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Auditory word identification in dyslexic and normally achieving readers

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Abstract

The integrity of phonological representation/processing in dyslexic children was explored with a gating task in which children listened to successively longer segments (gates) of a word. At each gate, the task was to decide what the entire word was. Responses were scored for overall accuracy as well as the children's sensitivity to coarticulation from the final consonant. As a group, dyslexic children were less able than normally achieving readers to detect coarticulation present in the vowel portion of the word, particularly on the most difficult items, namely those ending in a nasal sound. Hierarchical regression and path analyses indicated that phonological awareness mediated the relation of gating and general language ability to word and pseudoword reading ability.

Keyword: Auditory word identification

Introduction

Developmental dyslexia is characterized by difficulty with fluency and/or accuracy of reading in the absence of serious intellectual, sensory, emotional, and/or experiential

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impediments to learning (Lyon, 1995). There is a strong consensus in the field that the proximal cause of the disorder involves phonological deficits (Brady, 1997; Fowler, 1991; Snowling, 2000; Stanovich & Siegel, 1994; Wagner & Torgesen, 1987). Phonological deficits are thought to underlie critical components of the reading process such as the learning of spelling–sound correspondences and the development of efficient word recognition (Bruck, 1992; Rack, Snowling, & Olson, 1992; Share, 1995; Stanovich & Siegel, 1994). Phonological deficits may also be causally related to specific kinds of language processing difficulties outside the domain of reading, including poor phonological awareness (Bruck, 1992; Liberman & Shankweiler, 1985; Manis, Custodio, & Szeszulski, 1993; Pratt & Brady, 1988; Swan & Goswami, 1997), inefficient use of verbal working memory (Berninger et al., 2006; Brady, Shankweiler, & Mann, 1983; Griffiths & Snowling, 2002; McDougall, Hulme, Ellis, & Monk, 1994), and slow access to the mental lexicon as manifested in naming tasks (Denckla & Rudel, 1976; Wolf & Bowers, 1999).

Many research studies have explored the relation between phonological awareness and reading disability, yet the underlying cause of these phonological impairments remains ambiguous. Some have argued that poor phonological awareness reflects difficulties in analysis of the sound structure of words, particularly at the level of the phoneme. Such difficulties would lead directly to problems in learning spelling–sound correspondences in alphabetic languages (Liberman & Shankweiler, 1985; Share, 1995). A problem with this approach is that phonological awareness at the level of the phoneme appears not to develop actively until the onset of reading instruction, and it may be heavily influenced by the individual's experience with printed words in alphabetic languages (Morais, Cary, Alegria, & Bertelson, 1979; Perfetti, Beck, Bell, & Hughes, 1987; Ziegler & Goswami, 2005). Others have argued that poor performance on phonological awareness tasks may reflect incomplete or inaccurate phonological representations rather than analytic problems per se (Boada & Pennington, 2006; Elbro, Borstrom, & Petersen, 1998; Fowler, 1991; Snowling & Hulme, 1989; Swan & Goswami, 1997). We term this broad view the *phonological representations hypothesis* (after Swan & Goswami, 1997).

The primary goal of the current study was to investigate the integrity of underlying phonological representations among dyslexic children and normally achieving readers. In addition, we wanted to correlate the quality of phonological representations with phonological awareness and reading ability. Atypical phonological representations, if they do exist in dyslexic children, may be related to subtle problems in perceiving spoken words. Children with a speech perception problem would not succeed in accurate categorization of the phonemes in their language; therefore, they would have difficulty in creating accurate representations for words in long-term memory. However, an isolated phoneme categorization problem alone is unlikely to be the sole explanation for reading problems among dyslexic children. Although several studies have reported categorical speech perception deficits in dyslexics as a group (Chiappe, Chiappe, & Siegel, 2001; Godfrey, Syrdal-Lasky, Millay, & Knox, 1981; Maassen, Groenen, Crul, Assman-Hulsmans, & Gabreëls, 2001; Reed, 1989; Serniclaes, Sprenger-Charolles, Carré, & Demonet, 2001; Werker & Tees, 1987), many individual dyslexics show normal speech perception (Adlard & Hazan, 1998; Joanisse, Manis, Keating, & Seidenberg, 2000; Manis & Keating, 2005; Manis et al., 1997; Pennington, Van Orden, Smith, Green, & Haith, 1990; Ramus et al., 2003).

In Joanisse and colleagues' (2000) and Manis and Keating's (2005) studies, a subset of dyslexics with combined oral language and phonological awareness impairments performed poorly on tests of speech perception, but the remainder of the dyslexic sample did not. Several dyslexic children with the "classic" profile of normal oral language, low phonological awareness, and low nonword reading performed normally on speech perception tasks, and some had better than expected discrimination ability (similar results were reported by Serniclaes et al., 2001), suggesting that their difficulty lies in categorization rather than in more general auditory processing. Thus, it is unlikely that general and extreme problems with speech perception are the cause of any representational problems that children with dyslexia may experience. Their difficulties are more likely to arise from poorly specified long-term representations of phonological entities and/or an impairment in the process of comparing auditory input with long-term representations.

The results of speech perception studies, when examined as a whole, are inconclusive at best. Either only a subset of dyslexics have speech perception difficulties or studies finding null effects used a task that was not sensitive enough. Categorical perception of consonants, a task typically used in speech perception studies, is not very demanding for school-age children and so might not identify subtle speech perception deficits. Thus, there is a need for studies of speech perception using methods that are more sensitive to subtle differences in performance and that are suitable for looking at the processing of the speech signal.

We designed a gating task, modeled after the one by Grosjean (1980) but scored as in Lahiri and Marslen-Wilson (1991), as a more sensitive measure of speech perception in dyslexic readers as compared with normally achieving readers. Gating tasks ask the listener to search his or her entire lexicon for matches to auditory inputs; both the long-term representations and processing must be robust to generate appropriate responses.

In a typical gating task, the listener is presented with successively longer portions of the word (gates) beginning with the onset. At each gate, the listener is asked to guess the entire word. This type of task requires intact and highly integrated phonological representations because participants must use limited acoustic information to identify a word by comparing the acoustic information with many possible stored representations (Salasoo & Pisoni, 1985). Adults require as little as 150 ms of the word (less than half the length of a typical spoken word) to identify highly familiar words (Grosjean, 1980; Salasoo & Pisoni, 1985; Tyler & Wessels, 1985). Children require more acoustic information than do adults (Metsala, 1997a).

The gating task can be used as an index of the overall integrity of phonological representations and/or phonological processing because it does not depend on the ability to use phoneme-level segments to process spoken words, as is the case for certain tests of speech categorization or phonological awareness. Adequate performance on the gating task requires the ability to make comparisons with stored representations of entire words. There is no necessity that either the stored representations or the perceived fragments be encoded as a sequence of segments to perform this task (Griffiths & Snowling, 2001). In addition, gating tasks minimize confounding factors often present in other tests of phonological processing. Because gating tasks require a single untimed response on each trial, they place a minimal load on working memory and on the speed of phonological retrieval, two processes that may be compromised in dyslexic children (e.g., Wagner & Torgesen, 1987; Wolf & Bowers, 1999). Finally, problems with phonological retrieval (e.g., on confrontation naming tasks found in some dyslexic children [Wolf & Bowers, 1999]) are unlikely to interfere with gating performance because the stimulus items typically are very common words. Thus, gating is a task that is appropriate for children, yet it is potentially more sensitive to problems with phonological representations and processing than is categorical perception in that gating places greater demands on lexical access.

Furthermore, we argue that the gating task can be made even more sensitive by scoring responses at a sublexical level, specifically at the level of phonetic features. Coarticulation, which occurs when the articulations associated with different speech segments overlap in time (e.g., Farnetani, 1997; Keating, 2002), facilitates performance on the gating task. Normally developing children as young as 3 years of age (Nittrouer & Studdert-Kennedy, 1987; Repp, 1986) and even prelinguistic infants (Fowler, Best, & McRoberts, 1990) are able to perceive coarticulatory influences in speech sounds. Crucially for our purposes, Warren and Marslen-Wilson (1987) showed that adults can use the effect of anticipatory coarticulation on a vowel to identify spoken words in a gating task. In their study, adults were able to identify the target word at the beginning of the final consonant and, more important, nasal responses were prevalent much earlier in the vowel; this effect was independent of the effect of the frequency of the target word. Coarticulatory nasalization of a vowel is extra redundant information in the signal that listeners are clearly able to use to access lexical representations of nasal consonants. This ability is an indication that long-term lexical representations are specified below the level of the segment—either in terms of features or with full acoustic detail. Edwards, Fourakis, Beckman, and Fox (1999) proposed that some children have "a weak cognitive representation of the redundant perceptual cues for speech sounds" (p. 184) that tasks such as gating can reveal.

Relatively few studies have used the gating paradigm with children (Boada & Pennington, 2006; Dollaghan, 1998; Edwards et al., 1999; Elliot, Hammer, & Evan, 1987; Elliot, Scholl, Grant, & Hammer, 1990; Griffiths & Snowling, 2001; Metsala, 1997a, 1997b; Montgomery, 1999; Walley, 1988; Walley, Michela, & Wood, 1995; Wesseling & Reitsma, 2001). Performance is scored in terms of initial consonant or whole word matching. In general, the findings are that children require more gates (a longer piece of the word) for identification than do adults. For example, Metsala (1997a) assessed gating performance in 7-, 9-, and 11-year-olds as well as in adults. The 7-year-olds required significantly more gates (i.e., more acoustic input) to identify target words, as well as initial phonemes of the target words, when compared with 11-year-olds and adults. Both children and adults required fewer gates to identify high-frequency words and words with a larger number of lexical neighbors (i.e., words that share more phonemic units with the target words in a "dense" lexical neighborhood).

The results were interpreted in terms of the *lexical restructuring hypothesis* (Metsala, 1997a; Metsala & Walley, 1997). According to this view, phonological representations of young children initially are holistic but become more segmentally organized due to the pressure of vocabulary expansion. Eventually, the organization reaches the level of the phoneme. The denser a word's neighborhood, the greater the pressure on the individual to restructure and, therefore, the younger the age at which restructuring should occur. On this view, it must be the case that the adult participants do not have fully segmental representations for words in sparse neighborhoods because adults, as well as children, required more gates to recognize these words. The finding that neighborhood density is facilitative rather than competitive for word recognition runs contrary to the pattern established for other word recognition tasks and is perhaps surprising in terms of models of lexical competition (e.g., Dell & Gordon, 2003). Currently, it appears that the interpretation of neighborhood effects in gating tasks requires further scrutiny.

A small number of gating studies have been conducted with dyslexic children. Metsala (1997b) administered a gating task to younger and older groups of dyslexic and age-matched normal readers (mean ages of approximately 8 and 11 years). Stimuli in that study were grouped based on both frequency and lexical neighborhood density. High-frequency words, especially in sparse lexical neighborhoods, required fewer gates for identification. Furthermore, normally achieving readers needed fewer gates to identify words from sparse neighborhoods than from dense neighborhoods. This result is more in accord with other word recognition studies (neighbors compete rather than facilitate) but is the opposite of the result found by Metsala (1997a) and the opposite of the prediction made by the lexical restructuring hypothesis. Here it would need to be the case that the normal readers had more segmental representations for words in sparse neighborhoods. The result for the dyslexic children was that they needed more gates than did normal readers to identify words in sparse neighborhoods, whereas the groups did not differ in gating performance on words in dense neighborhoods. That is, neighborhood density had no effect on the dyslexic children's performance; they performed like normal readers for words in dense neighborhoods. By itself, this lack of an effect would accord with the restructuring hypothesis—none of the dyslexics' lexicons would have undergone restructuring—except for the fact that the normal readers' performance is in the wrong direction.

Griffiths and Snowling (2001), in contrast, found that not only dyslexic but also normally achieving readers (both groups 8–12 years of age) required the same number of gates to identify words regardless of neighborhood density. The dyslexic sample in Griffiths and Snowling's study showed the commonly observed pattern of deficits in nonword pronunciation and rapid name retrieval. Therefore, their null results could not be attributed to an unrepresentative dyslexic sample. They concluded, contrary to Metsala (1997b), that dyslexic children had segmentally organized phonological representations. They argued, based on null results for the gating task and the presence of rapid name retrieval difficulties, that phonological deficits in dyslexia involve problems in the generation of phonological output rather than the adequacy of phonological representations per se. In sum, the evidence to date on the role of lexical neighborhood density in responses in the gating task, and its implications for the nature of lexical representations, is contradictory. However, it does appear that high-frequency words are recognized with fewer gates, implying that representations are more intact or more easily accessed for highly familiar words.

Boada and Pennington (2006) focused on children's recognition of the initial consonant in a gating task. Children with dyslexia performed worse on this task than did the age-matched, but not the reading level-matched, controls. However, when scored for whole word matching, the children with dyslexia performed worse than did both groups of controls. There were no differences between dyslexic groups with and without broader language impairments.

A methodological issue with the studies by Metsala (1997b), Boada and Pennington (2006), and especially Griffiths and Snowling (2001) is the items themselves. The items chosen have a number of embedded words. For example, the word *weed* contains the word *we*, and the word *fork* contains the word *for.* For such items, a correct whole word response probably would require a late gate because on earlier gates one would have a tendency to guess the shorter word *we* simply because the earlier gate sounds identical to the intact word *we.* It is possible that, for these items, listeners require stronger evidence of anticipatory information to induce them to select the longer response, and the test might lack sensitivity.

One aspect of these studies worth reconsideration is that responses were scored correct only when participants named the exact target word for a given trial. According to this scoring method, if the target word was /kæt/ and a child guessed /kæp/, that answer would be incorrect. However, both words end in a voiceless oral stop consonant. Stop consonants typically have relatively little influence on the articulation of the preceding vowel. The place of articulation difference between /t/ and /p/ is seen only in the formant transitions at the end of the vowel; the effect of their stop manner is likewise seen late in the vowel (in the speed of the first formant transition), and their voicelessness results in a shorter vowel with a different voice quality at its offset. Therefore, these two words sound quite similar until late in the vowel. For a listener to know that the final consonant is a voiceless oral stop (at any place of articulation) already shows sensitivity to a good deal of acoustic phonetic information (Warren & Marslen-Wilson, 1988). Yet an incorrect response is not given partial credit, so to speak, for the strong resemblance of /kaet/ to /kaep/, as opposed to /kaen/ or /kaemp/, which would have substantially nasalized and lengthened vowels. An exact match scoring procedure, therefore, might not be sensitive to subtle differences in listeners' ability to make full use of the acoustic phonetic information available in early portions of words.

The gating procedure used in the current study provided more direct information about the organization of phonological representations in dyslexic and nondyslexic children. We made use of Warren and Marslen-Wilson's (1987) demonstration that listeners are sensitive to nasal coarticulation as well as West's (1999) demonstration that listeners are sensitive to liquid coarticulation. Warren and Marslen-Wilson showed that listeners can detect and use nasalization by the middle of a vowel to anticipate an upcoming nasal consonant. West showed that listeners can detect an /l/ or /r/ a full syllable away, presumably on the basis of large and extensive perturbations in the third formant frequency. For purposes of the current study, therefore, it was reasoned that if normally achieving readers possessed more fully specified phonological representations, they would be able to distinguish between words with nasals (or liquids, e.g., lateral /l/) and other types of words (e.g., with oral stops) at earlier gates than would dyslexics. We had no hypotheses about reader ability group differences between these consonant categories, but we included them all for completeness. We obtained two different scores for responses in the gating task. The first, a category score, was based on whether the child named a word in the correct category (nasal vs. lateral vs. oral stop), as in Lahiri and Marslen-Wilson (1991). For example, if the item was /kaet/, the response /kaep/ would receive a correct score in terms of category, whereas the response /kaen/ would not. Second, a total score was given based on production of an exact match to the target word. In this case, if the target was /kaet/, the only correct response would be /kaet/. We hypothesized that dyslexic children would perform more poorly than normally achieving readers of the same age on both measures, but we expected the category measure to be more sensitive. To our knowledge, our use of a category match score is new in studies of children with or without dyslexia.

Although our primary goal was to explore group differences between dyslexic and nondyslexic children on the gating task, we also investigated individual differences within the dyslexic sample. Two critical dimensions that may be important are the degree of phonological deficit and the degree of language impairment (Gallagher, Frith, & Snowling, 2000; Griffiths & Snowling, 2002; Joanisse et al., 2000; Manis, Seidenberg, Doi, McBride-Chang, & Petersen, 1996; Stanovich, Siegel, & Gottardo, 1997). According to the phonological representations hypothesis, the degree of phonological impairment should be the primary variable affecting gating task performance. We obtained a measure of phonological awareness to explore this alternative.

Performance on the gating task may depend in part on the child's level of language development, with vocabulary perhaps assuming the most important role (Metsala & Walley, 1997; Walley, 1993). We obtained several measures of language ability, including measures of sentence memory, receptive vocabulary, expressive vocabulary, and ability to follow oral directions. In addition to the overall comparison of dyslexic and nondyslexic groups, multiple regression analyses were used to tease apart the relations among gating performance, phonological awareness, language skill, and reading.

Method

Participants

Children were recruited from elementary schools in a major metropolitan area in the state of California in the western United States. The total number of participants was 46 (23 dyslexic children [14 boys and 10 girls] and 23 normally achieving readers [13 boys and 10 girls]). Children ranged in age from 8 to 14 years (dyslexic children: 9–14 years; normally achieving readers: 8–14 years). Years of parental education were similar across groups (dyslexic children: 15.53 years; normally achieving readers: 15.59 years). Ethnic backgrounds (as assessed by parental reports) of the dyslexic children were as follows: 43.5% Caucasian, 17.4% mixed descent, 4.3% Hispanic, and 4.3% Asian (34.8% of parents did not report ethnicity). For the normally achieving readers, the ethnic backgrounds were as follows: 21.7% Caucasian, 21.7% mixed descent, 17.4% Hispanic, 8.7% African American, and 8.7% Asian (21.7% of parents did not report ethnicity). All children were fluent in English, 3 children (in the normally achieving readers group) were fluent in a language other than English, and 4 children (also in the normally achieving readers group) were exposed to another language in their homes but were not fluent in any language other than English.

To be included in the study, participants were required to have a scaled score greater than 7 (corresponding to a standard score of 85) on either the Verbal IQ (average of Vocabulary and Similarities subtests) or the Performance IQ (average of Block Design and Picture Completion subtests) estimate of the Wechsler Intelligence Scale for Children-III (WISC-III) (Wechsler, 1992). This criterion was used to avoid participants who would likely have poor reading ability due to general cognitive impairments while not overly restricting the range of oral language ability within the dyslexic sample. Children were excluded from the study based on the following criteria as determined from parental reports: neurological problems, uncorrected hearing or vision problems, and serious emotional or behavioral problems such as attention deficit hyperactivity disorder (ADHD). According to parental reports, 5 children (4 in the dyslexic children group and 1 in the normally achieving readers group) were currently taking medication for ADHD and were well controlled enough to participate in the testing.

Dyslexic children

Dyslexic children were defined by a score at or below the 25th percentile (standard score = 90) on either of two subtests, Word Identification or Word Attack, of the Woodcock–Johnson Reading Mastery Test–Revised (Form G) (Woodcock, 1987). Both subtests are standardized measures of reading level. Word Identification contains a series of increasingly difficult English words, and Word Attack contains orthographically regular nonwords whose pronunciations are scored based on common spelling–sound correspondence patterns in English. Norms updated in 1993 were used to calculate percentile scores (Woodcock, 1998).

Normally achieving readers

To be classified as a normally achieving reader, children were required to score at or above the 40th percentile on both the Word Identification and Word Attack subtests of the Woodcock–Johnson Reading Mastery Test. All other criteria for inclusion in the sample as a whole applied (e.g., estimated IQ criteria, absence of attention or neurological problems).

Test of phonological abilities

The Elision task from the Comprehensive Test of Phonological Processing (Wagner, Torgesen, & Rashotte, 1999) was administered in the standard format. The Elision task requires children to delete syllables or phonemes from words spoken by the examiner. The test taps mostly phoneme awareness, with only the first 3 items involving syllable deletion. The remaining 17 of the 20 test items involve the deletion of a single phoneme (from the word onset, middle or end, including blends at the beginnings of the words). The test is terminated if the child misses three in a row. The test manual reports Cronbach's alpha reliability of .91 at 10 years of age.

Oral language tasks

Language ability was assessed by means of the following standardized tests: Concepts and Directions and Recalling Sentences subtests from the Clinical Evaluation of Language Fundamentals-Revised (CELF-R) (Semel, Wiig, & Secord, 1995) and the Receptive One-Word Picture Vocabulary Test (ROWPVT) (Brownell, 2000). Concepts and Directions requires children to listen to a short sentence and carry out the action by pointing to black and white geometric forms (e.g., "Point to the small white square after you point to the large triangles"). Recalling Sentences requires children to listen to sentences of varying lengths and repeat each one back verbatim.

Gating task

All test items were monosyllabic English words. Approximately half of the words were low ($M = 116.45$, e.g., cone) and half were high ($M = 2052.45$, e.g., cat) in printed word frequency in a corpus of approximately 5.1 million words (Carroll, Davies, & Richman, 1971). Low and high are relative to the current study; all words were chosen because they were readily available in a third grader's vocabulary (according to Carroll et al., 1971). Groups of words that had CVC or CCVC structures but that differed in their final consonant were constructed, and printed word frequency was matched across these sets of items. The final consonant varied in terms of manner of articulation—nasal, lateral, or oral stop (/kod/). Most of the stimuli were constructed as minimal pairs (e.g., *sweat/swell*), but two sets—*cone/coal/code* and *bone/bowl/boat*—were minimal triples. The effect of neighborhood density on children's word recognition is not clear (Garlock et al., 2001); therefore, stimuli were chosen to have a moderate N (range = 2–19, M = 12.59, SD = 7.42) and neighborhood density was matched across based on final consonant class and frequency (high or low). The nasal items were *clown, cone, rang, dawn, pan, bone, scene*, and *can.* The lateral items were *swell, bowl, coal*, and *feel.* The stop items were *rag, pad, sweat, code, dot, cloud, seat, cat, boat*, and *feet.*

The listener was presented (via headphones) with partial word segments of varying durations and was asked to identify the words. There were a total of 25 words (3 practice items and 22 test items), and each word was divided into six gates. The gates were not of equal durations but rather were keyed to important acoustic properties of the words (Fig. 1) as follows. Gate 1 was just the initial consonant(s) until the beginning of a voiced vowel. This gate was not played in the experiment. Gate 2 added the initial 25 ms of the vowel, that is, most or all of the CV formant transition interval. From this gate, the initial consonant(s) can generally be fully perceived along with partial information about the vowel. It is unlikely that much information about nasality or laterality of the final consonant is available in this gate. Gate 3 gave an additional 25 ms of the vowel and, at 50 ms total, generally included the entire CV formant transition interval. From this gate, the initial consonant(s) plus the vowel ordinarily should be perceived, and some information about the final consonant's manner should already be available. Gate 4 presented the entire vowel *except* its last 25 ms, making the vowel even more likely to be perceived correctly. Nasalization and lateralization of vowels should be quite obvious in Gate 4 and some place of articulation information as well. Gate 5 added the last 25 ms of the vowel, that is, the remaining VC formant transition interval. From this gate, the entire word is likely to be perceived correctly. Gate 6 added the final consonant and, hence, was the full presentation of an intact complete word.

Gates 3 and 4 provide the crucial comparison with respect to anticipatory information about final consonant manner; a listener who is better able to make use of coarticulation

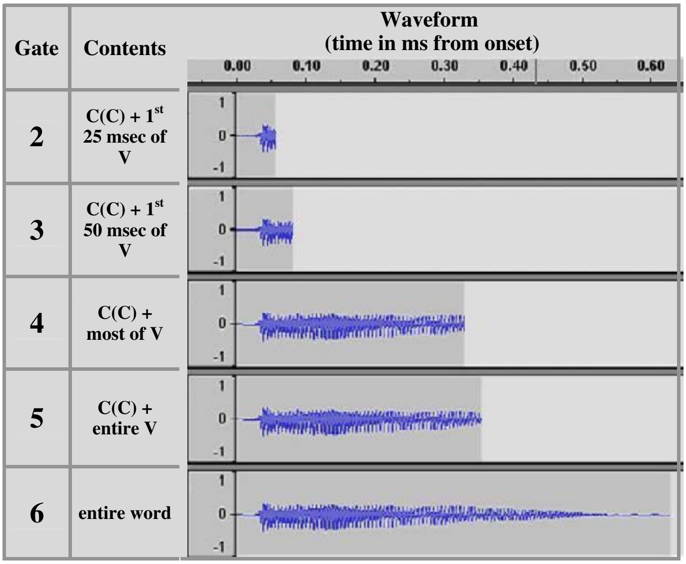

Fig. 1. Waveform representation of Gates 2 to 6 of the word boat. Gate lengths for each word vary due to different lengths of onsets and the like. Amplitude is shown in arbitrary units.

should be able to perceive the consonant manner in Gate 3, whereas other listeners will need the much greater amount of information in Gate 4. Similarly, Gates 4 and 5 provide the crucial comparison with respect to identifying the exact final consonant; Gate 5 provides more of the VC formant transitions that reflect the consonant's place of articulation, but a listener who is better able to make use of more minimal formant transition information should be able to perceive the consonant from Gate 4.

Because the word sets contained different vowels that inherently differ in duration, and because the final consonant affects vowel duration, words differed in their total vowel durations within and across sets, but no one class (stop, lateral, or nasal) was significantly different from another by analysis of variance (ANOVA) test. The durations of Gates 4 and 5 were very similar across words with final nasals, laterals, and orals; they were particularly closely matched for final nasals versus laterals. Gate 6, the original complete recording of each word, varied in duration as a function of the final consonant durations. In contrast, Gates 1 to 3 differed in duration as a function of their initial consonant durations because Gate 1 was just the consonant(s), Gate 2 was the consonant(s) plus 25 ms, and Gate 3 was the consonant(s) plus 50 ms. As a result of initial consonant differences, Gate 3 for the nasal-final words happened to be much shorter in total duration (including the consonant). Total length of the words did not differ significantly as a function of item class.

For the practice trials, each of three practice items was played four times (Gates 3–6) to familiarize participants with the gating task. For the experimental trials, the presentation of the 22 test items was duration blocked (as in Walley et al., 1995), where each successive block contained only one duration of gate. Presentation began with Gate 2. Gate 1 was not used because pilot testing determined that children were not able to guess the correct word or category of the ending sound (nasal, lateral, or stop) based on such limited acoustic information, and many children said that they heard only a piece of static and, therefore, refused to guess the word. Order of items was randomized within each block. All five blocks corresponding to Gates 2 to 6 were presented. Responses were recorded via audiocassette for later transcription by linguistics students with phonetic training.

Children were encouraged to guess for each item regardless of confidence level. If a child refused to give a response at a particular gate, the response was removed from subsequent analyses. No feedback was given at any time except during administration of the practice items. One concern with gating tasks in the study of children in general, and of dyslexia in particular, is that children with higher verbal ability may perform better because they are better at guessing words from partial information. Although this is indeed a limitation of gating tasks, it is less of a problem with the current design for two reasons. First, all items were of relatively high frequency. Second, the categorical scoring method reduces the accuracy with which children need to guess. If children detect nasalization, for example, they are given credit for "being in the ballpark" (i.e., guessing a word ending in a nasal).

The set of words was recorded by a female who was selected because her pronunciations were typical of Californian speakers. The recording was made in a sound booth to DAT, which was then transferred to a computer disk and edited using Praat (Boersma & Weenink, 2002). The stimuli were presented using software written in MATLAB 7 (MathWorks, Natick, MA, USA) and are available for download from the following website: www.linguistics.ucla.edu/people/keating/dyslexia/dysweb2.htm. Gates were produced by cutting at zero crossings, but the amplitude of the end of the gate was not ramped. Because gates were cut at zero crossings, the nominal 25-ms increments between gates could not be exact but rather were to the closest zero crossing. Amplitudes were not normalized during the experiment, but the recorded levels of the items were similar.

Gating task scoring

One dependent measure for the gating task, *category score*, was the first gate at which the child was able to name a word that was within the correct category of consonant ending (nasal, lateral, or oral stop) as the target word. For example, if the word was /kon/, responses of /kon/ and /kom/ would be accepted as correct because both words have a nasal consonant following the vowel. A response of /kot/ would be incorrect in this case because /kot/ ends in an oral stop (/t/) and /kon/ ends in a nasal (/n/). The gate at which a child first identified the category of the final consonant correctly was used as his or her score even if the child later changed his or her answer. Analyses by Griffiths and Snowling (2001) supported this last scoring procedure in that they found a similar pattern of results whether counting the first correct response or counting only consistently correct responses. A second dependent measure, *exact match score*, was the first gate at which a participant was able to produce an exact identification of the target word. This measure is the one used in previous gating studies with child listeners. Once again, changes in responses at later gates were ignored in the analyses.

All words were divided into six gates as described in the previous section. Because participants were presented with Gates 2 to 6, the lowest and best possible score for each word was 2. Success at Gate 2, 3, or 4 meant that a subject used anticipatory acoustic information. In general, this was expected to be very unlikely for Gate 2 and quite likely for Gate 4. If a child never identified a word correctly, a score of 7 was assigned for that word (largest gate plus 1). In such a case, it was assumed that the child would be able to identify the word correctly if it was repeated or presented in context. This part of the scoring method was also used in the two previous gating studies with dyslexic children (Griffiths & Snowling, 2001; Metsala, 1997b). We also report alternative analyses in which participants' responses were excluded from analyses if they made an error in identifying either the category or the exact word on Gate 6 (which represented an intact word).

Reliability (Cronbach's alpha) was calculated for the 22 test items in terms of gating scores for all participants. Cronbach's alpha for category scores was .689. Removing any one of the test items resulted in a minor shift in Cronbach's alpha (values ranged from .643 to .699 with the removal of any one item). Cronbach's alpha for exact match scores was .795. Again, removing any one of the items resulted in only minor shifts in Cronbach's alpha (values ranged from .773 to .796 with the removal of any one item).

Procedure

Testing was conducted in a quiet room at a university laboratory or at the children's schools. The entire battery of tests was completed in approximately 2 h (including breaks) and took place within a period of time that did not exceed 3 weeks for any given child.

Results

Descriptive data

Mean scores on the standardized tests for dyslexic children and normally achieving readers are shown in Table 1. There was no group difference in general cognitive ability as measured by the Performance IQ estimate of the WISC-III. The mean Verbal IQ estimate of the WISC-III was significantly higher for normally achieving readers than for dyslexic children as a group, $F(1,44) = 17.38, p < .001, \Sigma^2 = .28$. The dyslexic group performed worse on all three language tasks and on the Elision task (for F values, see Table 1).

Gating task group results

The results, shown in Table 2, revealed that children were able to identify the correct category of consonant somewhere between Gates 3 and 4 on average. This means that many children were able to detect the category of consonant prior to the end of the vowel. Fewer gates were required for identification of words ending in stop consonants, followed by words ending in laterals and then words ending in nasals. Exact matches required more

Table 1
Means and standard deviations on standardized tasks for the undifferentiated groups

Measure	Dyslexic children ($n = 23$)		Normally achieving readers ($n = 23$)		F value and sign
	Mean	*SD*	Mean	*SD*	
Age (in months)	142.75	16.13	134.04	17.19	3.13, $p < .05$
Word Identification SS	78.43	8.09	107.04	7.10	162.5, $p < .001$
Word Attack SS	86.83	9.61	107.43	7.73	64.21, $p < .001$
WISC-III Verbal IQ estimate	8.67	2.55	11.52	2.06	17.39, $p < .001$
WISC-III Performance IQ estimate	9.98	2.18	11.09	2.23	2.91
Recalling Sentences SS	6.74	3.39	11.13	2.44	25.47, $p < .001$
ROWPVT SS	97.57	9.64	105.70	12.81	5.92, $p < .05$
Concepts and Directions SS	7.39	3.33	11.39	2.90	18.87, $p < .001$

Note. SS, standard score.

Table 2
Means on the gating measures by group

Measure	Dyslexic children ($n = 23$)		Normally achieving readers ($n = 23$)		F value and sign
	Mean	*SD*	Mean	*SD*	
Mean category score	3.55	0.46	3.23	0.25	8.55, $p < .01$
Category–stops	2.87	0.84	2.79	0.47	0.17
Category–laterals	3.57	0.53	3.22	0.65	3.93, $p = .054$
Category–nasals	4.20	0.55	3.68	0.53	10.93, $p < .005$
Mean exact match	4.70	0.71	4.45	0.47	1.89
Exact–stops	4.35	0.81	4.27	0.60	0.17
Exact–laterals	4.65	0.76	4.47	0.77	0.68

Note. Category score = first gate at which correct identification of consonant category was achieved (maximum score: 7); exact match = first gate at which an exact match to the target word was achieved (maximum score: 7).

gates on average (between Gates 4 and 5) than did category identification (between Gates 3 and 4.) Planned comparisons of the groups on each item type revealed a group difference favoring the normally achieving readers on the word-final nasal category, $F(1,44) = 10.93$, $p < .01$, and a trend on the word-final lateral category, $F(1,44) = 3.93$, $p = .054$. A two-way ANOVA with group and category as the factors revealed a main effect of group, $F(1,44) = 8.55$, $p < .01$. The overall group difference was approximately .3 of a gate. There was also a main effect of category of word ending, $F(1,44) = 7.16$, $p < .002$. Nasal-ending words were significantly more difficult to identify than words ending in a stop consonant (Tukey's procedure, $p < .001$), but laterals were not more difficult than nasals or stops. The interaction of group with category was not significant.

The category score was hypothesized to be a more sensitive measure than the exact match measure used in previous studies. The data bore this out. The exact match measure did not produce significant group differences pooling across stimulus types. When analyzing individual categories, the word-final nasal category was the only one for which dyslexics showed a significant deficit on the exact match measure (approximately .4 of a gate), $F(1,44) = 4.66$, $p < .05$. It is possible that more extreme deficits in the integrity of phonological representation/processing on the gating task would be found only for a subset of dyslexics. Accordingly, we turned to individual differences analyses.

To confirm the validity of stimuli used in the gating task, error rates were examined for identification of each item at Gate 6. No single item was missed by more than one third of the participants. This indicated that there were no problems with the recording or playback of any particular item. Most children made 1 or fewer of these errors. There were 4 children (3 dyslexic children and 1 normally achieving reader) who made 5 or more errors out of 22 items. We reanalyzed the data excluding individual participants' data when an error was made in identifying a word at Gate 6. Excluding errors lowered all of the gating scores slightly (by approximately .1 of a gate for the composite categorization score and approximately .2 of a gate for the composite exact match score). The group comparisons described here remained unchanged. Analyses were repeated, removing children who were bilingual with no significant difference in results.

Correlation and regression analyses

Significant group differences on the gating task support the phonological representations hypothesis; however, the nature of the relations among these variables was not clear. Conducting hierarchical regression analyses allowed us to determine the extent to which gating performance was related to reading ability because of its overlap with phonological awareness or whether there were other factors (e.g., age, language ability, estimated IQ) that mediated the relation between gating and word reading.

Bivariate correlations between the measures are shown in Table 3. Category identification scores were moderately correlated with standard score measures of Word Identification, Word Attack, Performance IQ estimate, Concepts and Directions, ROWPVT, Recalling Sentences, and Elision. The exact match score correlated only with category identification and was excluded from further analyses.

We conducted hierarchical regressions predicting standard scores for Word Identification and Word Attack from the three theoretically important variables in the study—gating category score, composite language ability, and phonological awareness—with age and IQ as control variables (Table 4). We collapsed the Verbal IQ and Performance IQ

Table 3
Correlations between measures

	AGE	WID	WAT	IQ-V	IQ-P	C&D	ROWPVT	RS	ELIS	Category
WID	−.30*									
WAT	−.29*	.90***								
IQ-V	−.12	.56***	.52***							
IQ-P	.01	.42**	.38**	.61***						
C&D	−.12	.61***	.54***	.64***	.54***					
ROWPVT	−.05	.45**	.42**	.73***	.55***	.66***				
RS	−.20	.62***	.63***	.75***	.49***	.73***				
ELIS	−.24	.69***	.70***	.46***	.40**	.59***	.36			
Category	.02	−.36*	−.39**	−.26	−.45**	−.43**	−.33*	−.39**	−.53***	
Exact	−.17	−.16	−.28	−.20	−.17	−.20	−.08	−.24	−.27	.66***

Note. All test data were standard scores. AGE, age (in months); WID, Word Identification; WAT, Word Attack; IQ-V, WISC-III Verbal IQ estimate; IQ-P, WISC-III Performance IQ estimate; C&D, Concepts and Directions; RS, Recalling Sentences; ROWPVT, Receptive One-Word Picture Vocabulary Test; ELIS, Elision; Category, first gate correct category identification was achieved; Exact, first gate an exact match to the target word was achieved.

* $p < .05$.

** $p < .01$.

*** $p < .001$.

Table 4
Hierarchical regression analyses for three criterion variables

Variable	R^2	Change in R^2	Final beta weight
Word Identification			
1. Age (in months)	.090	.050*	−.141
2. Estimated IQ	.381	.291***	.143
3. Language average	.487	.106**	.289
4. Category score	.493	.006	.061
5. Phoneme Elision	.598	.105**	.446**
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4. Phoneme Elision	.596	.109**	.446**
5. Category score	.598	.002	.061
Word Attack			
1. Age (in months)	.085	.085*	−.124
2. Estimated IQ	.320	.235***	.071
3. Language average	.433	.113**	.272
4. Category score	.450	.017	.022
5. Phoneme Elision	.574	.124**	.486***
- - - - - - - - - -	- - - - - - - - - -	- - - - - - - - - -	- - - - - - - - - -
4. Phoneme Elision	.574	.141***	.486***
5. Category score	.574	.000	.022
Phoneme Elision			
1. Age (in months)	.056	.056	.161
2. Estimated IQ	.273	.217***	.068
3. Language average	.381	.108**	.369*
4. Category score	.472	.091*	−.340*

* $p < .05$.

** $p < .01$.

*** $p < .001$.

estimates into a single estimated IQ measure. We entered three variables—age, estimated IQ, and average language score—on the first three steps of the analyses. On the fourth and fifth steps, we entered either category identification score (pooling across item types) first or Elision first to determine the unique contribution of these variables to reading.

Elision accounted for 10.5% and 12.4% of unique variance (i.e., when it was entered last in the equation), but category identification accounted for less than 1% of unique variance in Word Identification or Word Attack scores when entered on the last step. In an additional analysis (not shown in Table 4), we entered only age and the Performance IQ estimate along with the gating measure. The contribution of the gating variable remained significant. This demonstrates that it is some combination of the verbal ability measures (Verbal IQ estimate and average language score) and the phonological awareness measure (Elision) that reduced the contribution of the gating measure to nonsignificance. In other words, the common variance between gating and the reading measures is shared with the verbal ability, language, and phonological measures, but gating performance did not account for unique variance in reading beyond these measures.

The effect of one variable, Elision, in reducing the contribution of gating performance to variability in reading scores was particularly strong. Accordingly, we ran a hierarchical regression (shown in the bottom section of Table 4) controlling for age, average IQ, and average language ability and exploring the contribution of gating to Elision performance. Category score accounted for 9.1% of unique variance in Elision when entered on the fourth step after age, estimated IQ, and average language ability. Composite language ability accounted for 5.7% of the variance in Elision. Age and estimated IQ did not account for unique independent variance in Elision.

The path analysis diagram shown in Fig. 2 summarizes the series of regression analyses. It illustrates a proposed set of relations among the variables. The relations cannot be considered as true causal relations, or even as directional, because the data are not longitudinal.

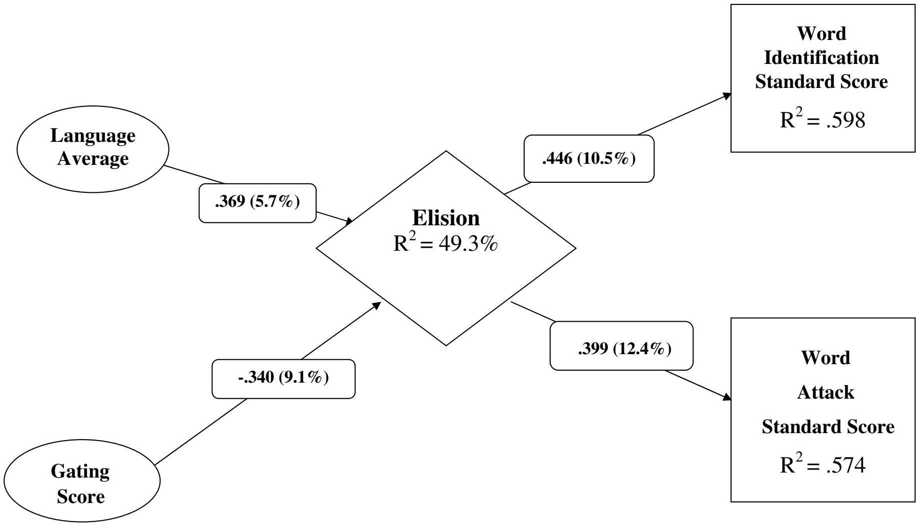

Fig. 2. Path analysis with standardized beta weights and percentages unique variance accounted for in parentheses. Gating score is the mean gate at which a word in the correct category of consonant (stop, lateral, or nasal) was first identified.

The beta weights shown in the diagram represent each variable's unique contribution to the dependent variable to which the arrow points. All relations among variables that were not significant (e.g., between age and phonological awareness, between IQ and reading) are not shown in the diagram. Beta weights for each variable's unique contribution to phonological awareness (Elision) and to reading ability (Word Identification and Word Attack) were obtained by rotating each variable into the final position in the sets of hierarchical regressions discussed previously. These values are shown along with the percentage unique variance accounted for in parentheses. Average language ability and gating category scores made indirect contributions to Word Identification and Word Attack, mediated by their relation with Elision. The overall model accounted for 59.8% of the variance in Word Identification and 57.4% of the variation in Word Attack.

One caution in interpreting the path analyses is that the data were concurrent; hence, one cannot determine the direction of the relation over time. It is possible that prior reading development has an impact on phoneme awareness or gating performance, but this cannot be determined without longitudinal analyses.

Discussion

The purpose of the study was to compare the amount of auditory input necessary to identify spoken words in dyslexic children and normally achieving readers using a gating task. We found that dyslexic children required more gates to generate a word response in the correct category for words ending in nasals, indicating that they were less sensitive to anticipatory coarticulation. There was a statistically nonsignificant trend toward poorer performance by dyslexic children on the laterals. For the exact match measure, commonly used in previous studies, the only significant group difference was on nasals.

In previous work on gating with dyslexic samples, overall group differences were not always observed. Metsala (1997b) found a group difference only for sparse neighborhoods, and Griffiths and Snowling (2001) found no group differences. Boada and Pennington's (2006) groups did differ, both on whole word matching and on initial consonant identification. Our study found an overall group difference for final consonant category identification, but differences were less pronounced for whole word matching.

One direct implication of our data is that measures of anticipatory coarticulation, such as initial consonant identification, may be more sensitive than the whole word matching measures used in previous studies. More important, because of the nature of how listeners represent and process coarticulation, poorer performance by dyslexics on this task implies that their phonological representations for common words are less well integrated than those of normally achieving readers. This finding extends previous results obtained with gating tasks in dyslexic samples (Boada & Pennington, 2006; Griffiths & Snowling, 2001; Metsala, 1997b) and supports the growing literature suggesting that dyslexics have less complete phonological representations of printed words (Elbro et al., 1998; Swan & Goswami, 1997; Wesseling & Reitsma, 2001).

A series of regression analyses was employed as a group (another term for this process is *path analysis*) to provide a more detailed picture of the relations among the variables than could be obtained with subgroup comparisons. The measure of sensitivity to coarticulation (the category score) contributed unique variance to the phonological awareness task, which in turn accounted for unique variability in word and nonsense word reading (Fig. 2). Gating scores did not make direct contributions to the reading tasks after age, estimated

IQ, language ability, and (particularly) phonological awareness were taken into account. The inference is that gating scores made indirect contributions to the reading variables, mediated by phonological awareness. The path analyses revealed a similar pattern of results for a composite language measure consisting of receptive and expressive subtests. Gating and language ability were correlated but made partially independent contributions to phonological awareness.

There are at least two theoretical interpretations of the pattern of group differences and regression findings. First, as we have argued, the gating task may index fundamental qualities of the phonological representation and processing of spoken words. Even subtle deficiencies at this level may interfere with the development of phonological awareness, which in turn interferes with the learning of spelling–sound correspondences and, hence, reading progress in general. This would mean that dyslexic children have separable deficits in phonological representations and in the development of phonological awareness. It is possible that dyslexic children approach the reading task with a deficit in phonological representation or access to these representations (Ziegler & Goswami, 2005) and acquire the phonological awareness deficit in the process of learning to read, partly as a consequence of attempting to apply inadequate phonological representations to the demanding task of learning spelling–sound correspondences. Evidence of early auditory/phonetic processing and speech categorization difficulties in infants at risk for dyslexia has been reported (Leppanen et al., 2002; Molfese, 2000; Richardson, Leppanen, Leiwo, & Lyytinen, 2003).

A second interpretation of our group differences and regression findings is that dyslexic children have intact, and perhaps even high-quality, holistic representations of spoken words but fail to organize their phonological representations at the segmental level, particularly phonemic segments that make lexical access easier (Garlock et al., 2001; Metsala, 1997b). Earlier, we described our reservations about this line of argument—attractive as it may be—due to the range of conflicting findings in the literature concerning neighborhood density effects and the difficulty in interpreting gating as reflecting the segmental nature of lexical representations.

It is important to point out that although there is a general consensus among developmentalists that segmentation of the speech stream into phoneme-sized units is a developmental process, it is somewhat controversial whether normal adult phonological representations are necessarily segmental (Walley, 1993). One view is that such representations arise only under the influence of alphabetic orthography (Morais et al., 1979). On this view, learners of languages with nonalphabetic writing systems, or with no writing system, will generally not form segmental representations. Another view is that segmental representations will arise normally (or "emerge") from the pressure of a crowded lexicon (Walley, 1993). However, some phoneticians, including Browman and Goldstein (1990), have rejected the traditional segment in favor of other kinds of discrete units of representation. Goldsmith's (1976) autosegmental phonology hypothesis states that mature phonological representations are only partly segmental. Derwing and colleagues (1986) provided an overview of arguments for and against the phoneme-sized segment in adult representations. It would be prudent to investigate alternatives to segmental representations in the quest to understand phonological deficits in dyslexia.

One particular finding of this study deserves additional scrutiny. We found that words ending in nasalization were the most difficult items for all participants, regardless of group membership, and that words ending in oral stops were the easiest. That orals should be easiest was unexpected relative to Lahiri and Marslen-Wilson's (1991) study of adults, but it suggests that the children in our study were able to use the nonnasal, nonlateralized quality of vowels as a positive cue about the upcoming consonant. In contrast, the literature provides no a priori expectations about whether nasals or laterals should be the most difficult, and it may well be a function of the particular degrees of nasal versus lateral coarticulation used by a given speaker. In addition, dyslexics as a group showed the most impaired performance on nasals compared with normally achieving readers. This could indicate that phonological representations for words ending in nasalization (or more specifically for nasal phonemes) are particularly impaired among dyslexic children for some reason. Alternatively, nasals were more difficult to identify for both participant groups, suggesting that we simply observed greater group differences on the more demanding task (a measurement characteristic). To distinguish between these two possibilities, dyslexic and nondyslexic readers would need to be tested on a wider range of stimuli, incorporating anticipatory features of pronunciation of equal or greater difficulty compared with nasalization and lateralization. If dyslexics have an overall impairment in phonological representations, it should be present on an appropriate and demanding spoken word perception task.

The study is limited in several respects. First, we did not include reading level-matched younger normal readers, as is often the case in studies of phonological processing in dyslexics. The typical argument for this group is that the task in question (in this case gating performance) might vary as a function of reading experience, as indexed by reading level. A strong test of the hypothesis that the gating deficit is a core deficit in dyslexia would be the observation of differences favoring reading level-matched younger normal readers. However, given the lack of group differences even between chronological age-matched normal readers and dyslexics in some conditions or age levels in past studies (Griffiths & Snowling, 2002; Metsala, 1997b), it was important to first establish that such group differences existed. Our sample had 5 younger normally achieving readers who could be equated to a subset of the dyslexic sample (15 dyslexic children) based on the mean and range of raw scores on the Word Identification subtest; thus, they could serve as a reading level comparison group. When these two groups were compared on the gating task, group differences failed to emerge. However, there are obvious power limitations for such an analysis. Future studies using sensitive measures of spoken word perception will need to include a reading level comparison group.

A second limitation is that the dyslexic children sample did not have the same overall IQ as the normally achieving reader sample, as is often the case in traditional studies of dyslexia. This was due primarily to the fact that we allowed the sample to include dyslexic children with low oral language scores (this tends to deflate the verbal portion of the estimated IQ). Language ability accounted for some variance in Word Identification and Elision scores for the sample as a whole, and it did reduce the contribution of gating to word reading to nonsignificance, even when gating scores were entered at a step prior to Elision in the regression equation (see the top two sections of Table 4). However, language ability did not detract from the relation of gating to Elision. In fact, language ability and gating made independent contributions to Elision scores (Fig. 2). Nevertheless, caution must be observed in generalizing our findings to other dyslexic samples. It is possible that differences would be difficult to observe if only dyslexic children with average oral language ability were tested or, conversely, that differences in gating would be more pronounced in a sample with more severe language impairments.

In conclusion, the use of a gating task enabled us to explore the integrity of phonological representation and processing in dyslexic children by means of a novel method for the dyslexia literature, namely, sensitivity to anticipatory coarticulation. Our more sensitive gating paradigm detected group differences, whereas past studies using the gating paradigm did not find group differences consistently. In addition, we found that gating performance was not directly related to word reading and decoding skills but appeared to be related indirectly through its relation with phonological awareness. The results join the findings of other investigations using different techniques (e.g., Elbro et al., 1998; Swan & Goswami, 1997) in pointing to a basic deficit in phonological representation and processing in dyslexic children.

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References

Adlard, A., & Hazan, V. (1998). Speech perception in children with specific reading difficulties (dyslexia). *Quarterly Journal of Experimental Psychology, 51*, 153–177.

Berninger, V. W., Abbott, R. D., Thomson, J., Wagner, R., Swanson, H. L., Wijsman, E. M., et al. (2006). Modeling phonological core deficits within a working memory architecture in children and adults with developmental dyslexia. *Scientific Studies of Reading, 10*, 165–198.

Boada, R., & Pennington, B. F. (2006). Deficient implicit phonological representations in children with dyslexia. *Journal of Experimental Child Psychology, 95*, 153–193.

Boersma, P., & Weenink, D. (2002). *Praat: Doing phonetics by computer* (Version 4.3.14) [computer program] [Online]. Retrieved May 26, 2002, from www.praat.org.

Brady, S. A. (1997). Ability to encode phonological representations: An underlying difficulty for poor readers. In B. Blachman (Ed.), *Foundations of reading acquisition and dyslexia: Implications for early intervention* (pp. 21–48). Mahwah, NJ: Lawrence Erlbaum.

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

Browman, C. P., & Goldstein, L. (1990). Representation and reality: Physical systems and phonological structure. *Journal of Phonetics, 18*, 411–424.

Brownell, R. (Ed.). (2000). *Receptive one-word picture vocabulary test* (2nd ed.). Novato, CA: Academic Therapy.

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

Carroll, J. B., Davies, P., & Richman, B. (1971). *Word frequency book*. Boston: American Heritage.

Chiappe, P., Chiappe, D. L., & Siegel, L. S. (2001). Speech perception, lexicality, and reading skill. *Journal of Experimental Child Psychology, 80*, 58–74.

Dell, G. S., & Gordon, J. K. (2003). Neighbors in the lexicon: Friends or foes. In N. O. Schiller & A. S. Meyer (Eds.), *Phonetics and phonology in language comprehension and production: Differences and similarities* (pp. 9–37). Berlin: Mouton de Gruyter.

Denckla, M., & Rudel, R. G. (1976). Rapid "automatized" naming (RAN): Dyslexia differentiated from other learning disabilities. *Neuropsychologia, 14*, 471–479.

Dollaghan, C. A. (1998). Spoken word recognition in children with and without specific language impairment. *Applied Psycholinguistics, 19*, 193–207.

Edwards, J., Fourakis, M., Beckman, M. E., & Fox, R. A. (1999). Characterizing knowledge deficits in phonological disorders. *Journal of Speech and Language and Hearing Research, 42*, 169–186.

Elbro, C., Borstrom, I., & Petersen, D. K. (1998). Predicting dyslexia from kindergarten: The importance of distinctness of phonological representations of lexical items. *Reading Research Quarterly, 33*, 36–57.

Elliot, L. L., Hammer, M. A., & Evan, K. E. (1987). Perception of gated, highly familiar spoken monosyllabic nouns by children, teenagers, and older adults. *Perception & Psychophysics, 42*, 150–157.

Elliot, L. L., Scholl, M. E., Grant, W. K., & Hammer, M. A. (1990). Perception of gated, highly familiar spoken monosyllabic nouns by children with and without learning disabilities. *Journal of Learning Disabilities, 23*, 248–259.

Farnetani, E. (1997). Coarticulation and connected speech processes. In W. J. Hardcastle & J. Laver (Eds.), *The handbook of phonetic sciences* (pp. 371–404). Oxford, UK: Blackwell.

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

Fowler, C. A., Best, C. T., & McRoberts, G. W. (1990). Young infants' perception of liquid coarticulatory influences on following stop consonants. *Perception & Psychophysics, 48*, 559–570.

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

Godfrey, J. J., Syrdal-Lasky, A. K., Millay, K. K., & Knox, C. M. (1981). Performance of dyslexic children on speech perception tests. *Journal of Experimental Child Psychology, 32*, 401–424.

Griffiths, Y. M., & Snowling, M. J. (2001). Auditory word identification and phonological skills in dyslexic and average readers. *Applied Psycholinguistics, 22*, 419–439.

Griffiths, Y. M., & Snowling, M. J. (2002). Predictors of exception word and nonword reading in dyslexic children: The severity hypothesis. *Journal of Educational Psychology, 94*, 34–43.

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

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.

Keating, P. (2002). Coarticulation and timing. *Oxford international encyclopedia of linguistics* (2nd ed.). New York: Oxford University Press.

Lahiri, A., & Marslen-Wilson, W. (1991). The mental representation of lexical form: A phonological approach to the recognition lexicon. *Cognition, 38*, 245–294.

Leppanen, P. H. T., Richardson, U., Pihko, E., Eklund, K. M., Guttorm, T. K., Aro, M., et al. (2002). Brain responses to changes in speech sound durations differ between infants with and without familial risk for dyslexia. *Developmental Neuropsychology, 22*, 407–422.

Liberman, I. Y., & Shankweiler, D. (1985). Phonology and the problems of learning to read and write. *Remedial and Special Education, 6*, 8–17.

Lyon, G. R. (1995). Toward a definition of dyslexia. *Annals of Dyslexia, 45*, 3–27.

Maassen, B., Groenen, P., Crul, T., Assman-Hulsmans, C., & Gabreëls, F. (2001). Identification and discrimination of voicing and place-of-articulation in developmental dyslexia. *Clinical Linguistics and Phonetics, 15*, 319–339.

Manis, F. R., Custodio, R., & Szeszulski, P. A. (1993). Development of phonological and orthographic skill: A 2-year longitudinal study of dyslexic children. *Journal of Experimental Child Psychology, 56*, 64–86.

Manis, F. R., & Keating, P. (2005). Speech perception in dyslexic children with and without language impairments. In H. W. Catts & A. G. Kamhi (Eds.), *The connections between language and reading disabilities* (pp. 77–99). Mahwah, NJ: Lawrence Erlbaum.

Manis, F. R., McBride-Chang, C., Seidenberg, M. S., Keating, P., Doi, L. M., Munson, B., et al. (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 basis of two subtypes of developmental dyslexia. *Cognition, 58*, 157–195.

McDougall, S., Hulme, C., Ellis, A., & Monk, A. (1994). Learning to read: The role of short-term memory and phonological skills. *Journal of Experimental Child Psychology, 58*, 112–133.

Metsala, J. L. (1997a). An examination of word frequency and neighborhood density in the development of spoken word recognition. *Memory & Cognition, 25*, 47–56.

Metsala, J. L. (1997b). Spoken word recognition in reading disabled children. *Journal of Educational Psychology, 89*, 159–169.

Metsala, J. L., & Walley, A. C. (1997). Spoken vocabulary growth and the segmental restructuring of lexical representations: Precursors to phonemic awareness and early reading ability. In J. L. Metsala & L. C. Ehri (Eds.), *Word recognition in beginning literacy* (pp. 89–120). Mahwah, NJ: Lawrence Erlbaum.

Molfese, D. L. (2000). Predicting dyslexia at 8 years of age using neonatal brain responses. *Brain and Language, 72*, 238–245.

Montgomery, J. W. (1999). Recognition of gated words by children with specific language impairment: An examination of lexical mapping. *Journal of Language and Hearing Research, 43*, 735–743.

Morais, J., Cary, L., Alegria, J., & Bertelson, P. (1979). Does awareness of speech as a sequence of phones arise spontaneously? *Cognition, 24*, 323–331.

Nittrouer, S., & Studdert-Kennedy, M. (1987). The role of coarticulatory effects in the perception of fricatives by children and adults. *Journal of Speech and Hearing Research, 30*, 319–329.

Pennington, B. F., Van Orden, G. C., Smith, S. D., Green, P. A., & Haith, M. M. (1990). Phonological processing skills and deficits in adult dyslexics. *Child Development, 61*, 1753–1758.

Perfetti, C. A., Beck, I., Bell, L. C., & Hughes, C. (1987). Phonemic knowledge and learning to read are reciprocal: A longitudinal study of first grade children. *Merrill–Palmer Quarterly, 33*, 283–319.

Pratt, A. C., & Brady, S. (1988). Relation of phonological awareness to reading disability in children and adults. *Journal of Educational Psychology, 80*, 319–323.

Rack, J. P., Snowling, M. J., & Olson, R. K. (1992). The nonword reading deficit in developmental dyslexia: A review. *Reading Research Quarterly, 27*, 29–53.

Ramus, R., Rosen, S., Dakin, S. C., Day, B. L., Castellote, J. M., White, S., et al. (2003). Theories of developmental dyslexia: Insights from a multiple case study of dyslexic adults. *Brain, 126*, 841–865.

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

Repp, B. H. (1986). Some observations on the development of anticipatory coarticulation. *Journal of the Acoustic Society of America, 79*, 1616–1619.

Richardson, U., Leppanen, P. H. T., Leiwo, M., & Lyytinen, H. (2003). Speech perception of infants with high familial risk for dyslexia differ at the age of 6 months. *Developmental Neuropsychology, 23*, 385–397.

Salasoo, A., & Pisoni, D. B. (1985). Interaction of knowledge sources in spoken word identification. *Journal of Memory and Language, 24*, 210–231.

Semel, E., Wiig, E. H., & Secord, W. A. (1995). *Clinical evaluation of language fundamentals-revised*. San Antonio, TX: Psychological Corporation.

Serniclaes, W., Sprenger-Charolles, L., Carré, R., & Demonet, J.-F. (2001). Perceptual discrimination of speech sounds in developmental dyslexia. *Journal of Speech, Language, and Hearing Research, 44*, 384–399.

Share, D. L. (1995). Phonological recoding and self-teaching: Sine qua non of reading acquisition. *Cognition, 55*, 151–218.

Snowling, M. J. (2000). *Dyslexia: A cognitive developmental perspective* (2nd ed.). Oxford, UK: Blackwell.

Snowling, M., & Hulme, C. (1989). A longitudinal study of developmental phonological dyslexia. *Cognitive Neuropsychology, 6*, 653–659.

Stanovich, K. E., & Siegel, L. S. (1994). The phenotypic performance profile of reading-disabled children: A regression-based test of the phonological-core variable-difference model. *Journal of Educational Psychology, 86*, 24–53.

Stanovich, K. E., Siegel, L. S., & Gottardo, A. (1997). Converging evidence for phonological and surface subtypes of reading disability. *Journal of Educational Psychology, 89*, 114–128.

Swan, D., & Goswami, U. (1997). Phonological awareness deficits in developmental dyslexia and the phonological representations hypothesis. *Journal of Experimental Child Psychology, 66*, 18–41.

Tyler, L. K., & Wessels, J. (1985). Is gating an on-line task? Evidence from naming latency data. *Perception & Psychophysics, 34*, 409–420.

Wagner, R. K., Torgesen, J. K., & Rashotte, C. A. (1999). *Comprehensive test of phonological processing*. Austin, TX: Pro-Ed.

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.

Walley, A. C. (1988). Spoken word recognition by children and adults. *Cognitive Development, 3*, 137–165.

Walley, A. C. (1993). The role of vocabulary development in children's spoken word recognition and segmentation ability. *Developmental Review, 13*, 286–350.

Walley, A. C., Michela, V. L., & Wood, D. R. (1995). The gating paradigm: Effects of presentation format on spoken word recognition by children and adults. *Perception & Psychophysics, 57*, 343–351.

Warren, P., & Marslen-Wilson, W. (1987). Continuous uptake of acoustic cues in spoken word recognition. *Perception & Psychophysics, 41*, 262–275.

Warren, P., & Marslen-Wilson, W. (1988). Cues to lexical choice: Discriminating place and voice. *Perception & Psychophysics, 43*, 21–30.

Wechsler, D. A. (1992). *Wechsler intelligence scale for children-III*. San Antonio, TX: Psychological Corporation.

Werker, J., & Tees, R. (1987). Speech perception in severely disabled and average reading children. *Canadian Journal of Psychology, 41*, 48–61.

Wesseling, R., & Reitsma, P. (2001). Preschool phonological representations and development of reading skills. *Annals of Dyslexia, 51*, 203–229.

West, P. (1999). Perception of distributed coarticulatory properties of English /l/ and /r/. *Journal of Phonetics, 27*, 405–426.

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

Woodcock, R. W. (1987). *Woodcock reading mastery test–revised*. Circle Pines, MN: American Guidance Service.

Woodcock, R. W. (1998). *Woodcock reading mastery test–revised–normative update*. Circle Pines, MN: American Guidance Service.

Ziegler, J. C., & Goswami, U. C. (2005). Reading acquisition, developmental dyslexia, and skilled reading across languages: A psycholinguistic grain size theory. *Psychological Bulletin, 131*, 3–29.