Phonology, Decoding, and Lexical Compensation in Vowel Spelling Errors Made by Children with Dyslexia

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Abstract

A descriptive study of vowel spelling errors made by children first diagnosed with dyslexia (n=79) revealed that phonological errors, such as *bet* for *bat*, outnumbered orthographic errors, such as *bate* for *bait*. These errors were more frequent in nonwords than words, suggesting that lexical context helps with vowel spelling. In a second study, children with dyslexia (n=14) performed identically to ability matched normally developing but younger children in a task that measured the ability to identify a spoken target vowel among similarly articulated items. These findings suggest that the high incidence of vowel substitution errors seen in descriptive studies of spelling do indicate difficulty in phoneme perception for dyslexic spellers but difficulty is appropriate for their level of literacy development but not for their age or grade in school.

Phonology, Decoding, and Lexical Compensation in Vowel Spelling Errors Made by Children with Dyslexia

By definition, children with dyslexia experience severe and unexpected difficulty in learning to read and spell, despite adequate intelligence and an average amount of instruction. Converging evidence implicates a deficiency in phonological processing; this is the phonological core deficit hypothesis (Brady, 1997; Frith, 1985; Goswami & Bryant, 1990; Liberman, Rubin, Duques, & Carlisle, 1985; Morris et al., 1998; Ramus, 2001; Siegel, 1998; Stanovich, 1988; Stanovich, 1992). This hypothesis is based on studies that compare the ability to segment, manipulate, and identify phonemes in spoken words by children with dyslexia and age matched controls. For example, Swan and Goswami (1997) found that children with dyslexia performed more poorly than chronological and reading age-matched normally developing readers on tasks that included phoneme identification and counting. Studies also have shown that children with dyslexia perform worse than controls in the identification of spoken consonants (Breier, Gray, Fletcher, Foorman, & Klaas, 2002; Serniclaes, Sprenger-Charolles, Carre, & Demonet, 2001) and tend to mistake some vowels for similarly articulated items (Bertucci, Hook, Haynes, Macaruso, & Bickley, 2001; Ehri, Wilce, & Taylor, 1987; Post, Swank, Hiscock, & Fowler, 1999).

A study by Pennington and Lefly (2001) suggests that the phonological deficits experienced by poor readers are persistent. Children who were identified as being at high risk for reading disability when tested prior to kindergarten entry displayed a deficit relative to not-at-risk children in their performance on a battery of phonological awareness tasks. While both the at-risk and not-at-risk groups showed progress in developing phonological awareness skills, the between group differences remained equally large throughout the three years during which the children were tested. That is, when tested in the summer after second grade, children in the at-risk group displayed difficulties in tasks that include phoneme deletion and a phoneme reversal task that required children to segment words, identify phonemes, and manipulate phonemes.

Studies of spelling have been conducted to determine if the persistent difficulties in phonological awareness experienced by individuals with dyslexia have an impact on the development of spelling. One experimental design that is used to address the question involves comparing the phonetic accuracy of spellings made by children with dyslexia and younger, ability-matched, normally developing children. The phonetic accuracy of spellings is determined with post-hoc judgments. Phonetically accurate errors include responses that are plausible representations of the correct phonemes, such as unnecessary addition of doubled consonants, omissions of silent letters, and alternative spellings of vowels. Phonetically inaccurate errors include responses that could not be taken to represent the phonemes in the target words, such as phoneme omissions, additions, and substitutions. Six studies that have used this type of scoring found no difference in phonetic accuracy of spellings by children with dyslexia and ability matched normally developing younger children (Bourassa & Treiman, 2003; Bradley & Bryant, 1979; Cassar, Treiman, Moats, Pollo, & Kessler, 2005; Moats, 1983; Nelson, 1980; Pennington et al., 1986). These studies confirm that children with dyslexia are poor spellers and also indicate that the phonetic accuracy of their spellings is appropriate for their overall level of literacy development. Some of these studies have also considered another potential reason that children with dyslexia could be generating phonetically accurate spellings of words – through compensating for their deficits in phonemic awareness with word specific knowledge.

Nonword Spelling and the Compensation Hypothesis

According to the *compensation hypothesis* (e.g. Nation & Snowling, 1998) children with dyslexia compensate for phonological deficits by relying on whole-word processing (lexical knowledge). Some studies of reading have supported the compensation hypothesis in children with dyslexia. For example, Elbro (1991) found that children with dyslexia were less accurate in pronouncing nonwords than words, while reading level matched controls were equally accurate on both types of items. Studies that extend this design to spelling involve matching children with dyslexia to younger participants based on equivalent word spelling performance. This comparison addresses the question of whether children with dyslexia achieve phonetically accurate performance in spelling through a different process than normally developing spellers.

Cassar et al. (2005) compared the nonword spelling ability of 25 children with dyslexia, age 11, with 25 normally developing controls performing at the second grade level. Children were matched on their ability to spell real words. There were no differences between the groups in the phonetic accuracy of their nonword spellings. The children with dyslexia had no more trouble than normally developing controls with consonants in clusters, letter name spellings, and reduced vowels in unstressed syllables. A nonword spelling choice test was also included to test the hypothesis that children with dyslexia have relatively well developed knowledge of permissible letter patterns that they use to compensate for poor phonemic awareness and decoding skills. There were also no differences between groups in spelling choice. Children with dyslexia and controls were equally accurate in recognizing allowable vowel and consonant doublets as well as initial and final clusters.

Bourassa and Treiman (2003) also compared the spelling performance of children with dyslexia and spelling-level-matched (with the WRAT) controls. They tested 30 children with dyslexia (average age 11 years) and 30 controls (average age 7 years 5 months) with a dictation spelling test consisting of 10 words and 10 nonwords. The groups did not differ in the ability to accurately represent the phonological structure of words. There was also no effect of group on the orthographic acceptability of their spellings. While word spellings were more accurate than nonword spellings, this lexicality effect did not interact with group, as would have been the case if the children with dyslexia used word specific knowledge to compensate for deficits in phonological awareness. The only difference between the groups was age – the children with dyslexia were 3.5 years older than the controls yet both groups were performing at a second grade level on the spelling subtest of the WRAT. Bourassa and Treiman (2003) concluded that the spelling level match design may not have the leverage to give insights about why children with dyslexia experience persistent spelling problems.

Descriptive Analyses of Spelling Errors

Descriptive analyses of spelling errors are an alternative to ability matched control group designs. The purpose of these studies is to quantify the nature of the phonological processing deficits within a group of children with dyslexia, rather than comparing their performance to an ability-matched control group of normally developing spellers. Moats (1995) performed a descriptive study of spelling errors made by 19 adolescents (16 yr olds) with dyslexia who had spent two or more years at a remedial school where they received intensive instruction in decoding, spelling, and expository writing. The group was heterogeneous with respect to their progress in spelling words on graded lists. Half were characterized as poorer spellers because they had shown little progress in spelling words on graded lists over two years of instruction. The remaining participants were characterized as better spellers because they gained 2.5 grade levels in 2 years of instruction. Moats performed a descriptive analysis of spelling errors these children made in expository writings. Four essays per participant were included, each of which contained an average of 105 words. The spelling error rate ranged from 1% to 26%, with an average of 13% for the five poorest spellers. The spelling error classification system was quite detailed, but overall it divided responses within three categories: orthographic (phonetically accurate) errors, phonetically inaccurate errors, and morphological errors. Errors were pooled within the good and poor speller groups to create response sets that were large enough to yield meaningful insights into performance.

Moats (1995) found that adolescents who experienced persistent difficulty in learning to spell had underlying problems with segmentation and phoneme identification. Specifically, the poorer spellers made more (46%) errors in the combined phonetically and morphophonologically inaccurate categories than better spellers (26%). Misspellings and omissions of sonorant consonants (/l/, /r/, /m/, /n/, /ŋ/) constituted the greatest percentage (24% of errors) of the phonetically inaccurate errors made by the poorer spellers.[1] For instance, they would frequently omit the /n/ in *sink*. The poorer spellers also omitted consonants within clusters and substituted consonants. Vowel errors involved the deletion of stressed vowels (2% of errors), deletion of unstressed vowels (2% of errors), and implausible vowel substitutions (3% of errors). Morphophonological errors included errors on inflected endings (-*s* and –*ed*) and omission of plural /s/.

Orthographic (phonetically accurate) errors constituted a greater proportion (74%) of errors made by the better spellers compared to the poorer spellers (54%). These include the substitution of homophones (buy→by); schwa misspellings (attitude→attatude), letter name spellings (opening→opning), and overgeneralization of silent e (plan→plane). It is unclear whether the higher proportion of orthographic errors made by the better spellers in this study represents an increased incidence of orthographic errors or if the incidence of orthographic errors is comparable across groups and the change in proportion is a result of there being fewer phonetically and morphologically inaccurate errors made by the better spellers (43 total errors = 26% of all errors) than the poorer spellers (289 errors = 46% of all errors). Regardless, this study demonstrated that poor spellers with dyslexia experience persistent problems with segmentation and identification, especially with consonants. However, the pooling of responses to create two groups of individuals precludes any insights about the extent to which the proportions of errors seen for a group generalize to the individuals within the group.

Sawyer, Wade, and Kim (1999) used the error classification system from Moats (1995) in a descriptive analysis of spelling errors made by a younger sample of 100 children with dyslexia. Their ages ranged from 7 to 15 years with an average of 10. Responses from the developmental spelling analysis (DSA: Ganske, 1993) were analyzed. The test was given during children's initial diagnostic testing for dyslexia. The DSA consists of three lists of 25 items. The specific initial list that an individual receives depends on performance on screening list. Additionally, if a participant scores more than 22 out of 25 items correct on the initial list, the next higher list is given. Consequently the study involved a relatively small number of responses made by a relatively large group of participants – 68 participants were tested with only one list (25 items) and 32 were tested with two lists of 25 items (50 items). Errors were pooled across all participants as in the Moats (1995) study in order to create large response sets.

As Moats had observed with older children, Sawyer and colleagues (1999) found that consonant coding errors were frequent, accounting for 32% of total errors. Many of these errors involved liquids and nasals (10% of errors). However, unlike Moats (1995), Sawyer and colleagues observed that children's most frequent errors involved vowels – vowel substitutions constituted 28% of children's responses overall and 40% of their spelling errors. Differences in the source of the spelling data could be a contributing factor to the difference between the results of the Moats (1995) and Sawyer et al. (1999) studies. Moats (1995) analyzed the results of essays while Sawyer et al. (1999) analyzed the results of spelling tests with prescribed sets of items. The results of descriptive analyses could be skewed if children tend to choose words they can spell correctly in essays.

The pattern of errors observed by Sawyer and colleagues (1999) are interesting in that they suggest that difficulty in phoneme perception has an impact on vowel spelling accuracy for children when first diagnosed with dyslexia. The most frequent errors within vowel substitutions were for similarly articulated items, /ɪ/ → /ɛ/ (16.9% of errors), /ʌ/ → /o/ (9% of errors), and /ɛ/ → /ɪ/ (4% of errors). The authors concluded that these three substitutions were likely cases of difficulty in perceiving height of articulation, in that many of the substituted pairs of phonemes neighbored in tongue and jaw position. The concept of neighboring height is illustrated in Figure 1, which is a plot of tongue position in vowel articulation based on Ladefoged (1999). The X axis in this plot refers to whether the tongue is placed towards the front or back of the mouth during articulation and the Y axis refers to the height of the tongue during articulation.

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insert Figure 1 about here

Vowel identification problems in spelling are consistent with errors in spoken word vowel perception that have been demonstrated among poor readers (Bertucci et al., 2001; Ehri, 1987; Post et al., 1999). However, Sawyer and colleagues (1999) could not reach a firm conclusion about the relative incidence of vowel coding difficulties given that the pooling of the data, necessitated by the small number of observations per participant, precluded correlating spelling accuracy with independent tests of phonological awareness and other factors that influence spelling accuracy, which include word knowledge and decoding ability. This sort of analysis requires a larger sample of spellings made by individuals – which is currently possible within the database at the Tennessee center, and is the focus of the current study.

Another limitation of all descriptive studies of spelling errors is that the criteria used to classify responses can change the proportions that are counted as phonetically correct and incorrect. For instance, Treiman (1997) notes that Moats (1983) scored *warm*→*wom* as phonetically incorrect. However, Treiman notes that young children commonly omit liquids. Also, in a descriptive analysis of common spellings in American English, Cummings (1998) lists that /or/ is commonly spelled *or* in words like *porch* and *ar* in words like *warm*. Given these considerations, three out of four phonemes in the “phonetically incorrect” spelling of *warm* as *wom* have been correctly represented. The current study addresses this concern about post-hoc classification schemes for spelling errors by using Cummings’ (1998) comprehensive study of

American English spelling as an objective source for the determination of orthographically valid alternative spellings that are considered to be phonetically accurate.

Summary & Current Study

Moats (1995) performed a descriptive post-hoc classification of spelling errors made by adolescents with dyslexia and found that orthography accounted for more of their errors than phonology. These adolescents had been receiving treatment at a special school for dyslexia, which could account for the phonological accuracy of their spellings. Sawyer et al. (1999) used the same classification scheme with data from younger children, collected when they were first diagnosed with dyslexia, and found that they frequently made phonologically inaccurate vowel substitutions. However, Sawyer et al. (1999) did not quantify and compare the phonologically accurate and inaccurate vowel substitutions made by these younger children. This comparison was done in the current study with a different sample from the same population.

The present study is a detailed analysis of the most common type of spelling error made by children in the study by Sawyer et al. (1999) – vowel substitutions. The children with dyslexia in the current study are drawn from the same population studied by Sawyer et al. (1999). Compared to the sample size in the study by Sawyer et al. (1999), a smaller number of individuals were included but a much larger sample of their spelling performance was analyzed. Both word and nonword spelling data was included from three different dictation spelling tests that are given as part of the diagnostic test battery at the Tennessee Center for the Study and Treatment of Dyslexia. This samples meaningfully large numbers of errors within individuals and avoids the need to pool responses across individuals. Furthermore, obtaining scores for each individual allows for correlations and regressions measuring associations among vowel spelling accuracy and tests of phonological awareness, word knowledge, code knowledge. These analyses are important because they are independent of the post-hoc descriptive categorization of spelling errors and can be used as a check on validity.

To minimize the impact of segmentation difficulties and get a clearer picture of vowel perception, only monosyllabic items were included in this study. Errors were classified with a modified version of the categories from Moats (1995). There were two modifications. One involved using the results of a descriptive study of spelling conducted by Cummings (1988) to precisely define acceptable alternative spellings of vowels. The second modification involved dividing vowel substitution errors to capture substitutions of similarly articulated vowels. For instance, the error category *neighboring height* captures vowel substitutions such as *beat* → *bait*. The phonemes /i/ and /e/ are both front high vowels that are immediately adjacent in height, as seen in Figure 1. The following hypotheses were explored:

Separating Phonology and Orthography. The phonological core deficit hypothesis predicts that phoneme misclassification will have a significant impact on spelling that is independent of orthographic knowledge. The current study involves comparing the rate of phoneme misclassifications that are potentially orthographic (e.g. *lain* for *lane*), alphabetic errors (e.g. letter name spellings like *cr* for *car*), and phonological (e.g. *han* for *hen*) to determine the relative incidence of each type of vowel substitution. Phoneme misclassifications were also separated into categories: those that are similarly articulated (e.g. items neighboring in height as in *han* for *hen*) and those that are not, (e.g. differ from the target by more than one feature, such as height and front/back as in *crusp* for *crisp*). If the results of speech perception studies in which children have difficulty with similarly articulated vowels (Bertucci et al., 2003; Ehri et al., 1987; Post et al., 1999) generalize to spelling, one would expect a high rate of substitution errors for similarly articulated items.

Lexicality Effect. The current study also involves comparing how word knowledge interacts with phonetic, orthographic, and alphabetic errors. The question at stake is the extent to which children with dyslexia use word knowledge to help identify and spell vowels correctly. If the compensation hypothesis is correct, then vowel substitution errors should be more frequent in nonwords than in words. Furthermore, vowel spelling accuracy in words but not nonwords should be significantly correlated with independent measures of word knowledge, such as grade level equivalent scores on the word reading subtest of the Weschler Individual Achievement Test (WIAT, Wechsler, 1992).

Method

Participants

Participants were children (n = 79) who were referred for testing at the Tennessee Center for the Study and Treatment of Dyslexia. Children represented many different schools across the state of Tennessee, with varying instructional approaches, and visited the Center for testing and semi-annual progress monitoring. Following testing, a report was sent to children's schools with recommendations for remedial instruction, which was delivered by the schools. The children were identified as having dyslexia using criteria established by center personnel and validated by Padget, Knight, and Sawyer (1996): Reading comprehension is 8 or more standard score points below listening comprehension. Spelling, word attack, and word recognition are all 15 or more standard score points below listening comprehension and IQ. Phonological awareness and phonological sequencing are well below age level expectations. Participants did not have any documented co-morbid problems such as attention deficit hyperactivity disorder or a speech or language disorder. A summary of age, grade, and diagnostic test scores can be found in Table 1.

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insert Table 1 about here

Materials

The words that children spelled included items on the spelling subtest of the WIAT (Wechsler, 1992), words from the Developmental Spelling Analysis (DSA, Ganske, 1993), and words from the Assessment of Decoding and Encoding Progress Test (ADEPT, Sawyer, 1998). The items taken from these lists include monosyllabic words and nonwords with both long and short vowels with some consonant blends at the beginning and end of the words. For example, the words ranged from *bed* and *clap,* which are short vowel words with no digraphs to more complicated spellings like *bright* or *toast.*

Because the level and amount of testing done in the curriculum based measurements was based on mastery of graded lists, the lists of items that were attempted differed between participants. The entire list of words included in the study consists of 231 items and the number of times each item was attempted ranged from 1 to 78 (M = 36, SD = 24). The nonword list consists of 333 items and the number of times each item was attempted ranged from 1 to 76 (M = 10, SD = 18). When items appeared on multiple tests only the response from the first test given was recorded.

Procedure

Data for the participants was collected during their initial assessment visits to the Tennessee Center for the Study and Treatment of Dyslexia. Each of the dictation spelling tests listed in the materials section was administered similarly. In each test, an examiner said the target word to the child and the child repeated the word aloud. Mispronunciations were corrected. After the child demonstrated that they understood the word to be spelled, they would then spell the word on paper.

Children's spelling attempts were copied to a master list created by the experimenter that also includes a demarcation of the spoken vowel for the items in the International Phonetic Alphabet (IPA, International Phonetic Association, 1999) and the correct spelling for the vowel. The vowels in the spoken items were identified using the same criteria as Kessler and Treiman (2001), which are based on Flexner (1987). These IPA demarcations provided an objective basis for determining what type of vowel sound the word included. Correct spellings of the vowels were scored according to whether the item was spelled as it appeared in the test from which the items originated.

Incorrect spellings were classified in an effort to capture the type of error that resulted in the misspelling. All classifications of errors were done by a single individual. Error categories were mutually exclusive. Ambiguous errors that could count as multiple types were handled through scoring priority. That is, codes were assigned in two waves. Errors were first judged as to whether they could represent the correct phoneme. Any remaining errors that did not receive one of the phonetically correct error codes were judged to receive one of the phonetically incorrect error codes.

Phonetically Correct Codes. These were all cases where it was likely that the spoken vowel was perceived correctly. The following codes were assigned in the first wave of scoring:

Correct. Responses received this code if the vowel was spelled correctly, even if the consonants were spelled incorrectly. For instance, the vowel was considered to be correct in both *bump* → *bump* and *bump* → *bup*. This category also includes three responses in which an additional syllable was added but the vowel in the 'base word' was correct (*slept* → *slepet*, *fed* → *fedet*, *fed* → *feded*).

Orthographically Inappropriate. These responses were alternate spellings of the vowel listed in Cummings (1988). In order to receive this code, the spelling that the children used needed to be a major or minor spelling that was contextually appropriate according to the rules in Cummings. Spellings that appeared in very few items, categorized by Cummings as holdouts, were not counted as orthographically appropriate. For instance, *grain* → *grane* received this error code because /e/ can be spelled with *a & e* in word medial position. The error *done* → *don* received this code because /^/ can be spelled o in VC# strings, as in *son*, *ton*, and *won*. Similarly, *fear* → *fier* received this error code because /i/ can be spelled *ie* in medial position in words like *chief*. However, *boat* → *bout* did not receive this error code because /o/ is only spelled *ou* before *ld* or lt in words like *mould.* Similarly, *cap* → *caup* did not receive this error code because the correspondence of /æ/ to *au* is a holdout that is only present in a few words.

Letter Name. Two types of responses received this error code. One type of error was the omission of a final *e* in an item with a long vowel in which the letter name would result in a phonologically correct response. For instance, *smoke* → *smok* received this error code. The second type of response that received this error code was the omission of a vowel letter in a digraph in which the letter name would result in a phonologically correct response. For instance, *faith*→ *fath* received this error code.

Final e Added. These responses used the correct letter to represent a short vowel but included a final *e* (e.g. *trip* → *tripe*, *flag* → *flage*).

Reversal. These responses include the correct letters to spell a vowel but in the wrong order. (e.g. *girl* → *gril*, *point*→*ponit,* and *two* → *tow*). This error code also includes reversals of orthographically inappropriate alternative spellings, such as *clerk* → *clruk* because these errors also contain letters that validly spell the vowel but in the wrong order.

Phonetically Incorrect Codes. These codes were all cases where it was likely that the vowel had been perceived incorrectly. The following error codes were assigned in the second wave of scoring to errors that did not fit any of the phonetically correct categories:

Neighboring Height. This error code was assigned to incorrect spellings that were valid spellings of vowels that are directly neighboring in height according to the chart of vowel articulation from Ladefoged (1999). For instance, *pan* → *pen* received this code because /æ/ and /ɛ/ directly neighbor in height. The error *pan*

→ *pain* did not receive this code because /æ/ and /e/ are not directly neighboring in height.

Neighboring Place. This error code was assigned to incorrect spellings that were valid spellings of vowels that are directly neighboring in place of articulation (front, central, back) according to the chart of vowel articulation from Ladefoged (1999). For instance, *bet* → *but* received this code because /ɛ/ and /^/ are identical in height but neighbor in place of articulation. The error *bet* → *bit* did not receive this code because /ɛ/ and /I/ are not neighboring articulations.

Non-Neighboring Sound. This error code was assigned to incorrect spellings that were not representations of vowels that are similarly articulated to the target but were orthographically legal in English. For instance, *fast* → *fist* received this code because *i* is a valid spelling of /I/ in word medial position and /I/ is not a neighboring articulation of /æ/ according to the vowel articulation chart from Ladefoged (1999).

Other. This error code was assigned to incorrect spellings that were not orthographically legal in English. For instance, *ear* → *erey* received this error code because *e&ey* was intended to represent /i/ as did *eight* → *eaght* because *eagh* was intended to represent /e/.

Omits vowel. This error code was assigned to incorrect spellings that did not contain a vowel. For instance, *hand* → *hnd* received this code as did *drum* → *drm*.[2]

Results

The 79 children in the sample spelled between 23 and 173 words each (M = 106, SD = 30), for a total of 8,361 observations. Children also spelled between 12 and 195 nonwords each (M = 45, SD = 33), for a total of 3,575 observations. Accuracy for entire words ranged from 21% correct to 83% correct (M = 55%, SD = 13) which was not significantly different than accuracy for entire nonwords, which ranged from 16% correct to 100% correct (M = 53%, SD = 19), $t(78) = 1.365$, $p = .176$. Accuracy for just the vowel in words ranged from 36% to 92% correct (M = 66%, SD = 11) and was significantly lower than accuracy for just the vowels in nonwords, which ranged from 40% correct to 100% correct (M = 71%, SD = 14), $t(78) = -3.332$, $p < .001$.

The 2,754 vowel spelling errors for words and 1,089 vowel spelling errors for nonwords were divided by type and are summarized in Table 2 as a percentage of all responses. The total rate of phonologically correct and incorrect errors, listed in Table 2, was compared across words and nonwords with a repeated measures analysis of variance. Errors constituted a significantly greater proportion of responses in words than nonwords, $F\ (1, 78) = 11.184$, $p < .001$, $MSE = .004$. Phonetically incorrect errors constituted a greater proportion of responses than phonetically correct errors, $F\ (1, 78) = 108.995$, $p < .001$, $MSE = .017$. This effect significantly interacted with word/nonword, $F\ (1, 78) = 93.224$, p < .001, MSE = .003, such that it was larger in nonwords than words. This interaction was explored by first comparing the total phonetically correct and incorrect errors with matched pairs t-tests. These confirm that phonetically correct errors were significantly more common in words than in nonwords while phonetically incorrect errors were significantly more common in nonwords than words.

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insert Table 2 about here

Specific comparisons of each error type within the categories were done with matched pairs *t*-tests and a Bonferroni corrected alpha of .006 to maintain to maintain a family-wise alpha level of .05 across all 9 comparisons. Neighboring height errors constituted a significantly greater proportion of nonword than word responses. In contrast, orthographically inappropriate substitutions, letter name spellings, and non-legal vowel spellings all constituted significantly greater proportions of word than nonword responses.

Correlations and Regressions

Correlations and then regressions were calculated that contrast the extent to which vowel spelling accuracy is associated with a lexical factor (WIAT basic reading) and two non-lexical factors: decoding (word attack) and phonological processing (average score on the LAC manipulation & discrimination tests). In Table 3 both word and nonword vowel accuracy are significantly correlated with word reading accuracy, decoding, and phonological processing. However, measurements of word reading accuracy, word attack, and phonological processing are significantly correlated with each other, indicating that regressions are needed to assess the independent associations between each of these variables and vowel spelling accuracy.

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Regressions, which correct for shared variance, appear in Table 4. Grade in school was entered as a control variable because it shared significant associations with the other variables. In the first regression, vowel spelling accuracy in words served as the dependent variable and there were equally large significant associations with phonological processing (LAC average) and word knowledge (WIAT reading) but not decoding (word attack). In the second regression, vowel spelling accuracy in nonwords served as the dependent variable and there were equally large significant associations with decoding (word attack) and phonological processing (LAC average) but not word knowledge (WIAT reading).

Discussion

There are two open questions at the end of the first study. First is whether the significant association between word knowledge and vowel spelling accuracy in children with dyslexia reflects lexical knowledge improving the identification of ambiguous vowel phonemes when they are spoken. This could be the case given that a large proportion of vowel substitutions are for items neighboring in height, as Sawyer et al. (1999) also observed. However, it could also be the case that the impact of lexical knowledge is restricted to sound-to-print coding. The second question is whether there is lexical compensation in children with dyslexia – is the impact of lexicality in the children with dyslexia larger than in a matched group of younger, normally developing children. These questions were addressed in the second study, which examined the impact of lexicality on the perception of minimally different pairs of spoken vowels in children with dyslexia and matched controls.

Study 2

The second study was an experiment that explored the possibility that the vowel spelling errors observed in the first study were associated with the persistence of a phonological deficit in vowel identification. Fourteen children with dyslexia were compared to a reading level matched control group of younger participants in a timed vowel identification task. The task was designed to be procedurally similar to the dictation spelling tests: participants hear a word or nonword, repeat the item aloud, and then identify its vowel. The only difference with the procedure in the spelling study is that the final step in the dictation spelling tests is to spell the item. In order to measure spoken vowel perception and avoid the influence of letter knowledge, the task was entirely print free. A computer program presented spoken words and nonwords and participants identified the vowels in the items by pressing a button that corresponded to pictures on the screen representing the vowel in the target item and a similarly articulated vowel (e.g. does *set* sound like *fish* or *bed*). Items were presented in blocks of trials that contrasted similarly articulated vowels that had been confused in the spelling data (e.g., vowel height in *set* vs. *sit*).

If the spelling errors observed in the first study are caused by the persistence of a phonological deficit, then the children with dyslexia should be less accurate in vowel identification and take significantly longer to respond compared to the reading level matched controls. In contrast, the mapping hypothesis (Harm, McCandliss, & Seidenberg, 2003) predicts minimal effects of diagnosis when children with dyslexia are compared to a reading age matched control group because phonological deficits will have been remediated by the point in development where children's literacy skills are advanced enough to generate enough spellings to have been included the spelling study. As in the spelling study, performance on words and nonwords is compared in order to evaluate the lexical compensation hypothesis (e.g. Nation &

Snowling, 1998), which predicts that the size of nonword deficits in reaction time and accuracy should be larger in the children with dyslexia compared to the reading matched controls.

Method

Participants

The experimental group consisted of 14 children who met the criteria for dyslexia outlined in Experiment 1. A summary of their test scores appears in Table 5. An equally large reading level matched sample was obtained from a local elementary school. Children in the first and second grades were screened with the basic reading subtest of the WIAT and were included if their raw score matched one of the children with dyslexia in the experimental group. Control group participants were only included if they had not been diagnosed with a learning disability and were native speakers of English. Children in the reading level matched control group (M = 6.9, SD = 0.5) were younger than the children with dyslexia (M = 10.4 years, SD = 1.3). They were also in earlier grades (M = 1.4, SD = 0.5) than the children with dyslexia (M = 4.3, SD = 1.8).

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insert Table 5 about here

Children in the control group (*M* = 72.1, *SD* = 12.3) were matched to children with dyslexia (*M* = 73.0, *SD* = 10.8) based on their raw scores on the word identification subtest of the Wechsler Individual Achievement Test-Second Edition (WIAT-II, Wechsler, 2001). If a child participated in this study well after their initial diagnostic visit to the center, the word reading subtest of the WIAT-II was readministered. Raw scores were used because the intent was to match children of similar ability rather than children with similar standing relative to an age-matched normative group, which would have been the case if matching had been done with standard scores.

Materials

Six sets of stimuli were created and appear in the appendix along with filler and practice items. In each set, a pair of vowels was contrasted in items that share the same consonants (e.g. *disk* vs. *desk*). There were 16 items for each vowel, half were CVC words and half were CVC nonwords. Before beginning the task, the participants completed four examples in which they simply identified the concrete object nouns. Next, there were 2 examples of each item for a total of 4 stimuli per set. These stimuli were matched to the two concrete object nouns that serve as the picture choices for each set. For instance, in the *disk/desk* comparison, participants saw pictures of a *fish* and a *bed*. The words and nonwords were constructed to have as little overlap in consonants with the picture items as possible. A man with clear speech carefully spoke the stimuli, which were recorded digitally. The computer program then presented these stimuli through speakers.

In the identification task, the mouse was used to choose the answer on the screen by pressing the left and right buttons. The mouse was used as a two button response box that participants held with one finger on each button. Participants were not required to move a cursor with the mouse and then click before responding because the cursor movement would have impacted the precision of the response time measurement. For this task, there were two choices presented on the computer screen, which can be chosen by the left button for the left picture and the right button for the right picture. The computer recorded the responses of the participants and the amount of time it took them to respond.

Procedure

All participants completed three tasks for each of the six blocks of trials: a picture name practice, a training task, and a vowel identification task. The identification task was designed to closely match the procedure for testing in the dictation spelling tests analyzed in Experiment 1: participants hear a word, repeat the word aloud, and instead of spelling it they classified its vowel in the current experiment. All stimuli and instructions for the sound classification tasks were presented by a personal computer under the control of E-prime software, version 1.4.1 (Schneider, Eschman, & Zuccolotto, 2004). The task was configured so that participants would hear exactly the same recordings, through the same speakers, without visual cues to the speaker's face. Experimenters cued the computer to repeat items after errors rather than speaking themselves. There were six blocks of trials presented in a different random order for each participant. When a vowel was repeated across blocks, it appeared in the same left or right position, so that participants would not suffer from interference from previous learning. Following are the descriptions of the three tasks in each block.

Picture Name Practice. The first task was to ascertain that participants knew the names of the two pictures for the choice test. Recorded spoken instructions from the computer directed them to click the left button for the left picture and the right button for the right picture. The computer then played a spoken recording of the word to be matched with the pictures, which participants then repeated. The response was then coded as correct or incorrect (0 = correct, 1 = C_1 error, 2 = V error, 3 = C_2 error, 4 = word substitute, and 5 = other). If the word was repeated incorrectly, the experimenter coded the mistake by type of error, which made the program repeat the word. Once the word was repeated correctly, the program showed the two object pictures and the participant chose the picture that matched the word they had just spoken. Feedback was given for correct and incorrect responses: a yellow star for correct responses and a red *X* for incorrect responses. There were 2 trials for each picture, for a total of 4 trials in the picture name practice.

The Training Task. Each block continued with trials to practice the shared vowel sound task. For instance, the participants learned to press the left mouse button for words with /ɛ/ and the right mouse button for words with /ɪ/. The computer played a spoken recording of the word to be classified, which participants then repeated. The response was coded as correct or incorrect as discussed in the previous section. If the word was repeated incorrectly, the experimenter coded the mistake by type of error, which made the program repeat the word. Once the word was repeated correctly, the program showed the two object pictures and asked the participant "Which picture shares its vowel with _____)?" Feedback was given for correct and incorrect responses: a yellow star for correct responses and a red *x* for incorrect responses. There were 2 trials for each picture, for a total of 4 trials in the training task. The practice items did not overlap with the stimulus sets. It the child had a difficult time understanding the task or had any questions, the examiner gave further instructions to the child during the picture name practice and during the training task. No feedback or further instructions were given during the vowel identification task itself.

Vowel Identification Task. This task began with spoken instructions for participants, which directed them to choose the picture that shared its vowel or middle sound with the word they heard. The terms vowel and middle sound were used because not all first graders would understand the term vowel at the time of year they were tested. The recording then gave an example for each picture. Next, the computer program administered the item. As in the other two tasks, the child was first asked to repeat the word or nonword, and the response was coded as correct or incorrect. If incorrect, the computer readministered the item until the child either spoke the word correctly or had tried it 5 times. Following the repetition phase, participants chose from the two pictures used in the training phase of the trials, but without the cue "Which picture shares its vowel with _____?" The spoken cue was absent because it could interfere with the judgment task. The pictures were used so that the response did not require reading. Participants identified the vowel by pressing the left or right button on the mouse to correspond to one of two pictures that appeared on the screen. For instance, they saw pictures of a *bed* on the left and a *fish* on the right and learned to hit the left button for /ɛ/ and the right button for /ɪ/. There were 8 trials for each picture, for a total of 16 trials in the vowel identification task for each block of items. Accuracy in choosing the pictures was recorded, as well as reaction time for choosing an answer, and the number of repetitions required to correctly pronounce the word or nonword. If participants could not repeat an item correctly after five trials, the procedure did continue but the computer program recorded the error in repetition.

Results

The first analysis focused on the number of spoken repetitions of each item that were required until the experimenter keyed that the participant pronounced each item correctly. The within participants factors were stimulus set (6 item sets) and lexicality (word/nonword). The between groups factor was diagnosis (children with dyslexia/control). Participants did not require significantly more repetitions of nonwords (*M* = 1.30, *SD* = 0.20) than words (*M* = 1.25, *SD* = 0.20), $F(1, 26) = 3.083$, $p = .091$; this effect did not interact with diagnosis ($F < 1$). There were significant differences in the number of repetitions required across stimulus sets $F(5, 130) = 12.973$, $p < .001$. The effect of set significantly interacted with diagnosis, $F(5, 130) = 20.963$, $p < .001$. This interaction was explored with a series of independent samples *t* tests. The results of these tests are summarized along with the relevant means in Table 6, where it can be seen that children with dyslexia required significantly more presentations before correctly repeating items within three out of the six item sets.

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insert Table 6 about here

Accuracy and reaction time data from the sound classification task, averaged across item sets, appears in Table 7. Accuracy in vowel identification was examined with an analysis of variance identical in design to the repetition analysis. Accuracy for words (*M* = 88%, *SD* = 8) was slightly but not significantly higher than accuracy for nonwords (*M* = 87%, *SD* = 9), $F(1, 26) = 1.627$, $p = .213$. Accuracy significantly differed across sets of items, $F(5, 130) = 20.093$, $p < .001$, but the differences among sets did not interact with lexicality or with diagnosis (*F*s < 1). No other effects approached significance (all *F*s < 1).

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insert Table 7 about here

Mean reaction times for correct responses in vowel identification were examined with a mixed design analysis of variance identical in design to the analyses of repetitions and accuracy. Reaction times significantly differed across sets of items, $F(5, 130) = 6.799$, $p < .001$. The set differences did not interact with any other factors. Reaction times were significantly faster for words ($M = 2{,}274$, $SD = 1{,}063$) than for nonwords ($M = 2{,}552$, $SD = 1{,}214$), $F(1, 26) = 11.332$, $p < .01$. The size of this nonword performance difference was not significantly different in children with dyslexia and controls. There was not an overall difference in reaction times associated with diagnosis.

Discussion

Vowel identification performance in children with dyslexia was compared with a reading level matched control group of normally developing children to explore whether lexicality effects observed in spelling extended to phoneme perception and whether these effects would be larger in children with dyslexia compared to normally developing children. The vowel identification task in the second study was designed to be procedurally as close as possible to the dictation spelling test in the first study. Participants heard a spoken word, repeated the word until the examiner judged it to be pronounced correctly, and then identified its vowel as opposed to spelling the item in the first study.

The only effect of diagnosis was that children with dyslexia required significantly more repetitions than reading matched controls to pronounce items correctly in three of the six item sets. There were no effects of diagnosis on speed or accuracy in the vowel identification task. All participants classified the vowels in words significantly faster than the vowels in nonwords and there were no differences in accuracy. One limitation of this study is that the design only included an ability matched control group and did not include a second group of age-matched controls – hence the two groups differed in the amount of experience. However, the design was sufficient to answer the question at hand in the second study, which was whether the phoneme discrimination ability of children with dyslexia is unusual for their level of literacy development.

General Discussion

In the current study, spelling errors made by children when they were first diagnosed with dyslexia were more strongly associated with phonology than orthography. This is the opposite of what Moats (1995) observed in a descriptive analysis of spelling errors made by older children, adolescents with dyslexia, who had spent two or more years at a remedial school where they received intensive instruction in decoding, spelling, and expository writing. The rate of vowel spelling errors in the current study is dramatic. Children spelled one word in ten with an alternative representation of the correct vowel (e.g. *beat* → *bete*) and one word in five with a phonetically incorrect vowel (e.g. *beat* → *boot*). The beginning spellers in the current study frequently substituted phonemes neighboring in height of articulation, especially in nonwords, suggesting an underlying problem in phoneme identification that could be responsible for some, but not all, of their spelling errors.

Directly testing phoneme identification in words and nonwords in Study 2 revealed that lexicality effects on spoken vowel identification children with dyslexia were no different than in younger, ability matched normally developing children. This outcome is consistent with studies that have found the phonetic accuracy of spelling is identical in children with dyslexia and matched controls (Bourassa & Treiman, 2003; Cassar et al., 2005) and a finding that the way in which beginning spellers use context in learning novel spellings is not related to their ability (Bernstein & Treiman, 2001).

Classification of Vowel Spelling Errors

In the classification of vowel spelling errors, the children with dyslexia who were tested in the first study made significantly more phonetically incorrect errors than phonetically correct errors. The validity of the post-hoc classification of vowel spelling errors is supported by the results of the regressions, which were designed to be independent of the vowel classification data in that the dependent variable was vowels spelled correctly, not the incidence of any of the error classifications. An independent measurement of phonological awareness, the average score on two subsets of the LAC, accounted for significant unique variance in vowel spelling accuracy. This factor was the second largest beta weight in the analysis of word spelling accuracy and the largest in nonword spelling accuracy. These findings suggest that phonology is a critical factor in spelling errors made by young children first diagnosed with dyslexia.

Limitations

One weakness of the post-hoc descriptive analyses is that some categories of responses, such as non-neighboring sound substitutions, may not precisely capture the intended target of vowels that do not sound alike. For example, the errors *hot* → *hate* and *got* → *git* are ideal representations of spelling errors that are not neighboring sounds in that neither /ɑ/ – /e/ or /ɑ/ – /ɪ/ are minimal pairs of phonemes differing in height or of identical height and differing in front/back. However, this simple classification of articulatory similarity fails to account for how vowel articulations can be similar to each other in a multi-dimensional space, especially when dialect shifts reduce the differences between spoken vowels.

An analysis of articulatory patterns conducted by Labov (1996) shows that speakers of English in the southern United States tend to reduce the difference in the articulation of the front vowels /i/, /e/, and /æ/ as well as three back vowels /^/, /ɔ/, and /ɑ/. Therefore, it could be argued that these vowels should be considered neighboring articulations for some speakers and listeners even though they are not minimal pairs differing only in height. Substitution errors for diphthongs are also ambiguous because it could be argued that *spite* → *spot* represents another category of neighboring sound in that /ɑ/ is one of the two sounds that are blended in the diphthong /ɑɪ/. Increasing the complexity of the classification rules could result in greater precision in identifying substitution errors that are associated with phonological factors so that they can be separated from orthographic ones, but is unlikely to eliminate all the ambiguity and subjectivity involved in post-hoc classifications of spelling. A more precise approach was taken in the second study, which tested the lexical compensation hypothesis by measuring phoneme identification directly in a spoken word perception task.

Lexical Compensation & the Phonological Core Deficit Hypothesis

Substitutions of phonetically incorrect vowels were the most frequent spelling error type in the post-hoc descriptive analysis of spelling errors, even when orthographic and alphabetic errors were excluded. Comparison of errors in words and nonwords suggests that the children with dyslexia tested in this study did use lexical knowledge to help with vowel spelling accuracy. The same is not true for overall vowel accuracy, which was higher in nonwords than words. This finding is contradictory – if participants used lexical knowledge to help with vowel spellings in words, why were they significantly more accurate in spelling the vowels in nonwords? It is likely that this effect is an artifact of differences between the word and nonword lists – participants attempted to spell more words than nonwords and these additional word items tended to have more complicated orthography. This interpretation is supported by the results of the regression, in which word knowledge, represented by basic reading subtest scores on the WIAT, made a significant unique contribution to word vowel spelling accuracy but not nonword vowel spelling accuracy. This is the outcome predicted by the lexical compensation hypothesis.

The results of the vowel identification task from the second study suggest that lexicality effects do extend to vowel identification. Participants were significantly faster in identifying the vowels in words than nonwords. However, the equivalent lexicality effects for dyslexics and normals in the vowel perception task does not support the idea that children with dyslexia use lexical knowledge to compensate for poor phoneme perception any more so than normally developing readers.

Response to Intervention

Sawyer and Bernstein (in press) recently completed a study of reading and spelling progress made by a different sample of children from the population tested in the current study. Participation was restricted to 100 children with dyslexia who were diagnosed by the Center and were being given remedial instruction that included direct and systematic coverage of phonemic awareness, decoding, word reading, and spelling by 36 different schools across Tennessee. The Center's role was limited to progress monitoring and providing semi-annual reports to schools that included detailed instructional goals in phonemic awareness, decoding, word reading, spelling, and passage fluency. All children made progress in phonemic awareness, decoding, reading, and spelling, but the integration of skills only happened in children who were identified and served in earlier grades. For children identified in grades one through three, gains in phonemic awareness and decoding were strongly and significantly associated with gains in word reading in spelling. This was not true for children identified in grades four and up, for whom these associations were weak and non-significant.

Conclusions

These findings suggest that the high incidence of vowel substitution errors observed by Sawyer et al. (1999) does indicate some difficulty in phoneme perception. The difficulty in phoneme perception is not unusual for children's level of literacy development. What is unusual is that the children with dyslexia experience persistent difficulty in phonemic awareness at ages and in grades where regular instruction is likely to exclude specific training in phoneme identification. Taken together, these findings suggest that spelling instruction for children with dyslexia, even those in fourth grade and higher, include time devoted to phoneme identification and code knowledge in integrated lessons. However, Sawyer and Bernstein (in press) observed better outcomes for children with dyslexia who were identified and helped beginning in grades one through three than in grades four and up. In conclusion, early identification of dyslexia that is followed by the delivery of direct and systematic instruction in phonemic awareness, decoding, word reading, and spelling can make a difference so that children need not suffer the severe limitations in spelling that are documented in the current study.

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Footnotes

[1] Phonemes are represented using the alphabet of the International Phonetic Association (1999). Conventional spellings are given in italics and pronunciations in IPA symbols surrounded by slash marks. The values of most IPA symbols agree with those of the corresponding English letter, but the following require special attention: /aɪ/ ***ai***sle, /æ/ ***a***pple, /ɑ/ ***o***dd, /dʒ/ *jump*, /e/ ***a***pe, /ɛ/ ***e***dit, /i/ ***ea***t, /ɪ/ h**i**p, /o/ ***oa***t, /ɔ/ d***aw***n, /u/ r***u***de, /ʌ/ ***u***gly, /ʊ/ *put.*

[2] Note that 15 of the 80 vowel omissions could be classified as phonetically correct letter name spellings. These were 7 omissions with *en* as in *bend* → *bnd*, and 8 deletions with *er/ir/ur*, as in *clerk* → *clrk.*

Appendix

Stimuli for the Sound Classification Task

pictures	***fish***	***bed***	***cat***	***bed***	***foot***	***moon***
vowel	ɪ	ɛ	æ	ɛ	U	u
words	pig	peg	gas	guess	stood	stewed
	disk	desk	than	then	pull	pool
	lift	left	lag	leg	would	wooed
	sit	set	man	men	look	luke
	wrist	rest	past	pest	full	fool
filler	rip	hem	tag	mess	hoof	hoop
nonwords	dɪz	dɛz	gæk	gɛk	nUg	nug
	pɪb	pɛb	zæg	zɛg	kUb	kub
	gɪg	gɛg	sæf	sɛf	bUf	buf
	nɪm	nɛm	læn	lɛn	pUk	puk
	kɪp	kɛp	kæz	kɛz	zUd	zud
filler	rɪz	zɛf	jæf	pɛf	bUj	juf
practice	mit	Met	sack	wreck	cook	loop
	zɪb	zɛb	fæp	jɛp	pUj	zuk

Appendix Continued

pictures	***snake***	***leaf***	***sun***	***cat***	***sun***	***fox***
vowel	e	i	ə	æ	ə	ɑ
words	raid	read	tub	tab	luck	lock
	fade	feed	mud	mad	gut	got
	pace	peace	rug	rag	nut	not
	bait	beet	tuck	tack	pup	pop
	cape	keep	lump	lamp	bus	boss
Filler	cave	deep	duck	nap	cub	hop
nonwords	cet	cit	gəf	gæf	zəb	zɑb
	zep	zit	fəp	fæp	nəp	nɑp
	ged	gid	pəz	pæz	ləd	lɑd
	teb	tib	təs	tæs	jəf	jɑf
	jet	jit	məv	mæv	rəz	rɑz
Filler	cez	vig	wəf	væd	wəp	kɑv
practice	made	mean	bug	bad	gum	job
	teg	wig	təd	fæz	kək	gɑk

Table 1

Ages and Screening Test Scores for Participants in Experiment 1

	M	SD	Range
Age (years)	10.0	1.2	7.9 – 12.4
Grade	3.9	1.2	1 – 7
Full Scale IQ (WISC-III or Kbit)	100.8	10.6	78 – 127
WIAT Listening Comprehension			
standard	100.6	11.9	74 – 135
grade equivalent	4.5	1.9	1.3 – 9.4
WIAT Basic Reading Subtest			
standard	79.9	6.9	64 – 109
grade equivalent	2.2	0.9	0.3 – 4.8
WIAT Spelling Subtest			
standard	79.2	7.6	64 – 97
grade equivalent	2.4	0.7	0.7 – 4.3
WIAT Nonword Decoding			
standard	74.6	11.0	47 – 99
grade equivalent	1.8	0.9	0.3 – 7.2
LAC Discrimination (proportion correct)	0.89	0.16	0.00 – 1.00
LAC Manipulation (proportion correct)	0.49	0.23	0.08 – 1.00

Table 2

Vowel Errors by Type as a Percentage of All Responses by Participants

Response Category	*Example*	*Words*	*Nonwords*	*t*
Vowel Correct	beat → beat	66.4 (10.6)	70.9 (13.5)	*** -3.322
Phonetically Correct Errors				
Orthographically Inappropriate	beat → bete	4.6 (2.9)	0.9 (2.3)	‡10.407
Letter Name	wipe → wip	5.1 (3.4)	1.5 (4.5)	‡5.987
Adds final e	beat → beate	2.2 (4.0)	1.3 (2.3)	2.031
Sequence Incorrect	smile → smiel	0.5 (0.8)	0.1 (0.4)	‡3.713
Total Phonetically Correct Errors		12.3 (5.5)	3.8 (6.6)	*** 10.633
Phonetically Incorrect Errors				
Neighboring height	beat → bait	7.8 (0.6)	13.6 (8.4)	‡ -7.640
Neighboring place	beat → boot	0.5 (0.9)	0.8 (1.4)	-1.330
Non-Neighboring Sound	beet → but	9.8 (6.1)	8.7 (7.4)	1.480
Other – not a legal vowel spelling	bait → biyet	2.5 (3.2)	1.4 (2.9)	‡3.131
Omits Vowel	hand → hnd	0.8 (3.8)	0.9 (1.9)	-.233
Total Phonetically Incorrect		21.3 (10.7)	25.3 (12.6)	***-3.749

* $p < .05$

*** $p < .001$

‡ $p < .05$, Bonferroni correction for 9 comparisions, (critical value $p = .006$)

Table 3

Correlations among Screening Test Scores and Vowel Accuracy

	Age	LAC Average	Word Reading Grade	Pword Decode Grade	Word Vowel Accuracy
Age					
LAC Average	.05				
Word Reading	**.48	*.26			
Word Attack	.20	**.34	**.52		
Word Vowel Accuracy	.04	**.41	**.40	**.40	
Nonword Vowel Accuracy	-.13	**.35	.07	**.30	**.52

Table 4

Regressions Predicting Vowel Accuracy

	Response Category	β	*t*	*sig*
Words	Age (years)	-.155	-1.394	.167
	WIAT Reading (grade level)	.316	* 2.476	.016
	Word Attack (grade level)	.171	1.459	.149
	LAC Average	.278	** 2.669	.009
Nonwords	Age (years)	-.162	-1.360	.178
	WIAT Reading (grade level)	-.060	-0.439	.662
	Word Attack (grade level)	.263	* 2.091	.040
	LAC Average	.287	* 2.571	.012
Words –	Age (years)	.045	0.356	.723
Nonwords	WIAT Reading (grade level)	.346	* 2.389	.019
	Word Attack (grade level)	-.144	-1.080	.284
	LAC Average	-.073	-0.648	.519

Table 5

Participant Characteristics for Study 2

	M	SD
Full Scale IQ	99	11
Verbal IQ	97	10
Achievement (std scores)		
Word Reading	73	10
Spelling	79	11
Comprehension	80	12
Pseudoword Reading	79	9
LAC Discrimination (proportion correct)	.90	.07
LAC Manipulation (proportion correct)	.23	.15

Table 6

Presentations Per Item Required Before Correct Repetition in Experiment 2.

	Dyslexic	*Control*	*t*	*p*
/ɛ/ vs. /I/ (bed/fish)	1.10 (0.08)	1.20 (0.24)	-1.509	.143
/u/ vs. /ʊ/ (moon/foot)	1.29 (0.13)	1.20 (0.21)	1.351	.188
/æ/ vs. /ʌ/ (cat/sun)	1.33 (0.14)	1.02 (0.04)	‡ 7.857	.001
/æ/ vs. /ɛ/ (cat/bed)	1.45 (0.18)	1.27 (0.25)	2.149	.041
/e/ vs. /i/ (snake/leaf)	1.52 (0.24)	1.15 (0.22)	‡ 4.247	.001
/ɑ/ vs. /ʌ/ (fox/sun)	1.67 (0.25)	1.06 (0.10)	‡ 8.380	.001

Standard deviations appear in parentheses.

‡ $p < .05$, Bonferroni correction for 6 comparisions, (critical value $p = .008$)

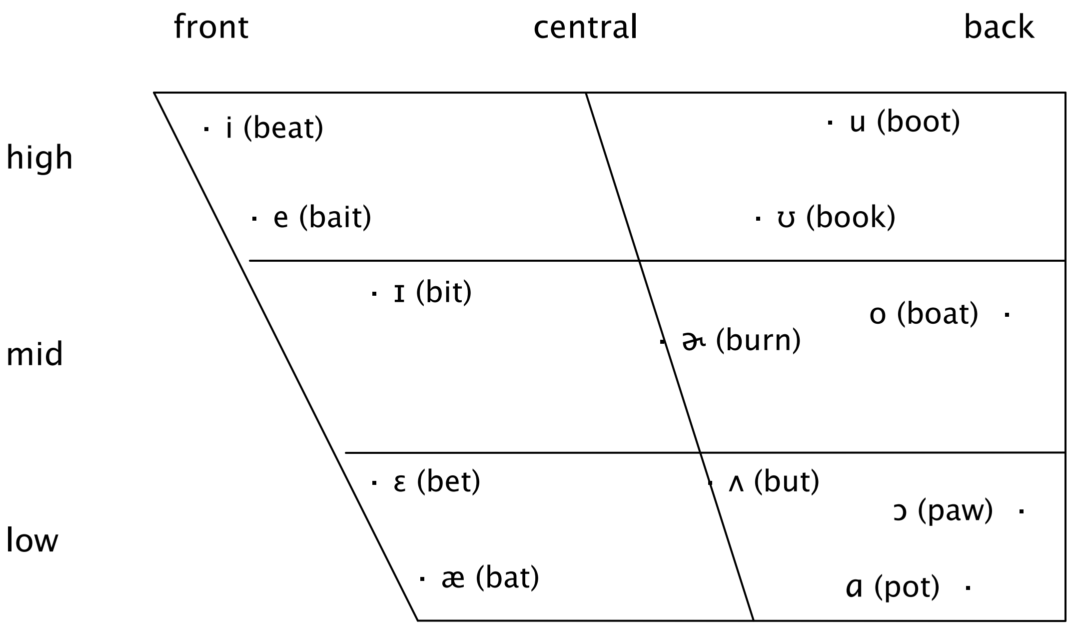
Table 7

Performance on the Sound Identification Task in Experiment 2

	Words			Nonwords		
	Repetition	*Accuracy*	*RT*	*Repetition*	*Accuracy*	*RT*
Dyslexic						
M	1.37	87	1,993	1.42	85	2,180
SD	0.17	10	998	0.15	10	1,003
Nondyslexic						
M	1.13	89	2,555	1.18	88	2,924
SD	0.14	5	1,086	0.16	9	1,326

Figure Captions

Figure 1.Chart of American English Vowels, (adapted from Ladefoged, 1999)


front
central
back
high
mid
low
i (beat)
e (bait)
u (boot)
ʊ (book)
ɪ (bit)
ɚ (burn)
o (boat)
ɛ (bet)
ʌ (but)
ɔ (paw)
æ (bat)
ɑ (pot)