Lexical Access and Phonological Decoding in Adult Dyslexic Subtypes

R. Duncan Milne, Tom Nicholson, and Michael C. Corballis
University of Auckland

Lexical access and phonological decoding were tested in 100 normal adult readers and 21 adult dyslexic individuals. Within the dyslexic sample, 11 dysphonetic dyslexic and 10 dyseidetic dyslexic participants were classified on the basis of spelling patterns. In the 1st experiment, adult dyseidetic readers showed a marked deficit on the lexical-access decision task in comparison with adult dysphonetic readers. In the 2nd experiment, the phonological-decoding decision task did not separate the subtypes. A lexical-access deficit in adult dyseidetic dyslexia cannot be explained in terms of a developmental delay. A phonological-decoding deficit in adult dyseidetic dyslexia may be explained by increased involvement of the lexical procedure in phonological assembly under an analogy strategy.

A considerable amount of research on children with dyslexia has provided evidence of a deficit in phonological awareness (Blanchman, 1997; Bradley & Bryant, 1983; Brady & Shankweiler, 1991; Felton & Brown, 1990; Shankweiler et al., 1995; Torgesen, Wagner, & Rashotte, 1994). Dyslexic children have also shown slower naming speed (Bowers, Steffy, & Swanson, 1988; Lovett, 1992; McBride-Chang & Manis, 1996; Wood & Felton, 1994). Some researchers believe that slow naming speed is associated with the core phonological deficit (Morris et al., 1998), but others have argued that it represents a deficit in itself (Wolf & Bowers, 1999, 2000), or one in lexical retrieval (Allor, Fuchs, & Mathes, 2001). Adult dyslexic individuals have also shown impairments in phonological awareness and rapid naming (Felton, Naylor, & Wood, 1990), and it is likely that these variables reflect genuine impairments, as opposed to some form of developmental delay. It can also be argued that phonological awareness and rapid naming represent distinctly different cognitive components underlying reading (Wolf & Bowers, 1999, 2000), giving rise to different subtypes of adult dyslexia.

Although the heterogeneity of dyslexic populations has supported the separation of dyslexic subtypes, in many cases the evidence has been purely empirical and has lacked theoretical grounding. One theoretical approach comes from models of word recognition. The dual-route theory of reading (Coltheart, 1978; Coltheart, Curtis, Atkins, & Haller, 1993) can explain both developmental and acquired dyslexic patterns. Under this theory, reading is believed to involve two separate reading procedures: a lexical procedure that uses whole-word representations and a sublexical procedure that uses rules of grapheme-to-phoneme conversion. The dual-route theory of reading has been applied to samples of developmental dyslexic children in a quest to separate surface and phonological subtypes. Phonological dyslexic children are characterized by a phonological deficit involving the use of grapheme-to-phoneme conversion or the sublexical procedure. Surface dyslexic children are characterized by an orthographic deficit involving connections between the written word and its location in the orthographic lexicon or lexical procedure.

Castles and Coltheart (1993) classified dyslexic children with surface or phonological characteristics depending on their irregular-word and nonword reading performances. Irregular-word reading is considered dependent on the lexical procedure, whereas nonword reading is considered dependent on the sublexical procedure. In the control sample, chronological age showed positive correlations with nonword and irregular-word reading performances allowing regression-based 90% confidence intervals to be established for defining dyslexic patterns. Of the 53 dyslexic children tested in the Castles and Coltheart study, only 18 fell below confidence limits for either nonword or irregular-word reading, resulting in 10 being classified as surface dyslexics and 8 as phonological dyslexics. Although these subtypes were identified by abnormal performance on one measure and normal performance on the other, further subtype cases were also identified by examining relative performance of one measure as predicted from the other. This allowed for dyslexic children who fell below the confidence limit for both nonword and irregular-word reading to be classified into subtypes, depending on their relative word type performance. The final analysis identified 16 surface dyslexic and 29 phonological dyslexic children accounting for 43 out of the 53 dyslexic children in the sample.

One concern regarding the regression-based procedure introduced by Castles and Coltheart (1993) is the use of

R. Duncan Milne and Michael C. Corballis, Department of Psychology, University of Auckland, Auckland, New Zealand; Tom Nicholson, School of Education, University of Auckland.

Correspondence concerning this article should be addressed to R. Duncan Milne, Smart Kids (United Kingdom), 5 Station Road, Hungerford, Berkshire RG17 0DY, United Kingdom. E-mail: duncan@smartkids.co.uk. After December 2003, correspondence should be addressed to R. Duncan Milne, Department of Psychology, Private Bag 92019, University of Auckland, Auckland, New Zealand. E-mail: rd.milne@auckland.ac.nz

chronological-age control participants for calculating the regression line and confidence intervals, as opposed to reading-level controls. Manis, Seidenberg, Doi, McBride-Chang, and Petersen (1996) used a method similar to that of Castles and Coltheart to identify subgroups with surface and phonological profiles, but instead of testing only chronological-age control participants, they also tested reading-level controls. Although 12 of the 17 phonological dyslexic participants were also accounted for by the reading-level matched regression, only 1 of the 15 surface dyslexic individuals remained classified. Surface dyslexic individuals showed a similar pattern to reading-level matched control participants, a relationship that was not observed for the phonological dyslexic individuals. The phonological classification may represent a specific deficit in phonological processing, in comparison with the surface classification that appears to represent some form of developmental delay (Manis et al., 1996, p. 179).

Irrespective of subtype, dyslexic readers show significantly poorer performance than chronological-age matched controls for both irregular- and nonword reading (Castles & Coltheart, 1993; Castles, Datta, Gayan, & Olson, 1999; Curtin, Manis, & Seidenberg, 2001; Manis et al., 1996; Sprenger-Charolles, Cole, Lacert, & Serniclaes, 2000; Stanovich, Siegel, & Gottardo, 1997). It has been argued that the dual-route model does not explain why both dyslexic subtypes show poorer performance across irregular words and nonwords (Manis et al., 1996) and that a single-route model (see Seidenberg & McClelland, 1989) may explain these effects. According to this model, a single procedure is used to read aloud both irregular words and nonwords. This procedure involves a learning algorithm that places weights based on frequency or exposure to print to generate correct pronunciations. In doing so, the learning algorithm can simulate the reading of both irregular words and nonwords correctly. The model "reads" nonwords through piecing together pronunciations based on previous exposure to real words, providing no specific grapheme-to-phoneme rule mechanism as in the dual-route model. Instead, a single orthography-to-phonology mechanism is used to read all word types. In the case of phonological dyslexia, nonword reading is most affected because of impairment in phonological representation, but regular- and irregular-word reading is also subsequently affected. For the surface dyslexic readers, it is argued that there is a developmental delay limiting the resources of the model. This subsequently has the greatest impact on irregular-word reading, as irregular-word reading is the most sensitive to resource limitation (Seidenberg & McClelland, 1989).

Although the dual-route theory of reading suggests that nonwords are read aloud by a sublexical procedure involving the rules of grapheme-to-phoneme conversion, it has been argued that the process may instead be one of analogy (Glushko, 1979; Marcel, 1980). Under an analogy strategy, visually similar words are accessed lexically and used to help produce the correct pronunciation. Debate over this issue (see Humphreys & Evett, 1985) led eventually to development of a dual-route cascaded model that incorporated feedback from lexical access (Coltheart et al., 1993).

Rather than being a static picture of the mature reading system, connections and feedback loops between the input and output modules of the lexical and sublexical reading procedures make this model computational. The dual-route cascaded model can be applied to previous findings. Surface dyslexic individuals with impairment to the lexical procedure show poor performance for irregular-word reading. Phonological dyslexic individuals with impairment to the sublexical procedure show poor performance for nonword reading. Both dyslexic subtype groups fall significantly below control participants for irregular and nonword reading as impairment to either reading procedure results in poorer performance. The lexical procedure's involvement in nonword reading through analogy explains poorer performance for the surface dyslexic individuals at nonword reading. The sublexical procedure's involvement in acquiring lexical representations explains poorer performance for phonological dyslexic individuals at irregular-word reading.

Dyslexia also involves severe and persistent difficulties in spelling (Curtin et al., 2001; Lennox & Siegel, 1993; Moats, 1983). The Boder typology (Boder, 1973) can be used to classify dyslexic subtypes according to spelling patterns (Flynn, Deering, Goldstein, & Rahbar, 1992; Milne, Hamm, Kirk, & Corballis, 2003). Dysphonetic individuals have difficulty developing phonic word analysis, whereas dyseidetic individuals have difficulty developing sight vocabulary (Boder & Jarrico, 1982, p. 7). This terminology is conceptually consistent with the phonological–surface distinction, as each taps differences in the phonological–orthographic dimension (Share, 1995). Types of spelling errors observed in surface and phonological dyslexia are also empirically consistent with Boder's typology. The misspellings of surface dyslexic individuals, like those of dyseidetic individuals, are comparable with those made by control participants matched for reading-level in terms of phonological accuracy, whereas phonological dyslexic individuals, like dysphonetic individuals, tend to misspell with less phonological accuracy than reading-level matched control participants (Curtin et al., 2001).

The current study examines adult dyslexic participants in terms of the dyseidetic and dysphonetic subtypes, as classified by the Boder Test of Reading and Spelling Patterns (BTRSP). The word classes identified by Castles and Coltheart (1993) and associated with lexical and sublexical procedures are used as stimuli in experimental tasks. The first task is aimed at testing lexical access or the lexical procedure of reading. The second task is aimed at testing phonological decoding or the sublexical procedure of reading.

Method

Participants

Adult dyslexic participants were recruited via learning and disability centers at the University of Auckland ($N = 14$) and the Auckland University of Technology ($N = 9$). The purpose of these centers is to provide special examination conditions for dyslexic students. Dyslexic participants who had been previously assessed with reading disability were then classified by subtype according

to their good phonetic equivalence (GFE) scores on the Unknown Words Spelling subtest of the BTRSP. A misspelling was classed as a GFE if it could be pronounced like the target word by use of grapheme-to-phoneme correspondences. Positional constraints (such as the silent 'e' rule) were considered as phonologically accurate (see Curtin et al., 2001, p. 526). Two trained examiners independently scored the GFEs. Interrater reliability for GFE scoring was .95. To ensure that groups remained pure, 2 participants with mixed subtype classification were not used in the study. There were 10 dyseidetic and 11 dysphonetic participants in the resulting groups. 100 normal readers were selected through advertisements at the universities, on the basis of the following criteria: English as a first language, no history of neurological impairment, and no history of reading disability. Gender, handedness, and age were used as matching criteria to the dyslexic sample. Years of education were determined by the number of years of full-time education normally required to reach the reported final level (e.g., 10th grade = 10 years; 3-year bachelor's degree = 15 years). Individuals with a general university entrance qualification were credited with 12 years (see Coffey, Saxton, Ratcliff, Bryan, & Lucke, 1999). The resulting control sample and dyslexic subsamples showed no significant differences in years of education, age, handedness, or gender (see Table 1).

Materials

Two versions of lexical-decision task were used, each with 100 lowercase items. One identified as a *lexical-access decision task* was presented first. Lexical-decision tasks (see Forster & Bednall, 1976) are believed to measure earlier stages of word processing that contribute to lexical access, whereas same–different judgments and matching tasks are considered to include high-level phonological and semantic processes (Fiebach, Friederici, Muller, & von Cramon, 2002). The lexical-access decision task used here is similar to the usual lexical-decision task (requiring a word–nonword judgment), except that the items are manipulated to demand the lexical procedure. There were 50 irregular words and 50 pseudohomophone nonwords. A pseudohomophone is a nonword that produces a real word pronunciation when decoded phonetically (e.g., *phocks* sounds like the real word *fox*). According to the dual-route model of reading, the discrimination between irregular words and pseudohomophone nonwords requires determination of whether the printed form is or is not represented in the lexicon and is subject to interference from the sublexical reading procedure.

The second task was a *phonological-decoding decision task.* Participants were asked if each presented letter string did or did not sound like a word. There were 50 nonpseudohomophone nonwords and 50 pseudohomophone nonwords. This task has been used previously to examine phonological assembly in dyslexia under functional brain imaging (Milne, Syngeniotis, Jackson, & Corballis, 2002). It is expected to favor the sublexical procedure, as the use of nonwords prevents direct access of the word from sight vocabulary.

Of the 50 irregular words, 30 were drawn from Castles and Coltheart (1993). Additional irregular words were selected through the MRC psycholinguistic database (Coltheart, 1981). All word types were matched on the number of letters and syllables.

Procedure

Participants were seated in front of a computer to perform the experiment. The participants responded on a numerical keypad by pressing either the "1" or the "2" key with the right hand. The experiment included practice trials before both tasks, and feedback was provided to ensure that each participant understood the instructions. For each task, items were presented in random order in the center of the screen. The stimulus was presented for 3,000 ms or until the participant responded. After a response, a cross-hair appeared in the center of the screen for 1,000 ms before the next item was presented. The lexical-access decision task was presented first, followed by the phonological-decoding decision task.

Results

Control Group Performance

The control sample showed 95.6% accuracy for the lexical-access decision task and 92.5% accuracy for the phonological-decoding decision task. Mean response times were faster for the lexical-access decision task (870 ms) than for the phonological-decoding decision task (1,515 ms). Paired sample t tests revealed the lexical-access decision task to have significantly higher accuracy, $t(99) = 6.01$, $p < .01$, and faster response time, $t(99) = -20.82$, $p < .01$, than the phonological-decoding decision task. Within the lexical-access decision task, responses to irregular words were significantly more accurate than those to pseudohomo-

Table 1
Means and Standard Deviations for the Dyslexic and Comparison Groups: Years of Education, Age, Gender, and Handedness

Variable	Control (n = 100)	Dysphonetic (n = 11)	Dyseidetic (n = 10)	F	p
Education (years)				1.18	.31
M	13.6	13.2	12.8		
SD	1.8	1.3	1.1		
Age (years)				0.12	.89
M	32.3	33.7	31.2		
SD	11.8	11.3	11.1		
Gender				0.05	.95
Female	36	2	3		
Male	64	9	7		
Handedness				0.20	.82
Left	12	2	1		
Right	88	9	9		

phones, $t(99) = 2.05$, $p < .05$, and also significantly faster, $t(99) = 7.10$, $p < .01$. For the phonological-decoding decision task, responses to nonpseudohomophone nonwords were more accurate, $t(99) = 4.27$, $p < .01$, and faster, $t(99) = 12.94$, $p < .01$, than those to pseudohomophone nonwords.

Control Versus Dyslexic Performance

Normal readers performed the lexical-access decision task with 95.6% accuracy, in comparison with dyseidetic readers with 78.4% accuracy and dysphonetic readers with 91.7% accuracy. One-way analysis of variance (ANOVA), with group as the independent variable, showed that the groups differed significantly, $F(2, 118) = 88.91$, $p < .01$. These relationships are presented in Table 2 and are plotted on Figure 1. Mean response time for normal readers was 870 ms, in comparison with dyseidetic readers with 1,221 ms and dysphonetic readers with 980 ms, again leading to a significant effect of group, $F(2, 118) = 16.60$, $p < .01$. Post-hoc comparisons for the lexical-access decision task showed the normal readers to be significantly more accurate than both the dyseidetic, $t(108) = 12.88$, $p < .01$, and dysphonetic participants, $t(109) = 4.27$, $p < .01$. Normal readers also showed significantly faster response times than both the dyseidetic, $t(108) = -5.61$, $p < .01$, and the dysphonetic participants, $t(109) = -2.02$, $p < .05$.

Accuracy and response time performance for the phonological-decoding decision task is presented in Figure 2. Normal readers performed the phonological-decoding decision task with 92.5% accuracy, in comparison with dyseidetic readers with 77.5% accuracy and dysphonetic readers with 80.6% accuracy. One-way ANOVA again revealed a significant difference between groups, $F(2, 118) = 37.19$, $p < .01$. Normal readers showed a mean response time of 1,515 ms; dysphonetic readers, 1,760 ms; and dyseidetic readers, 1,615 ms. These means did not differ significantly, $F(2, 118) = 2.82$, $p = .06$. Post hoc comparisons for the phonological-decoding decision task showed the normal readers to be significantly more accurate than both the dyseidetic, $t(108) = 7.71$, $p < .01$, and dysphonetic readers, $t(109) = 6.39$, $p < .01$. Normal readers showed significantly faster response times than the dysphonetic participants, $t(109) = -2.24$, $p < .05$, but not the dyseidetic participants, $t(108) = -0.88$, $p = .38$.

Dyslexic Group Performance Within Tasks

In comparing the two subtypes of dyslexia, only the lexical-access decision task showed significant differences. For this task, the dysphonetic sample was significantly more accurate than the dyseidetic sample, $t(19) = 4.23$, $p < .01$, and significantly faster, $t(19) = -2.10$, $p < .05$. Dysphonetic participants performed with significantly higher accuracy for both irregular words, $t(19) = 2.75$, $p < .05$, and pseudohomophones, $t(19) = 3.88$, $p < .01$. Two-way ANOVA, with dyslexic subtype as a between-subjects variable and irregular words versus pseudohomophones as a within-subjects variable, showed no significant interaction between these variables, $F(1, 19) = 1.29$, $p = .27$. The phonological-decoding decision task failed to differentiate significantly between the dyslexic subtypes on either accuracy, $t(19) = 0.62$, $p = .54$, or response time, $t(19) = 1.20$, $p = .24$.

Discussion

The results of this study show adult dyseidetic and dysphonetic subtypes of dyslexia performing significantly below normal readers for both lexical-access and phonological-decoding decision tasks. Similar results were reported in dyslexic children who had been classified into dyslexic subtype groups based on performance variability measures (Castles & Coltheart, 1993; Castles et al., 1999; Curtin et al., 2001; Manis et al., 1996; Sprenger-Charolles et al., 2000; Stanovich et al., 1997). For the lexical-access decision task, both dyslexic subtypes performed significantly below control participants, but dyseidetic participants performed significantly below dysphonetic participants, and as Figure 1 shows, there was little overlap between these two groups.

This finding is consistent with the dual-route model. Dysphonetic readers have relative strength in the lexical procedure providing better access to the irregular words from sight vocabulary. They also show a relative weakness in the sublexical procedure, implying less interference from incorrectly decoding pseudohomophones as real words and irregular words as nonwords. The dysphonetic group's lower performance relative to normal readers suggests that the two reading procedures are not completely independent. In the case of dysphonetic dyslexia, according to the dual-

Table 2

Means (and Standard Deviations) for Dyslexic and Comparison Groups: Lexical-Access and Phonological-Decoding Decision Tasks

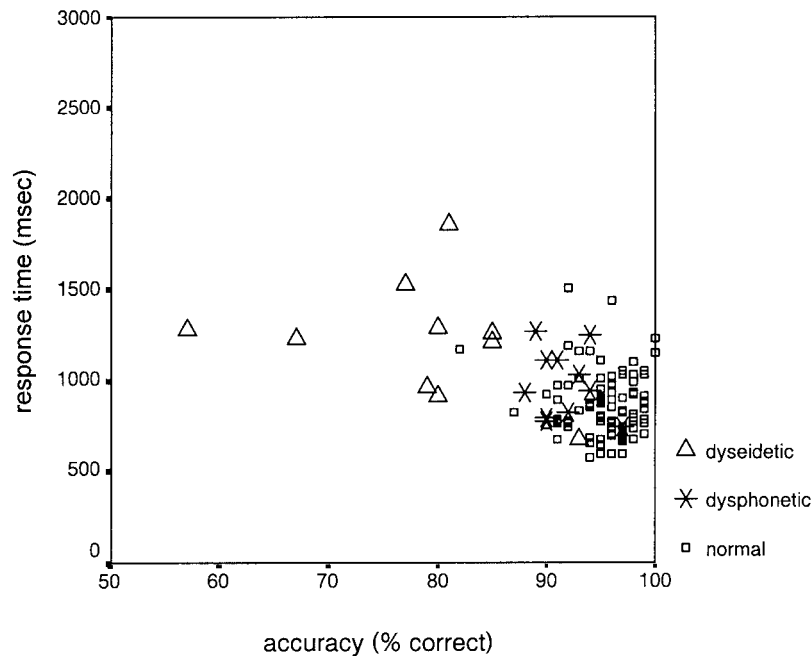| Decision task	Control (n = 100)	Dysphonetic (n = 11)	Dyseidetic (n = 10)	F	p
Lexical access					
% correct	95.6 (2.91)	91.6 (2.66)	78.4 (10.01)	88.9	< .01
M reaction time, ms	870 (171)	980 (188)	1,221 (909)	16.5	< .01
Phonological decoding					
% correct	92.5 (4.96)	80.6 (11.30)	77.5 (11.87)	37.2	< .01
M reaction time, ms	1,515 (348)	1,760 (289)	1,615 (261)	2.8	.06

Figure 1. Response time plotted against percentage correct for the lexical-access decision task. Normal readers show higher accuracy and faster response times for the lexical-access decision task in comparison with the dyslexic subtypes. Between the dyslexic subtypes, dyseidetic readers showed lower accuracy and slower response times for the lexical-access decision task in comparison with dysphonetic readers. msec = millisecond.

route model, impairment to the sublexical procedure should not reduce lexical-access decision-task accuracy. However, the sublexical procedure's role in introducing words to sight vocabulary may explain this finding (Coltheart & Leahy, 1996). Any impairment to the sublexical procedure inhibits sight vocabulary development, resulting in reduced lexical representations and subsequently poorer performance on the lexical-access decision task. A similar explanation is provided under the single-route model. Impairment in phonological representation is believed to affect the acquisition of lexical word-forms in phonological dyslexia (Manis et al., 1996, p. 188).

For the phonological-decoding decision task, the dyslexic groups performed below normal readers, but did not differ significantly from each other. Again, an independent dual-route model of reading cannot explain these results, because it would predict that dyseidetic readers would have relatively little difficulty with this task. Phonological assembly may require both reading procedures working interdependently, as explained under the dual-route cascaded model (Coltheart et al., 1993). When reading a nonword, each grapheme can be mapped onto a phoneme and blended to help produce a pronunciation, while visually similar known words can be accessed in the lexicon so that larger syllabic and subsyllabic sounds (that exist within the unknown word) can also be used to produce the pronunciation. In this respect, the phonological-decoding decision task, although tightly dependent on the sublexical reading procedure, may also draw on the lexical procedure for larger unit analysis

under analogy. This could explain why dyseidetic dyslexic participants performed significantly below control participants for the phonological-decoding decision task. Dyseidetic dyslexic individuals have fewer lexical representations of visually similar words, providing weaker support from an analogy.

However, this interpretation does not explain why dyseidetic participants performed at similar levels to dysphonetic dyslexic participants. There are a number of possible reasons why dyseidetic and dysphonetic readers showed similar phonological-decoding performance. First, if one considers that mature reading becomes more dependent on the lexical procedure, it is possible that the lexical procedure becomes more involved in analogous word support during phonological assembly, thus implicating increased phonological-decoding difficulties in adult dyseidetic individuals. Second, the phonological-decoding decision task may require more rapid processing than spelling tests that were not timed. Mean reaction times for the phonological-decoding decision task did not show a significant effect for dyslexia. If dyseidetic readers are slow but accurate decoders, the 3,000-ms presentation may have lead to faster reaction times at the expense of task accuracy. Finally, there are further issues concerning the fixed order of task presentation. As the lexical-access decision task was presented first, dyseidetic participants may have carried over fatigue or frustration effects into the phonological-decoding decision task.
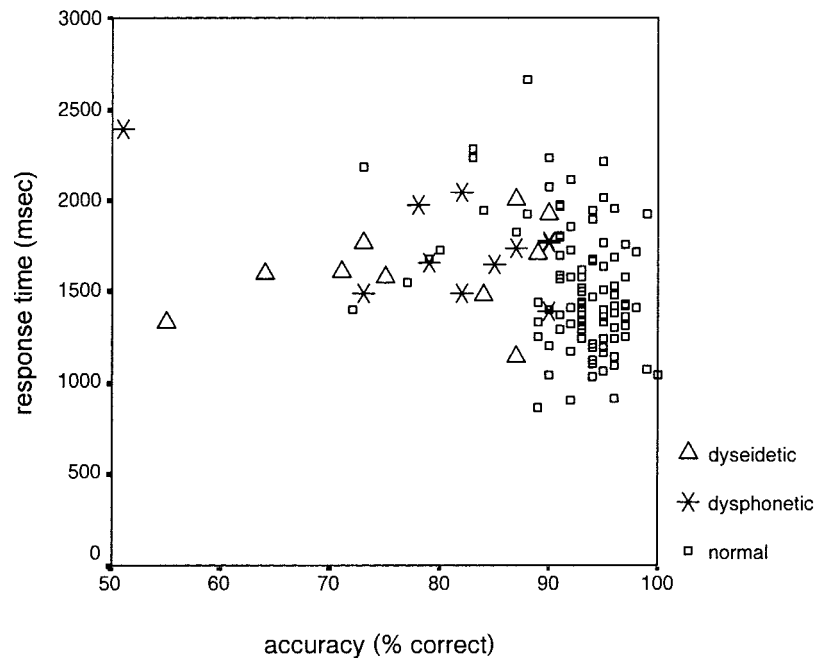
Figure 2. Response time plotted against percentage correct for the phonological-decoding decision task. Normal readers showed higher accuracy for the phonological-decoding decision task in comparison with the dyslexic subtypes. There were no significant differences between the dyslexic subtypes for accuracy or response time performance. msec = millisecond.

Alternatively, the dysphonetic participants could be performing above expectations. A number of functional neuro-imaging studies on dyslexic adults with phonological impairment suggest that right-hemispheric activation, together with overactivation in the inferior frontal gyrus, are associated with phonological compensation (Brunswick, Mc-Crory, Price, Frith, & Frith, 1999; Milne et al., 2002; Pugh et al., 2000; Shaywitz et al., 1997). Phonological compensation may allow dysphonetic adults to perform at a similar level to dyseidetic adults, but below normal adult readers.

We found evidence of dyseidetic dyslexia in an adult sample of dyslexic individuals who were distinguishable from dysphonetic individuals on the lexical-access decision task. Furthermore, almost one half of the sample was classified with dyseidetic dyslexia, a considerably higher rate than observed in children (Flynn et al., 1992). Surface dyslexia has been accounted for as a developmental delay resulting from a general resource limitation within a connectionist network (Manis et al., 1996). As the dyseidetic group in our study are adults, poorer performance and longer response time for the lexical-access decision task cannot easily be attributed to a developmental delay. The lexical-access deficit in dyseidetic dyslexia appears more recognizable at higher levels of reading attainment. In normal reading, the sublexical procedure develops after acquiring the alphabetic principle, whereas the lexical procedure requires considerable print exposure before it learns to process rapidly and efficiently. In this respect, the relative disability of dysphonetic dyslexia may diminish over time, whereas the relative disability of dyseidetic dyslexia may continue to manifest.

For identifying dyslexia, it is possible that dyslexic profiles may vary across development depending on subtype. As the results of this study come from a relatively elite group of dyslexic university students, further research is required on the dyslexic population at large. Adult dyseidetic readers may reveal a more severe pattern of reading disability, despite the fact that they show some spelling skills as measured by their ability to spell some words with phonological accuracy. Psychologists and teachers should continue to administer tests of phonological awareness, phonological memory, and rapid naming, as these skills correlate strongly with dyslexia. However, for those already established as dyslexic, and not just as poor spellers, an examination of spelling patterns for irregular words and unknown words (or nonwords) may be the best way to investigate whether the deficiencies lie in lexical or sublexical reading procedures.

References

Allor, J. H., Fuchs, D., & Mathes, P. G. (2001). Do students with and without lexical retrieval weaknesses respond differently to instruction? *Journal of Learning Disabilities, 34,* 264–275.

Blachman, B. A. (Ed.). (1997). *Foundations of reading acquisition in dyslexia.* Mahwah, NJ: Erlbaum.

Boder, E. (1973). Developmental dyslexia: A diagnostic approach based on three atypical reading–spelling patterns. *Developmental Medicine and Child Neurology, 15,* 663–687.

Boder, E., & Jarrico, S. (1982). *Boder Test of Reading and Spelling Patterns.* New York: Grune & Stratton.

Bowers, P. G., Steffy, R. A., & Swanson, L. B. (1988). Comparison of the effects of IQ controlled methods on memory and naming speed predictors of reading disability. *Reading Research Quarterly, 23,* 304–319.

Bradley, L., & Bryant, P. (1983). Categorizing sounds and learning to read. *Nature, 30,* 419–421.

Brady, S., & Shankweiler, D. (Eds.) (1991). *Phonological processes in literacy: A tribute to Isabelle Y. Liberman.* Hillsdale, NJ: Erlbaum.

Brunswick, N., McCrory, E., Price, C. J., Frith, C. D., & Frith, U. (1999, October). Explicit and implicit processing of words and pseudowords by adult developmental dyslexics: A search for Wernicke's wortschatz? *Brain, 122,* 1901–1917.

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

Castles, A., Datta, H., Gayan, J., & Olson, R. K. (1999). Varieties of developmental reading disorder: Genetic and environmental influences. *Journal of Experimental Child Psychology, 72,* 93–94.

Coffey, C. E., Saxton, J. A., Ratcliff, G., Bryan, R. N., & Lucke, J. F. (1999). Relation of education to brain size in normal aging: Implications for the reserve hypothesis. *Neurology, 53,* 189–196.

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

Coltheart, M. (1981). The MRC psycholinguistic database. *Quarterly Journal of Experimental Psychology. A, Human Experimental Psychology, 33A,* 497–505.

Coltheart, M., Curtis, B., Atkins, P., & Haller, M. (1993). Models of reading aloud: Dual-route and parallel-distributed-processing approaches. *Psychological Review, 100,* 589–608.

Coltheart, M., & Leahy, J. (1996). Assessment of lexical and nonlexical reading abilities in children: Some normative data. *Australian Journal of Psychology, 48,* 136–140.

Curtin, S., Manis, F. R., & Seidenberg, M. S. (2001). Parallels between reading and spelling deficits of two subgroups of developmental dyslexics. *Reading and Writing: An Interdisciplinary Journal, 14,* 515–547.

Felton, R. H., & Brown, I. S. (1990). Phonological processes as predictors of specific reading skills in children at risk of reading failure. *Reading and Writing: An Interdisciplinary Journal, 2,* 39–59.

Felton, R. H., Naylor, C. E., & Wood, F. B. (1990). Neuropsychological profile of adult dyslexics. *Brain and Language, 39,* 485–497.

Fiebach, C. J., Friederici, A. D., Muller, K., & von Cramon, D. Y. (2002). fMRI evidence for dual routes to the mental lexicon in visual word recognition. *Journal of Cognitive Neuroscience, 14,* 11–23.

Flynn, J. M., Deering, W., Goldstein, M., & Rahbar, M. H. (1992). Electrophysiological correlates of dyslexic subtypes. *Journal of Learning Disabilities, 25,* 133–141.

Forster, K. I., & Bednall, E. S. (1976). Terminating and exhaustive search in lexical access. *Memory and Cognition, 4,* 53–61.

Glushko, R. J. (1979). The organization and activation of orthographic knowledge in reading aloud. *Journal of Experimental Psychology: Human Perception and Performance, 5,* 674–691.

Humphreys, G. W., & Evett, L. (1985). Are there independent lexical and non-lexical routes in word processing? An evaluation of the dual route theory of reading. *Behavioural and Brain Sciences, 8,* 689–739.

Lennox, C., & Siegel, L. (1993). Visual and phonological spelling errors in subtypes of children with learning disabilities. *Applied Psycholinguistics, 14,* 473–488.

Lovett, M. (1992). Developmental dyslexia. In F. Boller & J. Grafman (Eds.), *Handbook of neuropsychology* (Vol. 7, pp. 163–185). Amsterdam: Elsevier.

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

Marcel, A. J. (1980). Surface dyslexia and beginning reading: A revised hypothesis of the pronunciation of print and its impairments. In M. Coltheart, K. Patterson, & J. C. Marshall (Eds.), *Deep dyslexia* (pp. 227–258). London: Routledge & Keegan Paul.

McBride-Chang, C., & Manis, F. R. (1996). Structural invariance in the associations of naming speed, phonological awareness, and verbal reasoning in good and poor readers: A test of the double deficit hypothesis. *Reading and Writing: An Interdisciplinary Journal, 8,* 323–339.

Milne, R. D., Hamm, J. P., Kirk, I. P., & Corballis, M. C. (2003). Anterior–posterior beta asymmetries in dyslexia during lexical decisions. *Brain and Language, 84,* 309–317.

Milne, R. D., Syngeniotis, A., Jackson, G., & Corballis, M. C. (2002). Mixed lateralization of phonological assembly in developmental dyslexia. *Neurocase, 8,* 205–209.

Moats, L. C. (1983). A comparison of the spelling errors of old dyslexic and second grade normal children. *Annals of Dyslexia, 33,* 121–140.

Morris, R. D., Stuebing, K., Fletcher, J., Shaywitz, S. E., Lyon, G. R., Shankweiler, D. P., et al. (1998). Subtypes of reading disability: Variability around a phonological core. *Journal of Educational Psychology, 90,* 347–373.

Pugh, K. R., Mencl, W. E., Shaywitz, B. A., Shaywitz, S. E., Fulbright, R. K., Constable, R. T., et al. (2000). The angular gyrus in developmental dyslexia: Task-specific differences in functional connectivity within the posterior cortex. *Psychological Science, 11,* 51–56.

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

Shankweiler, D., Crain, S., Katz, L., Folwer, A. E., Liberman, A. M., Brady, S. A., et al. (1995). Cognitive profiles of reading-disabled children: Comparison of language skills in phonology, morphology and syntax. *Psychological Science, 6,* 149–156.

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

Shaywitz, S. E., Shaywitz, B. A., Pugh, K. A., Fulbright, R. K., Constable, R. T., Mencl, W. E., et al. (1998). Functional disruption in the organization of the brain for reading in dyslexia. *Proceeding of the National Academy of Sciences, USA, 95,* 2636–2641.

Sprenger-Charolles, L., Cole, P., Lacert, P., & Serniclaes, W. (2000). On subtypes of dyslexia: Evidence from processing time and accuracy scores. *Canadian Journal of Experimental Psychology, 54,* 87–103.

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

Torgesen, J. K., Wagner, R. K., & Rashotte, C. A. (1994). Longitudinal studies of phonological processing and reading. *Journal of Learning Disabilities, 27,* 276–286.

Wolf, M., & Bowers, P. (1999). The "double deficit hypothesis" for the developmental dyslexias. *Journal of Educational Psychology, 91,* 1–24.

Wolf, M., & Bowers, P. (2000). The question of naming-speed deficits in developmental reading disabilities: An introduction to the double-deficit hypothesis. *Journal of Learning Disabilities, 33,* 322–324.

Wood, F. B., & Felton, R. H. (1994). Separate linguistic and developmental factors in the development of reading. *Topics in Language Disorders, 14,* 42–57.