Spelling Consistency Affects Reading in Young Dutch Readers with and without Dyslexia

Anna M. T. Bosman[1], Wietske Vonk[2], and Margriet van Zwam[2]

[1]Radboud University Nijmegen
Nijmegen, The Netherlands

[2]Max Planck Institute for Psycholinguistics
Nijmegen, The Netherlands

Lexical-decision studies with experienced English and French readers have shown that visual-word identification is not only affected by pronunciation inconsistency of a word (i.e., multiple ways to pronounce a spelling body), but also by spelling inconsistency (i.e., multiple ways to spell a pronunciation rime). The aim of this study was to compare the reading behavior of young Dutch readers with dyslexia to the behavior of readers without dyslexia. All students participated in a lexical-decision task in which we presented pronunciation-consistent words and pseudowords. Half of the pronunciation-consistent stimuli were spelling consistent and the other half were spelling inconsistent. All three reader groups, that is, students with dyslexia, age-match students, and reading-match students, read spelling-consistent words faster than spelling-inconsistent words. Overall reading speed of students with dyslexia was similar to that of reading-match students, and was substantially slower than that of age-match students. The results suggest that reading in students with or without dyslexia is similarly affected by spelling inconsistency. Subtle qualitative differences emerged, however, with respect to pseudoword identification. The conclusion was that the findings were best interpreted in terms of a recurrent-feedback model.

Key Words: Dyslexia, reading, resonance models, spelling, spelling consistency, visual-word perception

Frequency and consistency have been shown to affect visual-word identification in numerous studies with English readers. Beginning as well as experienced readers process words that occur relatively often in the (written) language more quickly and with fewer errors than words that rarely appear in print (for frequency effects in beginning readers, see Holligan & Johnston, 1988; for experienced readers,

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Monsell, 1991). Consistency also affects the speed and accuracy of single-word reading. Consistency refers to the extent to which spelling and sound covary in a predictable way. Here, we focus on the onset-rime/body distinction. The body in a monosyllabic word is what is left after removing the initial consonant or consonant cluster. For example, the English spelling body UST, as in *lust*, is pronounced the same in all monosyllabic words (e.g., *must, dust, just*), whereas the spelling body ULL in *pull* is pronounced differently from *dull* and *hull*. Thus, inconsistency at the body-rime level occurs when spelling bodies are pronounced differently, depending on the word in which they appear. This type of inconsistency has been investigated in depth in the English language. Words with inconsistent pronunciation bodies generally produce slower naming responses and more errors (Andrews, 1982; Backman, Bruck, Hebert, & Seidenberg, 1984; Glushko, 1979; Jared, 1997, 2002; Jared, McRae, & Seidenberg, 1990; Seidenberg, Waters, Barnes, & Tanenhaus, 1984; Treiman, Mullennix, Bijeljac-Babic, & Richmond-Welty, 1995), and longer lexical-decision latencies and more errors (Andrews, 1982; Pugh, Rexer, & Katz, 1994; Stone, Vanhoy, & Van Orden, 1997; but see Jared et al., 1990) than words with consistent pronunciation bodies in both beginning and experienced readers. The evidence with respect to the interaction between frequency and consistency is mixed. Some studies (lexical-decision and/or naming) showed consistency effects for low-frequency words and no or minimal effects for high-frequency words (e.g., Backman et al. 1984; Seidenberg et al., 1984; Taraban & McClelland, 1987; Treiman et al., 1995; Pugh et al., 1994), whereas others found consistency effects for both high- and low-frequency words (Andrews, 1982; Jared, 1997).

So far, our discussion of the consistency effect has been limited to the mapping from spelling to phonology. However, words may also be inconsistent in the opposite direction; that is, in the way they map phonology to spelling. For example, the pronunciation body [iep] in English is spelled two ways, EEP as in *keep* and EAP as in *heap*. The predominance of phonological spelling errors (e.g., *deap* where *deep* was intended) in spelling tasks is a clear demonstration of the effect of spelling inconsistency. Spelling inconsistency has been known to affect spelling performance in both beginning and experienced spellers (Barry & Seymour, 1988; Holmes & Ng, 1993; Kreiner & Gough, 1990; Peereman, Content, & Bonin, 1998; Perry, Ziegler, & Coltheart, 2002; Waters, Bruck, & Seidenberg, 1985; for an extensive overview, see Bosman & Van Orden, 1997).

The fact that pronunciation consistency affects reading performance and spelling consistency affects spelling performance has been known for a while. However, the question whether spelling inconsistency also affects reading was addressed less than a decade ago by Stone et al. (1997). They presented English-speaking participants with four types of words. The first set was bidirectionally consistent. An example is the word *lust*. Its spelling body UST is only pronounced one way in the various words that share this spelling body, and its pronunciation body [ʌst] is only spelled one way in the words that share this pronunciation body. A second set of words was bidirectionally inconsistent. For example, the spelling body EAK in *bleak* has multiple pronunciations, as in break [breɪk] and *leak* [lɪək], and the pronunciation body [ɪək] has multiple spellings, as in *freak* and *creek*. The third and fourth sets of words were consistent in one direction but inconsistent in the other. The example *heap* has a spelling body EAP that is always pronounced the same, but the pronunciation body [ɪəp] can be spelled multiple ways, as in *creep* and *leap*. The contrasting example *hull* has a pronunciation body [ʌl] that can only be spelled one way, but a spelling body ULL that can be pronounced multiple ways, [ʌl] as in *dull* and [Uəl] as in *pull*.

Participants in the Stone et al. study performed a lexical-decision task. Presented with words and nonwords, they had to decide as quickly and as accurately as possible whether the word that appeared on the computer screen was a word or not. As expected, words with inconsistent pronunciation bodies yielded slower correct responses and more errors than words with consistent pronunciation bodies. However, words with inconsistent spelling bodies and consistent pronunciation bodies (e.g., *heap*) also produced slower correct responses and more errors than words that were consistent in both directions. Note that this is a rather unintuitive finding. Despite the fact that these words that can only be pronounced one way, the visual-identification process is still slower in case words can be spelled multiple ways. In sum, words that are consistent in both directions were processed more quickly and more accurately than words that were either inconsistent in one direction or in both directions. Bidirectionally inconsistent words yielded responses comparable in speed and accuracy to words inconsistent in only one direction.[1]

Shortly after Stone et al. published their findings, Ziegler, Montant, and Jacobs (1997) demonstrated a spelling-consistency effect in French in both lexical decision and naming. Peereman et al. (1998) contested the French findings by Ziegler and his colleagues, however. In a series of five experiments, they were unable to obtain the spelling-consistency effect. They argued that the presence of the effect in the study by Ziegler et al. was due to a confound between consistency and subjective word frequency. A recent study by Lacruz and Folk (2004) revealed that the familiarity explanation put forward by Peereman et al. did not explain the effects obtained in English. They

[1]Inconsistent mapping from spelling to phonology in *reading* is also referred to as feedforward inconsistency and inconsistent mapping from phonology to spelling as feedback inconsistency (Stone et al., 1997). For *spelling*, it would be exactly the opposite; inconsistent mapping from phonology to spelling is feedforward inconsistency, and inconsistent mapping from spelling to phonology is feedback inconsistency. Because this terminology is dependent on the task at hand, we decided to adopt the context-indepedendent terms coined by Vanhoy and Van Orden (2001), which is pronunciation consistency (one way to pronounce a word) and spelling consistency (one way to spell a word).

found clear effects of feedback consistency in both lexical decision and naming with familiarity controlled for. Lacruz and Folk suggested that language differences, with English more reliant on word bodies than French, may be responsible for the experimental differences. Thus, the null finding of feedback consistency by Peereman et al. needs to be further verified.

In a subsequent study, Ziegler and Ferrand (1998) demonstrated the effect of spelling consistency in an auditory lexical-decision task. Their results showed that participants took longer and made more errors on spelling-inconsistent word than on spelling-consistent words (see also Ziegler, Ferrand, & Montant, 2004). Ziegler and colleagues, however, were not the first to demonstrate a spelling-consistency effect in auditory-word perception. Already in 1979, Seidenberg and Tanenhaus (see also Zecker, Tanenhaus, Alderman, & Siqueland, 1986) showed that English-speaking students, who performed an auditory rhyme-detection task, were faster to decide that two orthographically similar words (e.g., COAT-BOAT) rhymed than two orthographically dissimilar words (e.g., VOTE-BOAT).

The consistency findings reported above all pertain to normal reading behavior, suggesting that they are part and parcel of unimpaired reading. The question arises whether students with reading impairments or dyslexia are similarly affected by consistency. Zecker (1991) investigated this issue by conducting an auditory rhyme-detection task with orthographically similar (e.g., BUM-GUM) and dissimilar (e.g., THUMB-GUM) word pairs. His participants consisted of a group of English-speaking reading-disabled and normally achieving children. It appeared that disabled readers between 10.1 and 11.5 years did show the consistency effect but the younger, disabled readers did not, whereas all normally achieving readers (aged between 7.0 and 11.5) demonstrated the effect. Zecker's results suggest that literacy development in reading-impaired children is to some extent qualitatively different from that of children without a reading disability. This conclusion, however, is a little premature because the reading level of the reading-disabled children in his sample who did not demonstrate the consistency effect was substantially lower than that of the youngest readers in the normally achieving group. In fact, the disabled readers (aged between 10.1 and 11.5) who appeared to be susceptible to the consistency variable had a reading level that was equal to that of the youngest normally achieving readers (aged between 7.0 and 8.5). Thus, the reading-disabled children had a delay of about three years. Equating the reading groups on reading level suggests that the difference between the groups on the auditory rhyme-detection task is merely quantitative.

Recently, Davies and Weekes (2005) revisited the issue of spelling and pronunciation consistency, and were the first to show bidirectional-consistency effects in the reading and spelling of students with and without dyslexia. They had their participants spell and read aloud a set of 48 monosyllabic English words. These words were assigned to four groups of 12 words each. One group contained words that were consistent in both directions; one group had words that were inconsistent in both directions; one group consisted of words that were spelling-consistent and pronunciation-inconsistent; and one group had words that were pronunciation-consistent and spelling-inconsistent. The error scores on the reading task showed the well-researched pronunciation-consistency effect for both groups, and a spelling-consistency effect for the students with dyslexia only. The error scores on the spelling task showed a pronunciation-consistency effect as well as a spelling-consistency effect in both reader groups. In sum, Davies and Weekes showed that a) both types of consistency also affect spelling performance, b) consistency effects occur in young unimpaired readers as well as in readers with dyslexia, and c) consistency effects also emerge in accuracy scores. They measured response latencies, but this dependent variable did not appear to produce one or both consistency effects in reading.

As said, the majority of studies pertaining to consistency effects have been conducted in English and some in French, made possible to a large extent by the work of Ziegler and colleagues. They computed body-rime consistencies in both directions for a large number of monosyllabic words in both English (Ziegler, Stone, & Jacobs, 1997) and French (Ziegler, Jacobs, & Stone, 1996). Table I summarizes the mean consistency levels of the four word categories in the English and French languages. Bosman and Mekking (2006) computed similar statistics for the Dutch language on the CELEX database (Baayen, Piepenbrock, & van Rijn, 1993). Pronunciation consistency is equally high in French (81.2%) and Dutch (84.5%), and substantially higher than in English (69.3%), whereas spelling consistency is highest in Dutch (36.8%) followed by English (27.7%), and they are both substantially higher than in French (2.8%). In all three languages, pronunciation consistency is considerably higher than spelling consistency, which explains why spelling is more difficult than reading (Bosman & Van Orden, 1997).

In sum, these statistics suggest that pronunciation as well as spelling consistency should also affect reading behavior in Dutch. Although Dutch has about 15.5% pronunciation-inconsistent words, it should be possible to select an appropriate set of words that fulfill the necessary requirements. However, the fact that we conducted our study with beginning readers limited the choice of acceptable stimuli to such an extent that we decided to drop this variable, still leaving us with the most interesting variable with respect to reading, namely, spelling consistency. Note that a spelling-consistency effect in a language that is relatively consistent, like Dutch, is less likely to happen than in languages (like English and French) in which inconsistency is the rule rather than the exception. More pronunciation-consistent mappings may be too efficient to afford spelling consistency effects, making the extension of such findings to a language like Dutch more interesting.

Table I. Percentages of Pronunciation and Spelling Consistency Levels Based on the Number of Word Occurrences of Body-Rime Relationships in English (n = 2694), French (n = 1843), and Dutch (n = 6190) One-Syllable Words

	Spelling								
	Consistent			Inconsistent			Total		
	E	F	D	E	F	D	E	F	D
Pronunciation									
Consistent	19.3	2.6	33.6	49.9	78.6	50.9	69.3	81.2	84.5
Inconsistent	8.4	0.2	3.2	22.4	18.5	12.3	30.7	18.8	15.5
Total	27.7	2.8	36.8	72.3	97.2	63.2	100	100	100

Note. English (E) figures from Ziegler, Stone, and Jacobs (1997), French (F) from Ziegler, Jacobs, and Stone (1996), and the Dutch (D) are based on Bosman and Mekking (2006).

Stone et al. (1997) in English and Ziegler, Montani et al. (1997) in French used low-frequency words only because if consistency effects are real, they are most likely to appear in low-frequency words. In our study with young beginning readers, we used both high-frequency and low-frequency words. We decided to enter the frequency variable as a means of assessing the sensitivity of our experimental design. It has been known that frequency affects reading in Dutch beginning (Bosman & de Groot, 1991; Reitsma & Vinke, 1986) and experienced readers (e.g., Brysbaert, 1996; de Groot, 1989; del Prado Martín et al., 2005). We expect to find a straightforward frequency effect as well as a spelling-consistency effect in low-frequency words. Whether or not the spelling-consistency effect will emerge in high-frequency words remains to be seen. Based on earlier findings that showed no markedly different reading behavior in Dutch impaired and unimpaired readers in knowledge of coarse-grained and/or intermediate-grained phonological structure (Bosman, van Leerdam, & de Gelder, 2000) and on the more recent work by Davies and Weekes (2005) on English impaired and unimpaired readers, we expect a spelling-consistency effect in students with and without dyslexia.

As recommended by Backman, Mamen, and Ferguson (1984) and Vellutino and Scanlon (1989), we used a combination of a reading-match and age-match design to assess the nature of potential differences between impaired and unimpaired reading. The assumptions are: reading behavior of students with dyslexia that deviates from that of reading-match as well as from age-match students signifies a qualitative difference (i.e., a reading deficit), whereas, reading behavior of students with dyslexia similar to that of reading-match students and both different from that of age-match students signifies most likely a quantitative difference (i.e., a reading delay). We agree, however, with Vellutino and Scanlon (1989), who state that ". . . group differences favoring normal readers with a CA-matched design and no group differences with an

RL-matched design may be a meaningful and theoretically pattern of results, if the data are organized by a reasonably plausble theory and if the hypotheses generated by this theory are supported by independent research" (p. 365). Thus, a pattern of results that is in line with one of the two possibilities is a first step in the quest for the nature of reading disabilities. It requires additional research with a large variety of reading tasks to substantiate any claim.

In sum, the goal of the present experiment was to study similarities or differences in reading behavior of Dutch students with and without dyslexia using spelling-consistent and -inconsistent words and pseudowords in a lexical-decision task modeled after Stone et al. (1997) and Ziegler, Montani et al. (1997). In the Discussion, we will explain in detail that the presence of spelling-consistency effects in reading is best explained in terms of a theoretical account that assumes full recurrence between relevant aspects of processing, thus feedforward and feedback activation between orthography and phonology.

METHOD

PARTICIPANTS

Sixty-nine students from Dutch primary schools participated in this study. Twenty-three students constituted the group of children with dyslexia. The 46 remaining students did not have reading problems. These students were matched to the children with dyslexia on either word-reading level (reading-match group; 23 students) or on chronological age (age-match group; 23 students). The students with dyslexia were recruited from a school for special education and scored more than two years below their expected reading level. The students without reading problems attended a school for regular education.

Two weeks before the experiments were conducted, the word-reading and pseudoword-reading skills of all children were assessed. Word-reading level was measured with a standardized reading-decoding test (Brus & Voeten, 1973). The score on this test is the number of words read correctly in one minute. Pseudoword reading was assessed by means of a standardized pseudoword-reading test (van den Bos, Spelberg, Scheepstra, & de Vries, 1994). The score on this test is the number of pseudowords read correctly in two minutes. Table II presents the scores on the reading tests and the mean ages of the three experimental groups.

Performance on the word-reading test of the students with dyslexia was not statistically different from that of students in the reading-match group ($F < 1$), but the reading-match group performed significantly better on the pseudoword-reading test than the students with dyslexia $F(1, 44) = 7.0$, $p < .05$, $MSE = 112.7$. The mean age of the students with dyslexia was not statistically different from the students in the age-match group ($F < 1$), but their word-reading and pseudoword-reading levels were significantly lower than that of the students in the age-match group, $F(1,44) = 163.6$, $p < .0001$, $MSE =$

Table II. Reading Scores, Age in Months, and Sex Ratio of the Experimental Groups

	Experimental Groups		
	With Dyslexia	**Reading-match**	**Age-match**
Word reading (wpm)	31.2 (9.7)	31.5 (9.3)	69.5 (10.6)
Pseudoword reading (wp2m)	20.7 (10.8)	29.0 (10.5)	64.7 (11.1)
Age	124 (9)	92 (6)	123 (9)
Girls/Boys	13/10	9/14	11/12
n	23	23	23

Note. Standard deviations in parentheses

102.9 for word reading, and $F(1,44) = 185.8$, $p < .0001$, $MSE = 119.6$ for pseudoword reading. The students with dyslexia were on average 2.7 years older than those in the reading-match group.

Assuming that students with dyslexia may suffer from a phonological deficit visible in reduced performance on a nonword-reading task (Rack, Snowling, & Olson, 1992; van IJzendoorn & Bus, 1994; Wimmer, 1996), only students with a difference score on the word-reading and the pseudoword-reading tests less than 10 points were included in the age-match and reading-match samples. Thus, limiting the difference between the level of word and pseudoword reading minimizes the chance that students with undetected reading problems were included in the two samples without dyslexia.

MATERIALS

The 120 stimuli in this experiment consisted of 60 words and 60 pseudowords. The words were selected from the Woordfrequentielijst [Word frequency list] of Staphorsius, Krom, and de Geus (1988), a corpus of 202,526 words appearing in children's books, and consisted of 30 high-frequency words and 30 low-frequency words. The pseudowords were derived from the words (see below for details). All words and pseudowords were monosyllabic and contained either four or five letters. The average length of the words and pseudowords was 4.3 letters.

All word stimuli were spelling-to-sound consistent, with unambiguous pronunciations, but only half of the words were also sound-to-spelling consistent. The other half was sound-to-spelling inconsistent; that is, were words that could be spelled multiple ways. The inconsistent stimuli (words and pseudowords) used here either contained the phoneme [au], [Ei], [x], or [t]. The phoneme [au] can be spelled four ways, namely, AU, as in *Augurk* [gherkin], OU as in *Kou* [cold], AUW, as in *Gauw* [quick], or OUW as in *Touw* [rope]. The phoneme [Ei] can be spelled two ways, that is, IJ as in *Slijm* [slime] or EI as in *Klein* [small]. The phoneme [x] can also be spelled two ways, CH as in *Pech* [bad luck] and G as in *Leeg* [empty]. Finally, the phoneme [t] in one-syllable words can be spelled two ways; that is, T as in *Pret* [fun], and D as in *Tand* [tooth]. The grapheme D is pronounced [t] only when it occurs in the final position of a word or syllable; in all other cases, it is pronounced [d]. Dutch spelling bodies may have two inconsistent phonemes. For example, in the word *Tijd* [tEit], which is Dutch for *time*, both the [Ei] and [t] are inconsistent. Only words with one inconsistency in the body were selected.

The high-frequency words were words with a frequency greater than 17 and the low-frequency words were words with a frequency less than 14. The mean frequency of the high-frequency words was 94.3 (*SD* = 115.2, range from 18 to 422). The mean frequency of the low-frequency words was 4.4 (*SD* = 3.8, ranged from 1-13). The mean frequency of the consistent words was 49.4 (*SD* = 90.3) and of the inconsistent words was 49.3 (*SD* = 96.6). The difference in high-frequency and low-frequency words was significant ($F[1, 56] = 17.60$, $p < .0001$), but between consistent and inconsistent words was not ($F < 1$). The differences in frequency comparing high-frequency consistent words (*M* = 94.1) and high-frequency inconsistent words (*M* = 94.5), or low-frequency consistent words (*M* = 4.6) and low-frequency inconsistent words (*M* = 4.2) were not significant either, $F < 1$.

The pseudowords were derived from the words by changing one or two letters, but maintaining the number of letters and maintaining the inconsistent phoneme-grapheme relationship in the inconsistent stimuli. Consistent words were changed into consistent pseudowords. The entire list of stimulus materials is presented in the Appendix.

Two pseudo-random list orders were created, containing the same set of 120 stimuli. The order of the items in List A was from 1 to 120, and the one in List B from 61-120, followed by 1 to 60. Care was taken to present pseudowords derived from words as far apart as possible, and to avoid an order in which two or more consistent words or two or more high-frequency or low-frequency words succeeded each other. In both lists, each item occurred only once and the participants were assigned randomly to one of the lists.

PROCEDURE

Participants were seated in front of a computer screen at a distance of approximately 50 cm. They were instructed that words they knew and words they did not know would appear on the computer screen. They were asked to press as quickly and as accurately as possible the yes button on the button box, connected to the serial port of the computer, in case they knew the words, and to press the no-button in case they did not know the word. Experience with young Dutch children performing lexical-decision tasks had taught us that the standard instruction to press the no-button in case a pseudoword (or nonword) appeared on the screen led to long thinking times (Bosman & de Groot, 1996).

Following the offset of an auditory warning signal, there was a 250 ms interval before the stimulus was presented on the screen. The stimulus remained on the screen until the participant had responded. If the participant did not respond within 10 seconds, the stimulus disappeared from the screen automatically. One second following the response, a new trial was presented. Lexical-decision latencies were measured from the onset of the stimulus until the onset of the key press response. Prior to the experiment proper, participants were familiarized with the procedure in three practice trials in which they received feedback. During and after these trials, they were able to ask questions regarding anything that was related to the task. The response latencies on the practice trials were excluded from the data set. Participants were tested individually and a session lasted about 10 minutes; they did not receive feedback on experimental task performance.

RESULTS

Before subjecting the data to analysis, responses based on latencies exceeding 10 seconds (14 responses of students with dyslexia and three responses from the students in the reading-match group) or responses faster than 250 ms (three responses of students with dyslexia) were removed from the data set. Moreover, latencies based on errors (students with dyslexia 16.7%, reading-match 10.0%, and age-match 5.0%), and extremely long responses, that is three *SD* above the mean (students with dyslexia 1.2%, reading-match 1.1%, and age-match 1.3%), were also excluded from the analyses. Prior to the analyses proper, the effect of list was investigated. No effect of list emerged, so it was decided to drop this variable from subsequent analyses.

A final remark concerns the application of the statistics used here. After Clark's (1973) seminal article on the use of the proper *F*-test in psycholinguistics, researchers started to report min F', which enabled them to generalize beyond the materials used. This test treats both the subjects and the items as random effects in one and the same analysis. Shortly after Clark's publication, Wike and Church (1976) criticized the min F'-test as being too conservative and, therefore, leading to possible type II errors. The result was that researchers started to report F_1 (subject analysis) and F_2 (item analysis) separately, without computing min F'. Raaijmakers, Schrijnemakers, and Gremmen (1999; see also Raaijmakers, 2003) showed that this is statistically incorrect. They also made clear that if proper measures are taken, that is, stimulus materials are matched or each stimulus appears in each condition (either by random assignment or by experimental manipulation), the proper test is the subject analysis (F_1). In the present study, the stimuli were matched and had to be treated as a fixed effect because the number of stimuli that could be generated given the requirements had reached its limits.

WORDS

Errors. A 3 (group: dyslexia vs. reading-match vs. age-match) X 2 (frequency: high vs. low) X 2 (consistency: consistent vs. inconsistent) ANOVA was performed on the mean error scores of the participants.

Group was treated as a between-subjects variable and frequency and consistency as within-subjects variables. The means are presented in Table III. The main effects of group and frequency, as well as the interaction between group and frequency, reached significant levels, $F(2, 66) = 15.53$, $p < .0001$, $MSE = 85.1$, $F(1, 66) = 153.71$, $p < .0001$, $MSE = 64.9$, and $F(2, 66) = 4.84$, $p < .01$, $MSE = 64.9$, respectively. Post-hoc comparison with Tukey's test revealed that students with dyslexia did not commit significantly different numbers of errors than reading-match students, whereas both groups made more errors than age-match students ($p < .05$). Subsequent analyses indicated that all three groups showed a significant frequency effect, but this effect was substantially lower in the age-match group (7.8%; $F[1, 22] = 26.51$, $p < .0001$, $MSE = 53.1$) than in the reading-match group (14.8%; $F[1, 22] = 73.36$, $p < .0001$, $MSE = 68.5$), and in the students with dyslexia (13.5%; $F[1, 22] = 57.07$, $p < .0001$, $MSE = 73.2$). The main effect of consistency was not significant ($F < 1$), and the interaction effect between frequency and consistency was marginally significant, $F(1, 66) = 3.10$, $p < .08$, $MSE = 37.0$. Further analyses regarding the differences between high-frequency consistent and inconsistent words and between low-frequency consistent and inconsistent words did not reveal significant effects.

Latencies. A 3 (group: dyslexia vs. reading-match vs. age-match) X 2 (frequency: high vs. low) X 2 (consistency: consistent vs. inconsistent) ANOVA was performed on the words' mean response latencies of the participants. Group was treated as a between-subjects variable and frequency and consistency as within-subjects variables. The means are presented in Table IV. All three main effects were significant. The

Table III. Mean Error Percentages of Words

	Experimental Groups					
Stimulus	**With Dyslexia**		**Reading-match**		**Age-match**	
	HF	**LF**	**HF**	**LF**	**HF**	**LF**
Consistent						
M	6.7	21.2	4.6	21.4	3.2	11.9
SD	7.5	6.9	6.2	8.5	4.0	9.6
Inconsistent						
M	9.0	21.4	5.8	18.6	3.5	10.4
SD	7.7	12.2	7.3	9.2	4.9	7.2
Consistency effect						
M	1.3		-.9		-.6	
SD	9.9		7.2		5.7	
Frequency effect						
M	13.5		14.8		7.8	
SD	8.6		8.3		7.3	

Note. HF refers to high-frequency words and LF to low-frequency words.

Table IV. Mean Lexical-Decision Latencies of Words in Ms

	Experimental Groups					
Stimulus	**With Dyslexia**		**Reading-match**		**Age-match**	
	HF	**LF**	**HF**	**LF**	**HF**	**LF**
Consistent						
M	1850	2002	1742	2097	888	956
SD	779	778	430	691	167	174
Inconsistent						
M	1855	2245	1832	2143	916	984
SD	670	842	483	554	195	206
Consistency effect						
M	124		68		28	
SD	291		155		59	
Frequency effect						
M	271		333		68	
SD	230		264		74	

Note. HF refers to high-frequency words and LF to low-frequency words.

effect of group was $F(2, 66) = 29.46$, $p < .0001$, $MSE = 1115801.9$, of frequency it was, $F(1, 66) = 81.30$, $p < .0001$, $MSE = 42641.3$, and the effect of consistency was $F(1, 66) = 9.86$, $p < .005$, $MSE = 37524.7$. Before discussing the main effects, it is necessary to investigate the source of the significant three-way interaction between group, frequency, and consistency, $F(2, 66) = 3.22$, $p < .05$, $MSE = 41189.0$.

Separate analyses for each of the groups on frequency X consistency revealed that the interaction effect was not significant in the reading-match group or in the age-match group, both *F*'s <1. However, this interaction between frequency and consistency was marginally significant in the group of students with dyslexia, $F(1, 22) = 3.37$, $p < .08$, $MSE = 96042.7$. Subsequent analyses indicated a significantly larger consistency effect for the low-frequency words (243 ms) than for the high-frequency words (5 ms). Because all three groups revealed significant main effects of frequency and consistency, replicating the general main effect, we return to the overall main effects.

The main effect of frequency showed that lexical-decision latencies to high-frequency words ($M = 1514$, $SD = 648$) were shorter than latencies to low-frequency words ($M = 1738$, $SD = 795$). The main effect of consistency revealed that all participants responded faster to words with consistent phoneme-to-grapheme relationships ($M = 1589$, $SD = 716$) than to words with inconsistent relationships ($M = 1662$, $SD = 729$). Table IV also shows the frequency and consistency effects of each of the groups separately. The main effect of group showed that age-match students ($M = 936$, $SD = 178$) were significantly faster than reading-match students (M = 1954, SD = 521), and students with dyslexia (M = 1988, SD = 731), with no significant difference emerging between the latter two; in both cases $p < .0001$, based on Fisher's PLSD.

A final result of importance concerning the word stimuli was the significant interaction effect between group and frequency, $F(2, 66) = 10.36$, $p < .0001$, $MSE = 42641.3$. Although all three groups showed significant frequency effects, the effect was substantially smaller in the age-match group than in the reading-match group, and in the group of students with dyslexia. Note, neither the interaction effect between group and consistency nor the one between frequency and consistency reached significant levels.

PSEUDOWORDS

Errors. A 3 (group: dyslexia vs. reading-match vs. age-match) X 2 (consistency: consistent vs. inconsistent) ANOVA was performed on the pseudowords' mean error scores of the participants. Group was treated as a between-subjects variable and consistency as a within-subjects variable. The means are presented in Table V. The main effects of group and consistency, as well as the interaction between group and consistency, reached significant levels, $F(2, 66) = 21.26$, $p < .0001$, $MSE = 151.9$, $F(1, 66) = 6.77$, $p < .01$, $MSE = 24.1$, and $F(2, 66) = 4.10$, $p < .02$, $MSE = 24.1$, respectively. Subsequent analyses indicated that only in the group of students with dyslexia, did a significant consistency effect emerge,

Table V. Mean Percentages of Errors and Mean Lexical-Decision Latencies in Ms of Pseudowords

	Experimental Groups					
Stimulus	**With Dyslexia**		**Reading-match**		**Age-match**	
	C	**I**	**C**	**I**	**C**	**I**
Error rates						
M	16.5	22.0	6.7	7.7	3.2	3.2
SD	12.4	16.5	6.4	6.0	4.0	2.9
Latencies						
M	2657	2609	2581	2445	1107	1104
SD	1004	1060	776	831	255	248
Consistency effect						
Errors						
M	5.5		1.0		0	
SD	9.5		6.8		2.8	
Latencies						
M	-48		-136		-3	
SD	257		654		85	

Note. C refers to consistent pseudowords and I to inconsistent pseudowords.

$F(1, 22) = 7.79$, $p < .01$, $MSE = 44.8$, with students with dyslexia committing more errors to inconsistent than to consistent pseudowords. In the age-match and the reading-match group, this effect did not approach significance, both F's < 1. Subsequent analyses of the main effect of group indicated that age-match students did not make significantly different numbers of errors than reading-match students, while both groups made fewer errors than students with dyslexia; in both cases $p < .0001$, based on Fisher's PLSD.

Latencies. A 3 (group: dyslexia vs. reading-match vs. age-match) X 2 (consistency: consistent vs. inconsistent) ANOVA was performed on the pseudowords' mean response latencies of the participants. Group was treated as a between-subjects variable and consistency as a within-subjects variable. The means are presented in Table V. Neither the main effects of consistency nor the interaction between group and consistency reached significant levels. Only the main effect of group was significant, $F(2, 66) = 30.19$, $p < .0001$, $MSE = 1100137.9$. Subsequent analyses indicated that age-match students were significantly faster on the pseudowords than reading-match students and students with dyslexia; in both cases, $p < .0001$, based on Fisher's PLSD. Response times to pseudowords of reading-match students did not differ significantly from students with dyslexia.

WORDS VERSUS PSEUDOWORDS

Errors. Joint analysis of performance on words and pseudowords will pertain to effects not tested in the analyses above. A 3 (group: dyslexia vs. reading-match vs. age-match) X 2 (stimulus: word vs. pseudoword) X 2 (consistency: consistent vs. inconsistent) ANOVA was performed on the words' and pseudowords' mean error scores of the participants. Group was treated as a between-subjects variable and stimulus and consistency as within-subjects variables. Conforming to the results of the analyses above, the main effect of group was significant, $F(2, 66) = 31.2$, $p < .0001$, $MSE = 102.3$. The main effect of stimulus was not significant, but the interaction effect between group and stimulus was, $F(2, 66) = 7.56$, $p < .001$, $MSE = 92.1$. Subsequent analyses revealed that in the group of students with dyslexia, the number of errors made on words was not statistically different ($M = 14.6\%$, $SD = 4.8$) from the number of errors made on pseudowords ($M = 19.3\%$, $SD = 13.8$). In the reading-match and in the age-match group significantly more errors were made on words (12.6%, $SD = 4.9$, and 7.2%, $SD = 4.1$, respectively) than on pseudowords (7.2%, $SD = 5.2$, and 3.2%, $SD = 3.2$, respectively); reading-match students, $F(1, 22) = 31.57$, $p < .0001$, $MSE = 21.5$, and age-match students, $F(1, 22) = 12.31$, $p < .002$, $MSE = 30.8$. The interaction effect between stimulus and consistency was marginally significant, $F(1, 66) = 3.02$, $p < .09$, $MSE = 28.2$. Subsequent analyses revealed that the consistency effect of words was not significant, whereas of pseudowords it was, $F(1, 68) = 6.20$, $p < .02$, $MSE = 26.3$ (see above for further details).

Latencies. A 3 (group: dyslexia vs. reading-match vs. age-match) X 2 (stimulus: word vs. pseudoword) X 2 (consistency: consistent vs. inconsistent) ANOVA was performed on the words' mean response latencies of the participants. Group was treated as a between-subjects variable and stimulus and consistency as within-subjects variables. Conforming to the results of the analyses above, the main effect of group was significant, $F(2, 66) = 31.81$, $p < .001$, $MSE = 1514130.0$. The main effect of stimulus was also significant, revealing faster response latencies for words ($M = 1626$ ms, $SD = 716$) than for pseudowords ($M = 2084$ ms, $SD = 1011$), $F(2, 66) = 100.63$, $p < .0001$, $MSE = 1480607.6$. More detailed analysis was required because of the significant interaction between stimulus and group, $F(2, 66) = 10.28$, $p < .0001$, $MSE = 143975.0$. It appeared that the effect of stimulus was significant in all three groups, but that this effect was substantially smaller in the age-match group (169 ms) than in the reading-match group (559 ms), and in the group of students with dyslexia (655 ms). Finally, the significant interaction between stimulus and consistency ($F[2, 66] = 7.78$, $p < .01$, $MSE = 40894.4$) confirmed the absence of a consistency effect in the pseudoword condition and its presence in the word condition, $F(1, 68) = 9.77$, $p < .003$, $MSE = 18984.3$ (see above for further details).

DISCUSSION

The basic goal of the present study was to establish whether beginning readers with and without dyslexia reliably show a spelling-consistency effect on visual-word identification probed using the lexical-decision task. All three groups had longer response latencies on words that were spelling-inconsistent than words that were spelling-consistent. Only in the group of students with dyslexia did consistency interact with frequency: The spelling-consistency effect emerged in the set of low-frequency words only. The spelling-consistency effect in the two normal-reading groups emerged in both frequency conditions. This result is in accordance with the findings by Lacruz and Folk (2004). Their study with adult participants who performed both naming and lexical decision also revealed frequency and spelling-consistency effects, but no interaction. See also Metsala, Stanovich, and Brown (1998), who showed that frequency and pronunciation consistency affected reading similarly in students with and without dyslexia.

The error scores of the word stimuli yielded no spelling-consistency effect, and no spelling-consistency effect showed up in the pseudoword latencies of the three groups. The absence of a consistency effect on latencies of responses to pseudowords replicates the findings by Stone et al. (1997) in English and Ziegler, Montani et al. (1997) in French. There was, however, one significant spelling-consistency effect in the error scores of students with dyslexia: more errors were made on inconsistent pseudowords than on consistent pseudowords.

Why we did not, like Davies and Weekes (2005), find a consistency effect in the error data of the words is readily explained by the fact that all our stimuli were pronunciation-consistent, whereas half of their stimuli were pronunciation-inconsistent, causing another source of variation in their data. This showed up in their overall error rates: students with dyslexia had on average 42% reading errors and their reading-match students committed 23% reading errors. The overall word-reading errors of our participants were substantially lower: 14% in the group of students with dyslexia, 13% in the reading-match group, and 8% in the age-match group. The reduced number of errors nevertheless afforded sufficient latitude for a significant frequency effect. High-frequency words were identified more accurately than low-frequency words in all three reader groups, albeit the effect was reduced in the age-match group. The latency data revealed the same pattern; all three reader groups identified high-frequency words more quickly than low-frequency words, and the effect was also reduced in the age-match group.

Thus, all three groups demonstrated a spelling-consistency effect in the latencies of responses to words but not in the latencies of responses to pseudowords, and all three groups showed a frequency effect in the latency as well as the error data. Moreover, the overall error rate of students with dyslexia was similar to that of reading-match students, which, in turn, were higher than those of age-match students. Similarly with respect to the response latencies, students with dyslexia and reading-match students had similar response times, which, in turn, was higher than that of age-match students. These findings indicate that the reading behavior of students with dyslexia in the present lexical-decision task does not differ qualitatively from that of students who are unimpaired readers. Word identification in students with dyslexia resembles that of reading-match students, suggesting that the differences observed in comparisons of readers with dyslexia and age-match readers are quantitative in nature.

This conclusion must be qualified by the implications of the results relating to performance on pseudowords. The pattern of results with respect to pseudoword latencies mimicked those of the word latencies: similarly fast responses by students with dyslexia and reading-match students, who, in turn, were slower than age-match students. But students with dyslexia made more errors on the pseudowords than reading-match and age-match students did, who made a similar number of errors on the pseudowords. Moreover, only students with dyslexia committed more errors on inconsistent pseudowords than on consistent ones. The comparison of performance relating to word and pseudowords revealed that students with dyslexia had a similar number of errors on words and pseudowords (14% and 19% respectively), whereas reading match (13% and 7%, respectively), and age-match (8% and 3%, respectively) committed more errors on word stimuli than on pseudoword stimuli. These findings suggest a subtle difference between students with dyslexia and unimpaired readers pertaining to the production of responses to pseudowords. We will discuss potential reasons for this result below. This experimental finding converges with the test results of the three reader groups (consult Table II). Recall, word-reading level of the students with dyslexia was similar to that of the reading-match students (31.2 and 31.5, respectively), whereas pseudoword-reading level was lower than that of reading-match students (20.7 and 29.0, respectively).

Our findings motivate the conclusion that the word-identification process is highly similar in all three groups (they all showed a frequency and a consistency effect, and the error rates were similar in comparisons between reading-match students and students with dyslexia), but word-identification speed of students with dyslexia was at the level of students 2.5 years younger. Pseudoword identification showed a slightly different pattern. Although pseudoword-identification speed of the students with dyslexia was at the level of the reading-match students; they made many more errors. And, unlike the other reader groups, they also exhibited a consistency effect in the error rates of the pseudowords.

Many others who have studied dyslexia in both a pronunciation-consistent language like German and a pronunciation-inconsistent language like English have arrived at the conclusion that students with developmental dyslexia display a pseudo- or nonword deficit (Goswami, Ziegler, Dalton, & Schneider, 2003; Griffiths & Snowling, 2002; Rack et al., 1992; van IJzendoorn & Bus, 1994; Wimmer, 1996; Ziegler, Perry, Ma-Wyatt, Ladner, & Schulte-Körne, 2003).

A reliable spelling-consistency effect in conjunction with a pseudoword-reading deficit in the students with dyslexia requires a theoretical explanation that takes both into account. Many sophisticated implementations, localist as well distributed models, of normal and impaired word identification have been developed (e.g., Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001; Harm & Seidenberg, 1999, 2001; Plaut, McClelland, Seidenberg, & Patterson, 1996; Plaut & Shallice, 1993). The assumption underlying these models is that visual-word identification involves the activation of three main aspects; that is, orthography, phonology, and semantics. Initially, connectionist models simulated the most apparent aspect of reading only, namely, the covariations between orthography and phonology (Seidenberg & McClelland, 1989). All connectionist models were either strict feedforward models, in which activation is sent from letter nodes to phonemes nodes, or feedforward with a simple recurrent aspect. In later models, steps were taken to include semantics as well. Only recently did Harm and Seidenberg (2004) present simulations of a network in which all three aspects were fully incorporated. Their model is the most comprehensive version of a distributed word-perception model so far. It comprises recurrent-feedback relationships between semantics and phonology (i.e., feedforward and feedback), and feedforward relationships between orthography and semantics on the one hand, and feedforward relationships between orthography and phonology on the other. Between them, various connectionist models successfully simulated important intact and impaired word-perception phenomena (e.g., regularization error, the frequency by regularity interaction, homophone effects, semantic errors, and the like). Note that the regularization error in reading is a demonstration of a pronunciation-consistency effect. The counterintuitive phenomenon of a possible alternative spelling affecting the word-reading process can only be understood when activation from phonology is allowed to be fed back to orthography. We, therefore, agree with Stone et al. (1997) that spelling-consistency effects are strong evidence of the presence of interactive or feedback processes in reading.

McClelland and Rumelhart's (1981) interactive-activation model is the first example of the incorporation of interactivity in which feedback from a higher level (word level) is fed back to a lower level (letter level). Examples of subsequent developments are the resonance models by Grossberg and Stone (1986), Kawamoto and Zemblidge (1992), Stone (1994), and Van Orden and Goldinger (1994). Farrar and Van Orden (2001) implemented a resonance version of the triangle model, in which orthography, phonology, and semantics had full-recurrent connections among each other. The design of the resonance model of Van Orden and colleagues actually predicts the occurrence of spelling-consistency effects in reading and pronunciation effects in spelling. The design of their model, however, does not state that a frequency by consistency interaction has to occur; rather, they state that consistency effects may be reduced or eliminated in high-frequency words (Van Orden, Pennington, & Stone, 1990). Because Van Orden and colleagues described and implemented a fully-recurrent network and because they presented a theoretical account of developmental dyslexia in terms of a resonance model (Van Orden, Bosman, Goldinger, & Farrar, 1997), we will take their model as an explanation of our findings.

The model consists of three families of nodes with fully-recurrent connections: orthographic nodes, phonologic nodes, and semantic nodes (Figure 1). This means that there is a connection from each of the orthographic nodes to each of the phonologic and each of the semantic nodes, and there are backward connections from each of the phonologic and semantic nodes to the orthographic nodes, and similarly for the connections between phonologic and semantic nodes. On presentation of a printed word, the orthographic nodes get activated, which, in turn, activate phonologic and semantic nodes (feedforward activation). The recurrent connections cause the phonologic and semantic nodes to activate the orthographic nodes again (feedback activation). Whenever the feedback activation pattern matches the feedforward activation pattern, a temporarily stable, coherent dynamic whole emerges. Similarly, when the network is presented with a spoken word, phonologic nodes get activated, which, in turn, activate orthographic and semantic nodes. Again, the recurrent connections cause the orthographic and semantic nodes to activate the phonologic nodes again, and whenever the feedback pattern matches the feedforward pattern, a temporarily stable, coherent dynamic whole emerges.

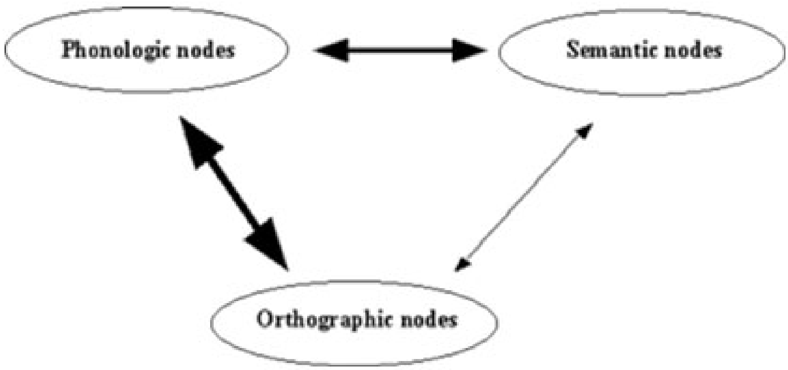

Figure 1. Macrodynamics of a recurrent-network account.

An important property of the present network is the difference in overall strength between node families, as illustrated by the relative boldness of the arrows. Connection strength indicates the speed with which dynamics cohere. In the present case, the connections between orthographic and phonologic nodes are strongest. In alphabetic languages, letters and phonemes correlate rather strongly. The letter P is almost always pronounced as [p] (exceptions are the P in PHOENIX or PSYCHO), and the phoneme [p] is almost always written with a P. The relations between phonemes and semantics are less strong. Knowing that a word starts with the phoneme P does not provide us with much information on its meaning (e.g., PAGE, PURE, or PRACTICAL do not share much meaning). Although phonologic and semantic nodes share only weak connections, they are stronger than those between semantic and orthographic nodes. This is primarily because we learned to speak before we learned to read, and we speak more often than we read. Note that before children learn to read, the strongest connections will be between phonologic and semantic nodes, but quickly after reading instruction starts, the ones between orthographic and phonologic nodes will supersede as a result of the strong correlations between letters and phonemes. Thus, this recurrent network predicts that dynamics involving the relation between orthography and phonology cohere before the dynamics between phonology and semantics, which, in turn, cohere before the dynamics between semantics and orthography. If this is true, it should not come as a surprise that phonology is an early and omnipresent constraint in reading as well as in spelling. For examples on reading, we refer the reader to Frost (1998) and Van Orden, Pennington, and Stone (1990), and for various examples on spelling to Bosman and Van Orden (1997).

More important with respect to the current issue is that recurrence in the network predicts that it matters for reading that words can be spelled multiple ways and for spelling that words can be pronounced multiple ways. According to the model, during reading activation from phonologic nodes is always fed back to orthographic nodes, inconsistency from phonology to orthography will negatively affect reading. Similarly, during spelling, activation from orthographic nodes is always fed back to the phonologic nodes and inconsistency from orthography to phonology will negatively affect spelling. The experiments by Seidenberg and Tanenhaus (1979) and the one by Zecker (1991) presented earlier provide beautiful demonstrations of the interactive nature of sound and spelling. Studies by Ziegler and colleagues reveal similar effects in a letter-search task (Ziegler & Ferrand, 1998; Ziegler et al., 2004). With respect to semantics, the nature of the model assumes that the role of semantics is comparable to that of orthography and phonology; that is, the relationships between semantics and orthography/phonology are also bidirectional. Thus, it should matter for reading that a word is ambiguous with respect to meaning, and that one meaning can be represented by more than one word. Studies by Pecher (2001) and Rodd, Gaskell, and Marslen-Wilson (2002, 2004) showed that this was indeed the case.

Although Van Orden and colleagues never simulated developmental dyslexia, in one of their publications, they presented a suggestion of how to go about this (Van Orden et al., 1997). Their idea is based on a neural analogy, without claiming anatomical plausibility. Post-mortem studies by Galaburda, Sherman, Rosen, Aboitiz, and Geschwind (1985) indicate anatomical anomalies (possibly as a result of neural migration) in the brains of people with dyslexia. Locally small anomalies in neural positioning may cause large changes in the patterns of interconnectivity between neurons in different regions of the brain. Translated in terms of our recurrent network, perhaps the problem in developmental dyslexia arises from haphazard connections rather than fully recurrent connections between orthographic and phonologic nodes. Haphazard connectivity precludes the emergence of fine-grain statistical structure (i.e., the level of letter-phoneme relationships), without preventing the development of coarse-grain statistical structure (i.e., multiletter or whole-word level). Only when the network or for that matter the reader is able to develop fine-grain statistical structure between letters and phonemes will pseudoword reading be possible. Moreover, in the case of words, the semantic-phonologic and/or the semantic-orthographic dynamic (see Figure 1) can come to a rescue, whereas these dynamics will not be able to help when pseudowords are read. This also explains why readers with developmental dyslexia display strong phonology effects in tasks involving words (e.g., Bosman et al., 2000; Van Orden & Goldinger, 1996) and at the same time, show the absence of phonology when reading pseudowords.

We briefly return to three empirical issues not discussed previously. The first one is the fact that students with dyslexia and reading-match students display greater frequency effects than age-match students. The difference between high- and low-frequency words is most likely larger for students with limited print exposure (i.e., the students with dyslexia and reading-match students). Suppose that with increasing experience, exposure to low-frequency words increases from two to 10 and those of high-frequency words from 100 to 200. That would mean a relatively larger increase for the low-frequency words than for the high-frequency words. Thus, becoming a more experienced reader would lead to smaller frequency effect. Note that this effect will show up in any network (not just recurrent ones).

The second effect that has not been discussed is the finding that only students with dyslexia presented a consistency effect on the accuracy data of nonword decisions. Caution should be exercised when interpreting these results. The relatively small number of errors made in the age-match (3.2%) and the reading-match group (7.2%) as compared to the group of students with dyslexia (19.3%) suggests that a floor effect has occurred in the former two groups. We refrain from presenting an interpretation, because we are not yet convinced that this is a meaningful difference.

The third and final effect that requires attention is the presence of an interaction effect between frequency and consistency of the word latency data in the group of students with dyslexia, and its absence in the two reading groups without dyslexia. One caveat: because resonance models are essentially nonlinear, any explanation is somewhat speculative, and needs to be tested in future research. We can only present a suggestion. Building on the assumption that dyslexia is characterized by haphazard connectivity in the orthographic-phonologic relationships, students with dyslexia are more reliant on the orthographic-semantic and the phonologic-semantic dynamics than students without dyslexia. These dynamics can help to clear up the inconsistencies in the orthographic-phonologic dynamic more easily in high-frequency words than in low-frequency words. Low-frequency inconsistent words suffer from a double disadvantage; they are semantically less well known and they are inconsistent from phonology to orthography. This may be the reason why a consistency effect emerges in low-frequency words only in students with dyslexia. In students without dyslexia, there is full connectivity between orthography and phonology, and their word-identification process is less reliant on the orthographic-semantic and the phonologic-semantic dynamics. The consistency effect can emerge in both high- and low-frequency words because the orthographic-phonologic dynamic develops relatively independently. In sum, because overall coherence is more important in students with than in students without dyslexia, their word-identification process may subtly deviate from that of students without. Three empirical findings support this conclusion: students with dyslexia have considerably slower decision times (more than twice as slow) compared to age-match students, their mean responses to low-frequency inconsistent words are the longest (2245 ms), and they are 100 ms longer than that of reading-match students (2143 ms).

To conclude, the empirically established interactive nature of spelling, sound, and meaning leads us to conclude that any word-perception model should incorporate the feedback principle. The feedback principle precludes that reading can be viewed as a linear sum of orthography + phonology + semantics. A system that includes feedback and feedforward processes causes continuous nonlinear alterations of the activation patters among orthographic, phonologic, and semantic nodes. We, therefore, agree with the conclusions drawn by Harm and Seidenberg (2001), who explained the impairments of two cases of acquired dyslexia in terms of a phonological impairment that interacts with the orthographic properties of stimuli. The way they phrased their conclusion suggests that they are not attributing the cause of reading failure to either orthography or phonology.

We would like to take matters a little further than this, because we believe that there is great utility in viewing reading (and for that matter, cognition in general) as an ongoing interaction between the organism and its environment (see Van Orden, Holden, Podgornik, & Aitchison, 1999). Reading is just like any other cognitive task strongly contextually situated. The most obvious context in reading an alphabetical writing system is the word context. Letters and letter clusters change their relationship to phonemes according to the contexts in which they appear. Other important contexts for visual-word identification are task variables: response mode (e.g., naming, lexical decision, semantic categorization), target stimuli (e.g., homophones, regular words, exception words, nonwords), filler stimuli (e.g., orthographically illegal pseudowords, orthographically legal pseudowords pseudohomophones), preceding trial (e.g., priming, [backward] masking), interstimulus-interval (ranging from 0 to seconds), response delay (e.g., immediate or delayed), and so forth. To complicate matters even further, not only experimental contexts codetermine the reading process. A reader's personal history and disposition provide yet another one. For example, the amount of print exposure, age, language experience, and functional impairments, like being deaf, blind, or having dyslexia, all contribute to the outcome of the reading process. Viewing the reading process as the result of the ongoing interaction between a person and the task at hand, without one having primacy over the other, has an important implication prudently discussed by Van Orden and Kloos (2005). Thus, reading performance of students with dyslexia is bound to be similar in some respects and different in others. They may reveal themselves between and within tasks. The present experiment showed both differences and similarities within one task.

Address correspondence to Anna M. T. Bosman, Radboud University Nijmegen, Faculty of Social Sciences, Department of Special Education and Behavioural Sciences Institute, P.O. Box 9104, 6500 HE Nijmegen, The Netherlands. E-mail: a.bosman@pwo.ru.nl

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APPENDIX

Mean response latencies in ms and percentages correct (below) on all Dutch experimental stimuli (English translation in italics) of students with dyslexia (Dys), reading-match (RM), and age-match (AM) students.

Stimulus	Dys	RM	AM	Stimulus	Dys	RM	AM	Stimulus	Dys	RM	AM
High-frequency consistent words											
mens	2001	1747	788	bruin	1587	1731	841	deur	1694	1487	812
human	4.3	4.3	0	*brown*	4.3	8.7	0	*door*	0	0	0
kans	2252	2122	901	broer	2461	2225	1004	ziek	1972	1322	814
chance	0	13	0	*brother*	8.7	0	4.3	*ill*	0	0	0
lang	1587	1702	843	stoel	2263	1556	906	huis	1374	1434	805
long	4.3	0	0	*chair*	4.3	0	4.3	*house*	0	0	4.3
niks	2035	1812	902	klas	1524	1943	847	neer	1826	1842	1138
nothing	13	4.3	4.3	*class*	8.7	0	0	*down*	39.1	21.7	8.7
soms	1940	1808	922	toen	1868	1752	952	vuur	1501	1659	928
sometimes	0	8.7	4.3	*then*	4.3	0	4.3	*fire*	0	8.7	4.3
High-frequency inconsistent words											
leeg	1634	1634	1046	touw	1626	1963	866	vlug	1652	1770	830
empty	4.3	8.7	0	*rope*	4.3	4.3	0	*fast*	13	0	0
huid	1960	1615	836	trein	1771	2177	908	best	2195	1874	1027
skin	8.7	8.7	4.3	*train*	4.3	13	8.7	*best*	21.7	4.3	0
fijn	2037	1540	951	klein	1522	1617	836	rond	2052	1842	968
fine	0	0	0	*small*	4.3	0	0	*round*	4.3	4.3	13
reis	1917	1952	871	droog	2636	1927	899	zich	2087	2002	879

(continued)

journey	4.3	4.3	0	*dry*	13	0	0	*oneself*	34.8	30.4	4.3
gauw	1451	2040	1067	vrouw	1582	1610	860	toch	1839	1904	897
quick	4.3	4.3	8.7	*woman*	4.3	0	4.3	*still*	8.7	4.3	0
Low-frequency consistent words											
koers	2556	2806	1237	stoom	2272	2252	999	reus	1858	1782	798
course	47.8	65.2	30.4	*steam*	13	34.8	21.7	*giant*	4.3	0	4.3
heks	1873	1865	858	knul	2082	2051	897	kuil	2087	1990	1030
witch	4.3	0	4.3	*lad*	8.7	13	8.7	*pit*	26.1	8.7	0
romp	3242	2715	1169	vloer	1667	2088	939	zuur	1798	2170	923
trunk	78.3	91.3	52.2	*floor*	8.7	0	4.3	*sour*	8.7	0	4.3
pink	2309	2373	929	pruik	2291	2334	1004	lief	1640	1906	843
little finger	8.7	8.7	4.3	*wig*	13	8.7	8.7	*kind*	0	0	0
mals	2289	2509	1152	spier	2129	2093	920	doos	1460	1624	879
tender	47.8	47.8	30.4	*muscle*	34.8	34.8	0	*box*	4.3	8.7	4.3
Low-frequency inconsistent words											
deeg	2102	1671	917	mouw	2534	2014	1184	brug	1754	1931	843
dough	21.7	8.7	0	*sleeve*	8.7	13	4.3	*bridge*	13	4.3	0
teil	2772	2465	1276	slijm	2865	2237	1051	vloot	3191	2758	1198
tub	52.2	60.9	56.5	*slime*	21.7	26.1	0	*fleet*	52.2	78.3	52.2
saus	1747	1801	964	dweil	2463	2718	1139	pech	1455	2235	917
sauce	8.7	8.7	13	*rag*	8.7	21.7	8.7	*bad luck*	39.1	8.7	0
zoet	1807	1619	824	kraag	2351	2343	977	tand	2466	2176	890
sweet	4.3	0	4.3	*collar*	13	4.3	8.7	*tooth*	13	4.3	0

dijk	1898	2162	1010	pret	2654	2139	888	hemd	2563	2497	1053
dike	21.7	8.7	0	*fun*	26.1	0	0	*shirt*	8.7	13	8.7
High frequency-based consistent pseudowords											
bins	2435	2497	1007	gruin	2901	2436	969	meus	2903	2522	1305
	13	4.3	0		13	0	4.3		34.8	13	0
wans	2529	2694	1248	droer	2487	2701	1072	bien	3505	2450	1040
	8.7	8.7	4.3		30.4	13	0		0	4.3	0
kang	3206	2837	1331	broel	2640	2180	1013	huim	2161	2058	1015
	21.7	8.7	8.7		0	8.7	0		8.7	4.3	4.3
sils	2823	3002	1280	klaan	2475	2433	1203	neek	2332	1750	1008
	8.7	8.7	4.3		34.8	13	0		8.7	0	4.3
noms	2172	2184	896	moen	2920	2668	1142	duuk	2741	2814	1025
	8.7	4.3	0		0	0	4.3		60.9	34.8	13
High frequency-based inconsistent pseudowords											
heeg	1943	2090	1058	jeut	2058	2438	981	drot	2522	2773	1082
	.261	4.3	0		0	0	0		8.7	4.3	0
muid	2311	2062	1085	vlein	2378	2975	1017	kest	2947	2800	1247
	21.7	4.3	0		8.7	0	0		52.2	8.7	4.3
hijn	1852	2074	1196	krein	2559	2815	1086	gond	3075	3130	1310
	43.5	8.7	4.3		26.1	8.7	0		47.8	8.7	13
deis	2429	2602	1059	stoog	2793	2789	1125	pich	2442	2998	954
	13	0	0		8.7	4.3	8.7		13	4.3	0
fouw	2196	2872	1155	krouw	2423	2488	1095	voch	2721	2533	1020
	65.2	39.1	8.7		39.1	4.3	0		30.4	8.7	8.7

(continued)

Low-frequency based consistent pseudowords											
doers	2392	2309	1020	zwoom	2456	2545	1112	weuf	2233	2686	984
	8.7	0	0		13	0	4.3		8.7	4.3	0
huks	2560	2725	1135	knum	2717	2848	951	duil	2469	2542	1106
	8.7	0	0		8.7	4.3	0		13	4.3	0
somp	2966	2772	1070	kloer	2434	2560	1099	luun	2293	2527	1201
	21.7	4.3	8.7		4.3	4.3	4.3		30.4	21.7	13
dink	2695	2806	1102	vluik	2561	2523	1192	liek	2424	2424	1161
	39.1	13	4.3		21.7	0	4.3		8.7	0	0
raks	2484	3055	1130	blier	2702	3301	1245	poor	2277	2588	1080
	8.7	8.7	0		4.3	8.7	4.3		8.7	0	4.3
Low-frequency based inconsistent pseudowords											
keeg	2368	2624	1197	sauw	2807	2283	1103	prug	2468	2457	1056
	21.7	0	0		30.4	0	0		8.7	4.3	0
seis	2380	2328	1382	brijm	2817	2416	1052	ploot	2687	2877	1162
	39.1	13	8.7		13	4.3	0		4.3	13	8.7
baus	2822	2431	1034	breil	2860	2712	1087	bech	2200	2528	1072
	13	13	4.3		13	4.3	0		13	4.3	4.3
noet	2272	2051	998	braag	2703	2801	1118	tard	2738	2934	1163
	4.3	4.3	0		13	8.7	4.3		8.7	8.7	0
hijf	2394	2194	925	kret	2634	3016	1192	hers	2713	2732	1234
	13	4.3	0		8.7	13	8.7		8.7	0	0