., & Seymour, P. H. K. (2003). How do children read multisyllabic words? Some preliminary observations. *Journal of Research in Reading, 26*, 101-120.

Dupoux, E., Peperkamp, S., & Sebastián-Gallés, N. (2001). A robust method to study stress deafness. *Journal of the Acoustical Society of America, 110*, 1606-1618.

Durand, M., Hulme, C., Larkin, R., & Snowling, M. J. (2005). The cognitive foundations of reading and arithmetic skills in 7- to 10-year olds. *Journal of Experimental Child Psychology, 91*, 113-136.

Eden, G. F., VanMeter, J. W., Rumsey, J. M., Maisog, J. M., Woods, R. P., & Zeffiro, T. A. (1996). Abnormal processing of visual motion in dyslexia revealed by functional brain imaging. *Nature, 382,* 66-69.

Facoetti, A., Ruffino, M., Peru, A., Paganoni, P., & Chelazzi, L. (2008). Sluggish engagement and disengagement of non-spatial attention in dyslexic children. *Cortex, 44*, 1221-1233.

Farmer, M. E., & Klein, R. M. (1995). The evidence for a temporal processing deficit linked to dyslexia: A review. *Psychonomic Bulletin and Review, 2*, 460-493.

Fawcett, A. J., Nicolson, R. I., & Dean, P. (1996). Impaired performance of children with dyslexia on a range of cerebellar tasks. *Annals of Dyslexia, 46*, 259-283.

Felton, R. H., & Wood, P. B. (1989). Cognitive deficits in reading disability and attention deficit disorder. *Journal of Learning Disabilities, 22,* 3-22.

Ferrand, L., Segui, J., & Humphreys, G. W. (1997). The syllable’s role in word naming. *Memory and Cognition, 25,* 458-470.

Fowler, A. E. (1991). How early phonological development might set the stage for phoneme awareness. In S. Brady & D. Shankweiler (Eds.), *Phonological processes in literacy: A tribute to Isabelle Y. Liberman* (pp. 97-117). Hillsdale, NJ: Lawrence Erlbaum.

Foxton, J. M., Talcott, J. B., Witton, C., Brace, H., McIntyre, F., & Griffiths, T. D. (2003). Reading skills are related to global, but not local, acoustic pattern perception. *Nature Neuroscience, 6*, 343-344.

Fry, D. B. (1955). Duration and intensity as physical correlates of linguistic stress. *Journal of the Acoustical Society of America*, *27*, 765-768.

Fry, D. B. (1958). Experiments in the perception of stress. *Language and Speech, 1*, 126-152.

Furness, B., & Samuelsson, S. (2009). Preschool cognitive and language skills predicting kindergarten and grade 1 reading and spelling: A cross-linguistic comparison. *Journal of Research in Reading*, *32*, 275-292.

Gallagher, A., Frith, U., & Snowling, M. J. (2000). Precursors of literacy delay among children at genetic risk of dyslexia. *Journal of Child Psychology and Psychiatry*, *41*, 203-213.

Gathercole, S. E., & Baddeley, A. D. (1990). Phonological deficits in language disordered children: Is there a causal connection? *Journal of Memory and Language*, *29*, 336-360.

Goldstein, E. B. (2002). *Sensation and Perception*. Belmont, CA: Thomson Wadsworth.

Gombert, J. E. (1992). *Metalinguistic Development*. London: Harvester Wheatsheaf.

Gomez, R. L., & Gerken, L., (2000). Infant artificial language learning and language acquisition. *Trends in Cognitive Sciences, 4*, 178-186.

Goodman, I., Libenson, A., & Wade-Woolley, L. (2007, July). Sensitivity to lexical and metrical stress in phonological awareness and early reading development. *Poster presented at the fourteenth annual meeting of the Society for the Scientific Study of Reading, Prague, Czech Republic.*

Goodman, I., Libenson, A., & Wade-Woolley, L. (2010). Sensitivity to linguistic stress, phonological awareness and early reading ability in preschoolers. *Journal of Research in Reading*, *33*, 113-127.

Goswami, U. (2000). Phonological representations, reading development and dyslexia: Towards a cross-linguistic theoretical framework. *Dyslexia, 6*, 133-151.

Goswami, U. (2002a). In the beginning was the rhyme? A reflection on Hulme, Hatcher, Nation, Brown, Adams, and Stuart, 2001. *Journal of Experimental Child Psychology, 82*, 47-57.

Goswami, U. (2002b). Phonology, reading development and dyslexia: A cross-linguistic perspective. *Annals of Dyslexia*, *52*, 1-23.

Goswami, U. (2003). Why theories about developmental dyslexia require developmental designs. *Trends in Cognitive Sciences*, *7*, 534-540.

Goswami, U. (2008). Reading, dyslexia and the brain. *Educational research, 50*, 135-148.

Goswami, U. (2011). A temporal sampling framework for developmental dyslexia. *Trends in Cognitive Sciences*, *15*, 3-10.

Goswami, U., Gerson, D., & Astruc, L. (2009). Amplitude envelope perception, phonology and prosodic sensitivity in children with developmental dyslexia. *Reading and Writing, 23*, 995-1019.

Goswami, U., Thomson, J., Richardson, U., Stainthorp, R., Hughes, D., Rosen, S., & Scott, S. K. (2002). Amplitude envelope onsets and developmental dyslexia: A new hypothesis. *Proceedings of the National Academy of Sciences, 99,* 10911-10916.

Goswami, U., Ziegler, J. C., Dalton, L., & Schneider, W. (2003). Nonword reading across orthographies: How flexible is the choice of reading units? *Applied Psycholinguistics, 24*, 235-247.

Grosjean, F. (1980). Spoken word recognition processes and the gating paradigm. *Perception & Psychophysics, 28,* 267–283.

Grosjean, F. (1996). Gating. *Language and Cognitive Processes, 11,* 597–604.

Grosjean, F. & Gee, J. P. (1987). Prosodic structure and spoken word recognition. *Cognition, 25*, 135-155.

Gutiérrez-Palma, N. (2010, June). Prosodic sensitivity and literacy acquisition in Spanish. *Paper presented at the Harvard Linguistic Rhythm Seminar, Harvard University, Cambridge, MA*.

Gutiérrez-Palma, N., Defior, S., & Calet, N. (2010, July). Prosodic sensitivity and the acquisition of punctuation marks in Spanish. *Poster presented at the seventeenth annual meeting of the Society for the Scientific Study of Reading, Berlin, Germany*.

Gutiérrez-Palma, N. & Palma-Reyes, A. (2007). Stress sensitivity and reading performance in Spanish: A study with children. *Journal of Research in Reading, 30*, 157-168.

Gutiérrez-Palma, N. & Palma-Reyes, A. (2008). On the use of lexical stress in reading Spanish. *Reading and Writing, 21*, 645-660.

Gutiérrez-Palma, N., Raya-García, M., & Palma-Reyes, A. (2009). Detecting stress patterns is related to children's performance on reading tasks. *Applied Psycholinguistics, 30*, 1-21.

Hämäläinen, J. A., Leppänen, P. H. T., Eklund, K., Thomson, J., Richardson, U., Guttorm, T. K., Witton, C., Poikkeus, A., Goswami, U., & Lyytinen, H. (2009). Common variance in amplitude envelope perception tasks and their impact on phoneme duration perception and reading and spelling in Finnish children with reading disabilities. *Applied Psycholinguistics*, *30*, 511-530.

Hämäläinen, J., A., Leppänen, P. H. T., Torppa, M., Muller, K., & Lyytinen, H. (2005). Detection of sound rise-time by adults with dyslexia. *Brain and Language*, *94*, 32-42.

Hari, R., & Renvall, H. (2001). Impaired processing of rapid stimulus sequences in dyslexia. *Trends in Cognitive Sciences*, *5*, 525-532.

Hari, R., Valta, M., & Uutela, K. (1999). Prolonged attentional dwell time in dyslexic adults. *Neuroscience Letters*, *271*, 202-204.

Harm, M. W., & Seidenberg, M. S. (1999). Phonology, reading, and dyslexia: Insights from connectionist models. *Psychological Review, 163*, 491-528.

Hatcher, J., Snowling, M. J., & Griffiths, Y. M. (2002). Cognitive assessment of dyslexic students in higher education. *British Journal of Educational Psychology*, *72,* 119-133.

Hatcher, J., & Snowling, M. J. (2002). *The York Adult Assessment*. The Dyslexia Institute.

Hatcher, P. J., Hulme, C., & Ellis, A. (1994). Ameliorating early reading failure by integrating the teaching of reading and phonological skills: The phonological linkage hypothesis. *Child Development*, *65*, 41-57.

Hawkins, P. (1992). *Introducing phonology*. London: Routledge.

Heggie, L., Wade-Woolley, L., & Briand, P. (2010, July). Suprasegmental phonological awareness and multisyllabic word reading. *Poster presented at the seventeenth annual meeting of the Society for the Scientific Study of Reading, Berlin, Germany*.

Herman, K. (1959). *Reading disability*. Copenhagen: Munksgaard.

Hirst, D. (1983). Structures and categories in prosodic representations. In A. Cutler & D. R. Ladd (Eds.), *Prosody: Models and measurements* (pp. 93-109). Berlin, Heidelberg: Springer-Verlag.

Holliman, A., Wood, C., & Sheehy, K. (2010a). The contribution of sensitivity to speech rhythm and non-speech rhythm to early reading development. *Educational Psychology, 30,* 247-267.

Holliman, A., Wood, C., & Sheehy, K. (2010b). Does speech rhythm sensitivity predict children's reading ability one year later? *Journal of Educational Psychology*, *102*, 356-366.

Holliman, A., Wood, C., & Sheehy, K. (2008a). Sensitivity to speech rhythm explains individual differences in reading ability independently of phonological awareness. *British Journal of Developmental Psychology, 26,* 357-367.

Holliman, A., Wood, C., & Sheehy, K. (2008b, March). The role of speech rhythm and prosody in children's reading development: Evidence from three studies. *Poster presented at the seventh British Dyslexia Association international conference, Harrogate, United Kingdom.*

Hulme, C., Hatcher, P. J., Nation, K., Brown, A., Adams, J., Stuart, G. (2002). Phoneme awareness is a better predictor of early reading skill than onset-rime awareness. *Journal of Experimental Child Psychology, 82,* 2-28.

Hulme, C., & Snowling, M. J. (1992). Deficits in output phonology: An explanation of reading failure? *Cognitive Neuropsychology, 9,* 47-72.

Hyatt, K. J., Stephenson, J., & Carter, M. (2009). A review of three controversial educational practices: Perceptual motor programs, sensory integration and tinted lenses. *Education and Treatment of Children, 32,* 313-342.

Jarmulowicz, L. (2006). School-aged children's phonological production of derived English words. *Journal of Speech, Language, and Hearing Research, 49,* 294-308.

Jarmulowicz, L., Taran, V. L., & Hay, S. E. (2007). Third graders' metalinguistic skills, reading skills, and stress production in derived English words. *Journal of Speech, Language, and Hearing Research, 50,* 1593-1605.

Jarvis, B. G. (2006). *DirectRT Research Software* (Version 2006.2). New York: Empirisoft Corporation.

Jednoróg, K., Marchewka, A. Tacikowski, P., & Grabowska, A. (2010). Implicit phonological and semantic processing in children with developmental dyslexia: Evidence from event-related potentials. *Neuropsychologia, 48,* 2447-2457.

Joanisse, M. F., Manis, F. R., Keating, P., & Seidenberg, M. S. (2000). Language deficits in dyslexic children: Speech perception, phonology, and morphology. *Journal of Experimental Child Psychology, 77,* 30-60.

Jusczyk, P. W. (1999). How infants begin to extract words from speech. *Trends in Cognitive Sciences, 3,* 323-328.

Jusczyk, P. W., & Aslin, R. N. (1995). Infants' detection of sound patterns of words in fluent speech. *Cognitive Psychology, 29*, 1-23.

Jusczyk, P. W., Cutler, A., & Redanz, N. (1993). Preference for the predominant stress patterns of English words. *Child Development, 64*, 675-687.

Jusczyk, P. W., Houston, D., & Newsome, M. (1999). The beginnings of word segmentation in English-learning infants. *Cognitive Psychology, 39*, 159-207.

Kelly, M. H. (2004). Word onset patterns and lexical stress in English. *Journal of Memory and Language, 50,* 231-244.

Kelly, M. H., & Bock, J. K. (1988). Stress in time. *Journal of Experimental Psychology: Human Perception and Performance, 14,* 389-403.

Kelly, M. H., Morris, J., & Verrekia, L. (1998). Orthographic cues to lexical stress: Effects on naming and lexical decision times. *Memory and Cognition, 26,* 822-832.

Kitzen, K. R. (2001). Prosodic sensitivity, morphological ability, and reading ability in young adults with and without childhood histories of reading difficulty (doctoral dissertation, University of Colombia, 2001). *Dissertation Abstracts International, 62, 460.*

Kucera, H., & Francis, W. N. (1967). *Computational Analysis of Present-Day American English.* Providence, RI: Brown University Press.

Kuhl, P. (2004). Early language acquisition: Cracking the speech code. *Nature Reviews Neuroscience, 5,* 831-843.

Ladd, R. A. & Cutler, A. (1983). Models and measurements in the study of prosody. In A. Cutler & D. R Ladd (Eds.), *Prosody: Models and measurements* (pp. 1-8). Berlin, Heidelberg: Springer-Verlag.

Lallier, M., Thierry, G., Tainturier, M. J., Donnadieu, S., Peyrin, C., Billard, C., & Valdois, S. (2009). Auditory and visual stream segregation in children and adults: An assessment of the amodality assumption of the 'sluggish attentional shifting' theory of dyslexia. *Brain Research, 1302*, 132-147.

Lehiste, I., & Fox, R. A. (1992). Perception of prominence by Estonian and English listeners. *Language and Speech, 35,* 419-434.

Leonard, C. M., Eckert, M. A., Lombardino, L. J., Oakland, T., Kranzler, J., Mohr, C. M., King. W. M., & Freeman, A. (2001). Anatomical risk factors for phonological dyslexia. *Cerebral Cortex, 11*, 148-157.

Liberman, I. Y., Shankweiler, D., Fisher, W. F. & Carter, B. (1974). Explicit syllable and phoneme segmentation in the young child. *Journal of Experimental Child Psychology, 18,* 201-212.

Liberman, M. Y. & Streeter, L. A. (1978). Use of nonsense syllable mimicry in the study of prosodic phenomena. *Journal of the Acoustical Society of America, 63*, 231-233.

Liberman, P. (1960). Some acoustic correlates of word stress in American English. *Journal of the Acoustical Society of America, 63*, 231-233.

Lindfield, K., Wingfield, A., & Goodglass, H. (1999). The role of prosody in the mental lexicon. *Brain and Language, 68,* 312-317.

Lundberg, I., Frost, J., & Peterson, O. P. (1988). Effects of an extensive program for stimulating phonological awareness in pre-school children. *Reading Research Quarterly, 23,* 263-284.

Lundberg, I., Olofsson, A., & Wall, S. (1980). Reading and spelling skills in the first school years predicted from phonemic awareness skills in kindergarten. *Scandinavian Journal of Psychology, 21*, 159-173.

Manis, F. R., McBride-Chang, C., Seidenberg, M. S., Keating, P., Doi, L. M., Munson, B., & Petersen, A. (1997). Are speech perception deficits associated with developmental dyslexia? *Journal of Experimental Child Psychology, 66*, 211-235.

Manis, F. R., Seidenberg, M. S., Doi, L. M., McBride-Chang, C., & Petersen, A. (1996). On the bases of two subtypes of developmental dyslexia. *Cognition, 58*, 157-195.

Mattingly, I. G. (1972). Reading, the linguistic process and linguistic awareness. In J. F. Kavanagh & I. G. Mattingly (Eds.), *Language by ear and by eye: The relationship between speech and reading* (pp. 133-147). Cambridge, MA: MIT Press.

Mattys, S. L. (2000). The perception of primary and secondary stress in English. *Perception and Psychophysics, 62*, 253-265.

Mattys, S. L., White, L., Melhorn, J. F. (2005). Integration of multiple speech segmentation cues: A hierarchical framework. *Journal of Experimental Psychology: General, 134*, 477-500.

McArthur, G. M., Ellis, D., Atkinson, C., & Coltheart, M. (2008). Auditory processing deficits in children with reading and language impairments: Can they (and should they) be treated? *Cognition, 107*, 946-977.

McPhillips, M. (2003). A commentary on an article published in the February 2003 edition of *Dyslexia*, ‘Evaluation of an exercise-based treatment for children with reading difficulties’ (Reynolds, Nicolson, & Hambly). *Dyslexia: An International Journal of Research and Practice, 9*, 161-163.

Milne, R. D., Nicholson, T., & Corballis, M. C. (2003). Lexical access and phonological decoding in adult dyslexic subtypes. *Neuropsychology, 17*, 362-368.

Mody, M., Studdert-Kennedy, M., & Brady, S. (1997). Speech perception deficits in poor readers: Auditory processing or phonological coding? *Journal of Experimental Child Psychology, 64*, 199-231.

Monaco, A. P. (2008, September). Genetics of developmental dyslexia. *Paper presented at the Autumn School in Cognitive Neuroscience, University of Oxford UK.*

Monsell, S., Doyle, M. C., & Haggard, P. N. (1989). Effects of frequency on visual word recognition tasks: Where are they? *Journal of Experimental Psychology: General, 118*, 43–71.

Morais, J. (2003). Levels of phonological representation in learning to read. *Reading and Writing: An Interdisciplinary Journal, 16*, 123-151.

Nakatani, L. H. & Schaffer, J. A. (1978). Hearing 'words' without words: Prosodic cues for word perception. *Journal of the Acoustical Society of America, 63*, 234-245.

Nicolson, R. I., & Fawcett, A. J. (1990). Automaticity: A new framework for dyslexia research? *Cognition, 35*, 159-182.

Nicolson, R. I., Fawcett, A. J., Berry, E. L., Jenkins, I. H., Dean, P., & Brooks, D. J. (1999). Association of abnormal cerebellar activation with motor learning difficulties in dyslexic adults. *Lancet, 353*, 1662-1667.

Nicolson, R. I., & Fawcett, A. J. (1999). Developmental dyslexia: The role of the cerebellum. *Dyslexia: An International Journal of Research and Practice, 5*, 155-177.

Nicolson, R. I., Fawcett, A. J., & Dean, P. (2001). Developmental dyslexia: The cerebellar deficit hypothesis. *Trends in Neurosciences, 24,* 508-511.

Nikolopoulos, D., Goulandris, N., Hulme, C., & Snowling, C. (2006). The cognitive bases of learning to read and spell in Greek: Evidence from a longitudinal study. *Journal of Experimental Child Psychology, 94*, 1-17.

Olson, L. A., Evans, J. R., & Keckler, W. T. (2006). Precocious readers: Past, present and future. *Journal for the Education of the Gifted, 30*, 205-235.

Orton, S. T. (1925). 'Word blindness' in school children. *Archives of Neurology and Psychiatry, 14*, 581-615.

Paizi, D., Zoccolotti, P., & Burani, C. (2011). Lexical stress assignment in Italian developmental dyslexia. *Reading and Writing, 24*, 443-461.

Pasquini, E. S., Corriveau, K. H., & Goswami, U. (2007). Auditory processing of amplitude envelope rise-time in adults diagnosed with developmental dyslexia. *Scientific Studies of Reading, 11,* 259-286.

Pennington, B. F., & Olson, R. K. (2005). Genetics of dyslexia. In M. J. Snowling & C. Hulme (Eds.), *The science of reading: A handbook* (pp. 453-472). Oxford: Blackwell.

Perry, C., Ziegler, J. C., & Zorzi, M. (2010). Beyond single syllables: Large scale modelling of reading aloud with the connectionist dual processing (CDP++) model. *Cognitive Psychology, 61*, 106-151.

Pickering, S. J. (2006). Working memory in dyslexia. In T. P. Alloway & S. E. Gathercole (Eds.), *Working memory and neurodevelopmental disorders* (pp. 7-40). Hove, England: Psychology Press.

Plaut, D. C., McClelland, J. L., Seidenberg, M. S., & Patterson, K. E. (1994). Understanding normal and impaired word reading: Computational principles in quasi-regular domains. *Psychological Review, 103,* 56-115.

Pokorni, J. L., Worthington, C. K., & Jamison, P., J. (2004). Phonological awareness intervention: Comparison of Fast ForWord, Earobics and LiPS. *Journal of Educational Research, 97,* 147-157.

Price, C. J., McCrory, E. (2005). Functional brain imaging studies of skilled reading and developmental dyslexia. In M. J. Snowling & C. Hulme (Eds.), *The science of reading: A handbook* (pp. 473-496). Oxford: Blackwell.

Protopapas, A. (2006). On the use and usefulness of stress diacritics in Greek. *Reading and Writing, 19,* 171-178.

Protopapas, A., Gerakaki, S., & Alexandri, S. (2006). Lexical and default stress assignment in reading Greek. *Journal of Research in Reading, 29,* 418-432.

Protopapas, A., Gerakaki, S., & Alexandri, S. (2007). Sources of information for stress assignment in Greek. *Applied Psycholinguistics, 28,* 695-720.

Protopapas, A., & Gerakaki, S. (2009). Development of processing stress diacritics in Greek. *Scientific Studies of Reading, 13,* 453-483.

Rack, J., Hulme, C., Snowling, M. J., & Wightman, J. (1994). The role of phonology in young children learning to read words: The direct mapping hypothesis. *Journal of Experimental Child Psychology, 57,* 42-71.

Rack., J., Snowling, M. J., & Olson, R. K. (1992). The nonword reading deficit in developmental dyslexia: A review. *Reading Research Quarterly, 27,* 29-51.

Ramus, F. (2001). Outstanding questions about phonological processing in dyslexia. *Dyslexia, 7,* 197-216.

Ramus, F., Rosen, S., Dakin, S. C., Day, B. L., Castellote, J. M., White, S., & Frith, U. (2003). Theories of developmental dyslexia: Insights from a multiple case study of dyslexic adults. *Brain, 126,* 841-865.

Ramus, F., & Szenkovits, G. (2008). What phonological deficit? *The Quarterly Journal of Experimental Psychology, 61*, 129-141.

Rastle, K., & Coltheart, M. (2000). Lexical and non-lexical print-to-sound translation of disyllabic words and nonwords. *Journal of Memory and Language, 42*, 342-364.

Reed, M. A. (1989). Speech perception and the discrimination of brief auditory cues in reading disabled children. *Journal of Experimental Child Psychology, 48*, 270-292.

Reynolds, D., Nicolson, R. I., & Hambly. (2003). Evaluation of an exercise-based treatment for children with reading difficulties. *Dyslexia: An International Journal of Research and Practice, 9*, 48-71.

Reynolds, D., & Nicolson, R. I. (2007). Follow-up of an exercise-based treatment for children with reading difficulties. *Dyslexia: An International Journal of Research and Practice, 13*, 78-96.

Richards, I. L., Moores, E., Witton, C., Reddy, P. A., Rippon, G., Rochelle, K. S. H., & Talcott, J. B. (2003). Science, sophistry and 'commercial sensitivity': Comments on 'Evaluation of an Exercise-Based Treatment for Children with Reading Difficulties' by Reynolds, Nicolson and Hambly. *Dyslexia: An International Journal of Research and Practice, 9*, 146-150.

Richardson, J. T. E., & Wydell, T. N. (2003). The Representation and attainment of students with dyslexia in UK higher education. *Reading and Writing: An Interdisciplinary Journal, 16,* 475-503.

Richardson, U., Thomson, J. T., Scott, S. K., & Goswami, U. (2004). Auditory processing skills and phonological representation in dyslexic children. *Dyslexia, 10,* 215-233.

Ridsdale, J. (2004). Dyslexia and self-esteem. In M. Turner & J. Rack (Eds.), *The study of dyslexia* (pp. 249-279). New York: Kluwer Academic/Plenum Publishers.

Rose, J. (2006). *Independent review of the teaching of early reading*. Nottingham: DfES Publications.

Rose, J. (2009). *Identifying and teaching children and young people with dyslexia and literacy difficulties*. Nottingham: DCSF Publications.

Rüsseler, J., Becker, P., Johannes, S., Münte, T. F. (2007). Semantic, syntactic, and phonological processing of written words in adult developmental dyslexic readers: an even-related potential study. *BMC: Neuroscience, 8,* 52. Published online July 17th 2007. DOI: 10.1186/1471-2202-8-52.

Saffran, J. R. (2003). Statistical language learning: Mechanisms and constraints. *Current Directions in Psychological Science, 12,* 110-114.

Saffran, J. R., Aslin, R. N., & Newport, E. L. (1996). Statistical learning by 8-month-old-infants. *Science, 274,* 1926-1928.

Saffran, J. R., Johnson, E. K., Aslin, R. N., & Newport, E. L. (1999). Statistical learning of tone sequences by human infants and adults. *Cognition, 70,* 27-52.

Saffran, J. R, Newport, E. L., & Aslin, R. N. (1996). Word segmentation: The role of distributional cues. *Journal of Memory and Language, 35,* 606-621.

Schiller, N. O. (1998). The effect of visually masked syllable primes on the naming latencies of words and pictures. *Journal of Memory and Language, 39,* 484-507.

Schiller, N. O. (1999). Masked syllable priming of English nouns. *Brain and Language, 68,* 300-305.

Seidenberg, M. S., & McClelland, J. L. (1989). A distributed, developmental model of word recognition and naming. *Psychological Review, 96,* 523-568.

Seidenberg, M. S., Waters, G. S., Barnes, M. A., & Tannenhaus, M. K. (1984). When does irregular spelling or pronunciation influence word recognition? *Journal of Verbal Learning and Verbal Behaviour, 23*, 383-404.

Serniclaes, W., Van Heghe, S., Mousty, P., Carré, R., & Sprenger-Charolles, L. (2004). Allophonic mode of speech perception in dyslexia. *Journal of Experimental Child Psychology, 87*, 336-361.

Serniclaes, W., Ventura, P., Morais, J., & Kolinsky, R. (2005). Categorical perception of speech sounds in illiterate adults. *Cognition, 98,* B35-B44.

Ševa, N., Monaghan, P., & Arciuli, J. (2009). Stressing what is important: Orthographic cues and lexical stress assignment. *Journal of Neurolinguistics, 22,* 237-249.

Seymour, P. H. K., & Duncan, L. G. (1997). Small versus large unit theories of reading acquisition. *Dyslexia, 3,* 125-134.

Shapiro, L. R., Carroll, J. M., & Solity, J. (2008). The impact of sensory, motor and cognitive skills on early reading, submitted. DOI: 10.1348/000709908_293850.

Shukla, M., Nespor, M., & Mehler, J. (2007). An interaction between prosody and statistics in the segmentation of fluent speech. *Cognitive Psychology, 54*, 1-32.

Singleton, C., & Morag, S. (2003). Measurement mischief: A critique of Reynolds, Nicolson and Hambly (2003). *Dyslexia*, *9*, 151-160.

Smith, P. T., & Baker, R. G. (1976). The influence of English spelling on pronunciation. *Journal of Verbal Learning and Verbal Behaviour, 15,* 267-285.

Smith, P. T., Baker, R. G., & Groat, A. (1982). Spelling as a source of information about children's linguistic knowledge. *British Journal of Psychology, 73,* 339-350.

Smith-Spark, J. H., & Fisk, J. E. (2007). Working memory functioning in developmental dyslexia. *Memory, 15,* 34-56.

Snowling, M. J. (2000). *Dyslexia* (2nd ed.). Oxford, England: Blackwell.

Snowling, M. J. & Hulme, C. (2003). A critique of claims from Reynolds, Nicolson & Hambly (2003) that DDAT is an effective treatment for children with reading difficulties – lies, damned lies and (inappropriate) statistics? *Dyslexia: An International Journal of Research and Practice*, *9*, 127-133.

Snowling, M. J., Stackhouse, J., & Rack, J. P. (1986). Phonological dyslexia and dysgraphia: A developmental analysis. *Cognitive Neuropsychology, 3,* 309-339.

Snowling, M. J., van Wagtendonk, B., & Stafford, C. (1988). Object naming deficits in developmental dyslexia. *Journal of Research in Reading, 11,* 67-85.

Soto-Faraco, S., Sebastián-Gallés, N., & Cutler, A. (2001). Segmental and supra-segmental mismatch in lexical access. *Journal of Memory and Language*, *45*, 412-432.

Stambak, M. (1951). Problems of rhythm in the development of the child and in developmental dyslexia. *Enfance*, *4*, 480-502.

Stanovich, K. E. (1986). Matthew effects in reading: Some consequences of individual differences in the acquisition of literacy. *Reading Research Quarterly*, 21, 360-407.

Stanovich, K. E. (1988). Explaining the differences between the dyslexic and the garden-variety poor reader: The phonological-core variable-difference model. *Journal of Learning Disabilities*, *21*, 590-612.

Stanovich, K. E. (1998). Refining the phonological core deficit model. *Child Psychology and Psychiatry Review*, *3*, 17-21.

Stanovich, K. E., Siegel, L. S., & Gottardo, A. (1997). Converging evidence for phonological and surface subtypes of reading disability. *Journal of Educational Psychology*, *89*, 114-127.

Stein, J., & Walsh, V. (1997). To see but not to read: The magnocellular theory of dyslexia. *Trends in Neurosciences*, *20*, 147-152.

Stoodley, C. J., Harrison, E. P. D., & Stein, J. F. (2006). Implicit motor learning deficits in dyslexic adults. *Neuropsychologia 44/45,* 795-798.

Strong, G. K., Torgeson, C. J., Torgeson, D., & Hulme, C. (2011). A systematic meta-analytic review of evidence for the effectiveness of the 'Fast ForWord' language intervention program. *Journal of Child Psychology and Psychiatry*, *52*, 224-235.

Studdert-Kennedy, M., & Mody, M. (1995). Auditory temporal perception deficits in the reading impaired: A critical review of the evidence. *Psychonomic Bulletin and Review, 2,* 508-514.

Tallal, P. (1980). Auditory temporal perception, phonics and reading disabilities in children. *Brain and Language, 9,* 182-198.

The Psychological Corporation. (1999). Wechsler abbreviated scale of intelligence. San-Antonio, TX: Harcourt Brace & Company.

Thiessen, E. D. & Saffran, J. R. (2003). When cues collide: Use of stress and statistical cues to word boundaries by 7- to 9-month old infants. *Developmental Psychology, 39*, 706-716.

Thomson, J. M., Fryer, B., Maltby, J., Goswami, U. (2006). Auditory and motor rhythm awareness in adults with dyslexia. *Journal of Research in Reading, 29,* 334-348.

Thomson, J., & Goswami, U. (2010). Learning novel phonological representations in developmental dyslexia: Associations with basic auditory processing of rise-time and phonological awareness. *Reading and Writing*, *23*, 453-473.

Torgesen, J. K. (2005). Recent discoveries on remedial interventions for children with dyslexia. In M. J. Snowling & C. Hulme (Eds.), *The science of reading: A handbook* (pp. 521-537). Oxford, England: Blackwell.

Torgesen, J. K., Alexander, A. W., Wagner, R. K., Rashotte, C. A., Voeller, K., Conway, T., & Rose, E. (2001). Intensive remedial instruction for children with severe reading disabilities: Immediate and long term outcomes from two instructional approaches. *Journal of Learning Disabilities, 34*, 33-58.

Torgesen, J. K., Wagner, R. K., & Rashotte, C. A. (1999). *The Test of Word Reading Efficiency*. Austin, TX: PRO-ED.

Torkildsen, J. V. K., Swersen, G., Simonsen, H. G., Moen, I., & Lindgren, G. (2007). Brain responses to lexical semantic priming in children at-risk for dyslexia. *Brain and Language, 102*, 243-261.

Treiman, R., & Zukowski, A. (1991). Levels of phonological awareness. In S. Brady & D. Shankweiler (Eds.), *Phonological processes in literacy: A tribute to Isabelle Y. Liberman* (pp. 67-83). Hillsdale, NJ: Lawrence Erlbaum.

van der Mark, S., Bucher, K., Maurer, U., Schulz, E., Brem, S., Buckelmuller, J., Kronbichler, M., Loenneker, T., Klaver, P., Martin, E., & Brandeis, D. (2009). Children with dyslexia lack multiple specialisations along the visual word-form (VWF) system. *NeuroImage, 47*, 1940-1949.

van Donselaar, W., Koster, M., & Cutler, A. (2005). Exploring the role of lexical stress in lexical recognition. *The Quarterly Journal of Experimental Psychology, 58A*, 251-273.

van Leeuwen, T., Been, P., Kuijpers, C., Zwarts, F., Maassen, B., & van der Leij, A. (2006). Mismatch response is absent in 2-month-old infants at risk for dyslexia. *Neuroreport: For Rapid Communication of Neuroscience Research, 17*, 351-355.

Vellutino, F. (1977). Alternative conceptualisations of dyslexia: Evidence in support of a verbal-deficit hypothesis. *Harvard Educational Review, 47*, 334-354.

Vellutino, F. (1979). *Dyslexia: Research and Theory*. Cambridge, MA: MIT Press.

Vellutino, F. R., Fletcher, J. M., Snowling, M. J., & Scanlon, D. M. (2004). Specific reading disability (dyslexia): What have we learned in the past four decades? *Journal of Child Psychology and Psychiatry, 45*, 2-40.

Vellutino, F. R., & Fletcher, J. M. (2005). Developmental dyslexia. In M. J. Snowling & C. Hulme (Eds.), *The science of reading: A handbook* (pp. 362-378). Oxford, England: Blackwell.

Vidyasagar, T. R., & Pammer, K. (2009). Dyslexia: A deficit in visuo-spatial attention, not in phonological processing. *Trends in Cognitive Sciences, 114*, 57-63.

Wade-Woolley, L., & Akaoka, E. (2006, July). Examining the role of prosody in fluent reading. *Poster presented at the thirteenth annual meeting of the Society for the Scientific Study of Reading, Vancouver, Canada*.

Wade-Woolley, L., & Kotanko, M. (2010, July). Prosodic sensitivity and punctuation skill in eight- and twelve-year-old children. *Poster presented at the seventeenth annual meeting of the Society for the Scientific Study of Reading, Berlin, Germany*.

Wade-Woolley, L. & Wood, C. (2006). Editorial: Prosodic sensitivity and reading development. *Journal of Research in Reading*, *29*, 253-257.

Wagner, R. K., & Muse, A. (2006). Short-term memory deficits in developmental dyslexia. In T. P. Alloway & S. E. Gathercole (Eds.), *Working memory and neurodevelopmental disorders* (pp. 41-57). Hove, England: Psychology Press.

Wagner, R. K., & Torgesen, J. K. (1987). The nature of phonological processing and its causal role in the acquisition of reading skills. *Psychological Bulletin*, *101*, 192-212.

Wagner, R. K., Torgesen, J. K., & Rashotte, C. A. (1999). *Comprehensive Test of Phonological Processing*. Austin, TX: PRO-ED.

Weikart, P. (1989). *Rhythmically Moving*. Ypsilanti, MI: High/Scope Educational Research Foundation.

Wells, B., Peppé, S., & Goulandris, N. (2004). Intonation development from five to thirteen. *Journal of Child Language, 31*, 749-778.

Whalley, K., & Hansen, J. (2006). The role of prosodic sensitivity in children's reading development. *Journal of Research in Reading, 29,* 288-303.

White, S., Milne, E., Rosen, S., Hansen, P., Swettenham, J., Frith, U., & Ramus, F. (2006). The role of sensorimotor impairments in dyslexia: A multiple case study of dyslexic children. *Developmental Science, 9*, 237-269.

Wilson, M. D. (1988). The MRC Psycholinguistic Database: Machine Readable Dictionary, version 2. *Behavioural Research Methods: Instruments and Computers, 20,* 6-11.

Witton, C., Stein, J. F., Stoodley, C. J., Rosner, B. S., & Talcott, J. B. (2002). Separate influences of acoustic AM and FM sensitivity on the phonological decoding skills of impaired and normal readers. *Journal of Cognitive Neuroscience, 14,* 866, 874.

Wolf, M., & Bowers, P. G. (1999). The double-deficit hypothesis for the developmental dyslexias. *Journal of Educational Psychology, 91*, 415-438.

Wood, C. (2006). Metrical stress sensitivity in young children and its relationship to phonological awareness and reading. *Journal of Research in Reading, 29,* 270-287.

Wood, C., & Joshi, P. (2007, July). Sensitivity to stress in speech and its relationship to spelling proficiency in adults. *Poster presented at the fourteenth annual meeting of the Society for the Scientific Study of Reading, Prague, Czech Republic.*

Wood, C., & Terrell, C. (1998). Poor readers' ability to detect speech rhythm and perceive rapid speech. *British Journal of Developmental Psychology, 16,* 397-413.

Wood, C., Wade-Woolley, L., & Holliman, A. (2009). Phonological awareness: beyond phonemes. In C. Wood & A. J. Holliman (Eds.), *Contemporary perspectives on reading and spelling* (pp. 7-23). London: Routledge.

World Health Organisation. (1993). *ICD-10 classification of mental health and behavioural disorders: Diagnostic criteria for research*. Geneva: World Health Organisation.

Yap, M. J. & Balota, D. A. (2009). Visual word recognition of multisyllabic words. *Journal of Memory and Language, 60*, 502-529.

Ziegler, J. C., Pech-George, C., Dufau, S., & Grainger, J. (2010). Rapid processing of letters, digits and symbols: What purely visual-attentional deficit in developmental dyslexia? *Developmental Science, 13,* F8-F14.

Appendix A

Table A1.

Spoken stimuli and response options presented during the DEEdee task

(Experiment 1a)

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

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 1b)

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 experimental primes also served as target words.

Appendix C

Table A3.

Word pairs used in the fragment identification task (Experiment 2)

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 experimental primes also served as target words.

Appendix E

Table A5.

Spoken primes and target words presented during the cross modal DEEdee priming task (Experiment 3)

	Spoken Primes		
Target Word	Control	Congruent DEEdee	Incongruent DEEdee
Díagram	Heróic	DEEdeedee	deeDEEdee
Próperty	Atténtion	DEEdeedee	deeDEEdee
Ínterval	Translátion	DEEdeedee	deeDEEdee
Entertáin	Depréssion	deedeeDEE	deeDEEdee
Immatúre	Cónfident	deedeeDEE	DEEdeedee
Comprehénd	Énvelope	deedeeDEE	DEEdeedee
Umbréllla	Mótorbike	deeDEEdee	DEEdeedee
Tobácco	Ímmigrant	deeDEEdee	DEEdeedee
Invéntion	Córridor	deeDEEdee	DEEdeedee
Admirátion	Priórity	deedeeDEEdee	deeDEEdeedee
Horizóntal	Catástrophe	deedeeDEEdee	deeDEEdeedee
Motivátion	Demócracy	deedeeDEEdee	deeDEEdeedee
Apólogy	Diabétes	deeDEEdeedee	deedeeDEEdee
Philósopher	Exhibítion	deeDEEdeedee	deedeeDEEdee
Ridículous	Conservátion	deeDEEdeedee	deedeeDEEdee

Note: To improve readability, upper case font has been used to indicate the syllable carrying primary stress in the DEEdee primes. Accents are used to indicate primary stress in the target words and real-word control primes.

Appendix F

Table A6.

Words used in the lexical decision task (Experiment 4)

Target Word	Stress Pattern	Spell-Stress	Target Word	Stress Pattern	Spell-Stress
Boutique	Iambic	Reliable	Cadet	Iambic	Unreliable
Cassette	Iambic	Reliable	Canal	Iambic	Unreliable
Cocaine	Iambic	Reliable	Duet	Iambic	Unreliable
Decree	Iambic	Reliable	Guffaw	Iambic	Unreliable
Duress	Iambic	Reliable	Lapel	Iambic	Unreliable
Gazelle	Iambic	Reliable	Cartel	Iambic	Unreliable
Giraffe	Iambic	Reliable	Cigar	Iambic	Unreliable
Shampoo	Iambic	Reliable	Motel	Iambic	Unreliable
Suspense	Iambic	Reliable	Motif	Iambic	Unreliable
Taboo	Iambic	Reliable	Guitar	Iambic	Unreliable
Trustee	Iambic	Reliable	Exam	Iambic	Unreliable
Bamboo	Iambic	Reliable	Fondu	Iambic	Unreliable
Roulette	Iambic	Reliable	Chagrin	Iambic	Unreliable
Distress	Iambic	Reliable	Conform	Iambic	Unreliable
Antique	Iambic	Reliable	Repel	Iambic	Unreliable
Burlesque	Iambic	Reliable	Compel	Iambic	Unreliable
Carton	Trochaic	Reliable	Carcass	Trochaic	Unreliable
Furrow	Trochaic	Reliable	Harness	Trochaic	Unreliable
Bubble	Trochaic	Reliable	Igloo	Trochaic	Unreliable
Impulse	Trochaic	Reliable	Palette	Trochaic	Unreliable
Vermin	Trochaic	Reliable	Migraine	Trochaic	Unreliable
Pellet	Trochaic	Reliable	Levee	Trochaic	Unreliable
Guru	Trochaic	Reliable	Voodoo	Trochaic	Unreliable
Basin	Trochaic	Reliable	Cocoa	Trochaic	Unreliable
Salad	Trochaic	Reliable	Omelette	Trochaic	Unreliable
Falcon	Trochaic	Reliable	Compass	Trochaic	Unreliable
Kettle	Trochaic	Reliable	Bureau	Trochaic	Unreliable
Menu	Trochaic	Reliable	Sheriff	Trochaic	Unreliable
Chorus	Trochaic	Reliable	Tariff	Trochaic	Unreliable
Taxi	Trochaic	Reliable	Famine	Trochaic	Unreliable
Turtle	Trochaic	Reliable	Impasse	Trochaic	Unreliable
Velvet	Trochaic	Reliable	Boycott	Trochaic	Unreliable