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What the reader's eye tells the mind's ear: Silent reading activates inner speech

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Although copious research has investigated the role of phonology in reading, little research has investigated the precise nature of the entailed speech representations. The present study examined the similarity of "inner speech" in reading to overt speech. Two lexical decision experiments (in which participants gave speeded word/nonword classifications to letter strings) assessed the effects of implicit variations in vowel and word-initial consonant length. Responses were generally slower for phonetically long stimuli than for phonetically short stimuli, despite equal orthographic lengths. Moreover, the phonetic length effects displayed principled interactions with common factors known to affect lexical decisions, such as word frequency and the similarity of words to nonwords. Both phonetic length effects were stronger among slower readers. The data suggest that acoustic representations activated in silent reading are best characterized as inner speech rather than as abstract phonological codes.

It is not uncommon for readers to experience "inner voices" during silent reading (Huey, 1908/1968). This appears to be an elusive experience; inner speech is most prominent in beginning readers, or when fluent readers process difficult text (Coltheart, Besner, Jonasson, & Davelaar, 1979). Despite its ephemeral nature, inner speech is interesting, considering the hotly debated role of phonology in silent reading. For example, dual-route theory states that word meanings are accessed through either a direct visual route or a phonological route (Coltheart, 1978; Donnenworth-Nolan, Tanenhaus, & Seidenberg, 1981; McCusker, Hillinger, & Bias, 1981; Seidenberg, Waters, Barnes, & Tanenhaus, 1984). Phonology is presumably the slower route because it entails translation of printed words into a speech code prior to lexical access. Thus, dual-route theory posits that phonology is used primarily by unskilled readers or when words are unfamiliar, as these situations preclude direct visual access.

Other theories, however, argue that phonology is always used in reading. To date, most evidence for direct visual access consists of null effects that are inherently difficult to interpret (Van Orden, 1987; Van Orden, Pennington, & Stone, 1990). However, copious positive evidence supports phonology's role in reading even in skilled readers. For example, Van Orden (1987) asked college students to verify if words were exemplars of categories. Given a category such as *animal*, participants made many false-positive errors to homophone foils, such as *bare*, relative to spelling control foils, such as *bade*. This finding, along with many others (e.g., Glushko, 1979; Healy, 1976; Lukatela & Turvey, 1993) indicates that phonology affects silent reading, regardless of a reader's skill.

Whatever researchers believe about its role in lexical access, most agree that phonology is involved postaccess to help store words in working memory for sentence comprehension (Baddeley, Thomson, & Buchanan, 1975; Huey, 1908/1968; McCutchen & Perfetti, 1982; Meyer, Schvaneveldt, & Ruddy, 1974; Perfetti, Zhang, & Berent, 1992). Although the role of phonology in reading has been studied extensively, few researchers have tried to define the nature of the implied phonological representations (McCusker et al., 1981). Are they similar to overt speech, such that readers experience "inner voices," or are they more abstract?

Phonology as Inner Speech?

In his well-known treatise on reading, Huey (1908/1968) proposed that phonological representations in reading were auditory in nature. He observed that silent reading involved auditory imagery, or a "voice in the head." Because some people do not notice this voice while reading, Huey explained that inner speech became abbreviated, hence less salient, as readers became more skilled. A closely related view is that inner speech entails *subarticulation*. Stricker (1880) proposed that silent reading was impossible without some movement of the larynx and lips. Behaviorists adopted this view, and mentalistic ideas such as auditory imagery were dropped in favor of more concrete, observable behaviors. Watson (1919) asserted that thought was rooted in overt speech, which became subarticulated as we matured. He proposed the same developmental sequence for reading. Beginning readers sounded out words overtly, and this vocalized reading gradually became internalized, covert speech.

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Given Watson's hypothesis, subarticulation became a popular topic of investigation. Reed (1916) found that subjects moved their tongues when reading text silently, whispering text, and reading text aloud, but not when they sat relaxed. The only differences in the three reading conditions were the amplitudes of tongue movements. Faaborg-Anderson and Edfeldt (1958) found that activity in vocal musculature increased with difficulty of text (see also Hardyck & Petrinovich, 1970; Sokolov, 1972). Despite these findings, it is not clear that silent reading always entails subvocal speech. As counterexamples, studies suggest that inner speech is faster than overt speech (Anderson, 1982; Foss & Hakes, 1978), that inner speech lags behind comprehension (Gough, 1972; Rohrman & Gough, 1967; although see McGuigan, 1984), and that thought can occur without subarticulation (Smith, Brown, Toman, & Goodman, 1947).

Given these conflicting results, McCusker et al. (1981) concluded that subarticulation was not necessary for reading; it might simply be epiphenomenal. Even so, McGuigan (1984) noted that subarticulation had lawful properties. For example, as cognitive workload increased, so did subvocal activity. Even if subarticulation is epiphenomenal, it may have heuristic value for readers, and its regularities make it suitable for continued study.

Phonology as Abstract Representations?

Phonology, as it is activated in reading, has also been described as abstract representations or codes (Fredriksen & Kroll, 1976; McCusker et al., 1981; Meyer et al., 1974; Spoehr & Smith, 1971). For example, phonology may be included in a model as idealized nodes, as in connectionist models (Seidenberg & McClelland, 1989). McCusker et al. (1981) use the term "phonological recoding" for the process of deriving such codes from printed input, suggesting mental representations based on speech sounds but without specifying form or constraints. Indeed, they state, "Opting for this term begs rather than answers some fundamental questions, and a high priority should be assigned to studies aimed at more precisely describing the nature of the internal representation" (p. 218).

The Evidence Thus Far

To the degree that research has followed this line of inquiry, it appears that phonological representations are quite similar to spoken phonology. Klapp (1971), for example, found a syllable-length effect in a same/different task using pairs of numbers. Although the stimuli were presented in digit form (e.g., 17–17 or 28–17), subjects were slower when the stimulus names contained more syllables. Klapp suggested that reading entailed implicit speech, which behaved like overt speech, at least with respect to syllable duration. More recently, McCutchen and Perfetti (1982) reported "visual tongue-twister" effects. Volunteers silently read sentences to determine if they made sense. Some sentences were alliterative tongue twisters (e.g., "Twenty toys were in the trunk"); others were neutral (e.g., "Several games were in the chest"). Semantic-judgment response times (RTs) were longer for the tongue twisters. This effect replicates with deaf participants, using both tongue twisters (Hanson, Goodell, & Perfetti, 1991) and ASL "finger-fumblers" (Klima & Bellugi, 1979), and with Chinese readers (Perfetti et al., 1992; Zhang & Perfetti, 1993). These findings suggest that phonological representations in reading are similar to overt speech, and may be less abstract than is often assumed.

In speech, a variety of phonetic regularities are well documented (e.g., Chen, 1970; Chomsky & Halle, 1968; Klatt, 1976; Peterson & Lehiste, 1960; Stevens & House, 1963). One relevant example is that the durations of speech sounds often depend upon surrounding, coarticulated speech sounds. Some combinations of phonemes take longer to say than others, as the articulators must be configured differently. If phonology in reading entails inner speech, rather than purely abstract codes, it should exhibit similar phonetic variations. The present investigation examined duration-based phonetic variations in lexical decision. Experiment 1 tested for effects of vowel length; Experiment 2 tested for effects of both vowel length and word-initial consonant length. In each experiment, these phonetic variables were crossed with classic lexical-decision variables, such as word frequency and the difficulty of word–nonword discrimination (Stone & Van Orden, 1993). Thus, principled interactions could be examined.

EXPERIMENT 1

In natural speech, spoken-word durations are typically changed as a function of vowel duration (Port, 1981). Such changes are often caused by surrounding consonants, usually the consonant following the vowel. One well-established effect is that vowels are typically lengthened when followed by voiced consonants (e.g., *d*, *b*, *m*), relative to voiceless consonants (e.g., *p*, *t*, *k*; see Chen, 1970; Chomsky & Halle, 1968; Klatt, 1976; Peterson & Lehiste, 1960; Stevens & House, 1963). The coarticulation, or blending of the vowel and subsequent consonant, leads to this *vowel-length effect*. For example, assuming equivalent speaking rates, the vowel in BAD is slightly longer than the vowel in bat. Port (1981) found that, in monosyllabic English words, vowels followed by voiceless consonants were 34% shorter than the same vowels followed by voiced consonants. Similarly, House and Fairbanks (1953) reported that vowels followed by voiceless consonants averaged 165 msec, while vowels followed by voiced consonants averaged 255 msec. In general, the dynamic range of vowel duration varies from 40 to 235 msec (Umeda, 1975).

If phonology in silent reading entails inner speech, this vowel-length effect may be observed in lexical decision. The variables studied in Experiment 1 were vowel length (i.e., subsequent consonants were voiced vs. voiceless), word frequency (low vs. high), lexicality (word vs. nonword), and nonword type (pseudohomophones vs. legal nonwords). Vowel-length effects were predicted; we expected slower responses to long-vowel stimuli than to short-vowel stimuli. It is well known that high-frequency words are less susceptible than low-frequency words to manipulations of phonological variables (Jared, McRae, & Seidenberg, 1990; Waters & Seidenberg, 1985), so word frequency was expected to interact with vowel length.

Since nonwords are similar to low-frequency words (as they are unfamiliar to the reader), they were expected to be more affected than words by variations in vowel length. However, all nonwords were not expected to behave equally. Two types of nonwords were used in a between-subjects design. The *legal nonwords* (e.g., *lape*) were pronounceable, nonsense letter strings. The *pseudohomophones* (e.g., *laik*) were both pronounceable and word-like (i.e., misspelled words).[1] Lexical decisions are typically slower for words in the context of pseudohomophones than for legal nonwords (Lewellen, Goldinger, Pisoni, & Greene, 1993; Stone & Van Orden, 1993). When the difficulty of word/nonword discrimination is increased, each letter string receives more careful analysis (Balota & Chumbley, 1984). Assuming that "more careful analysis" entails more salient inner speech, effects of vowel length should be stronger in the pseudohomophone context than in the legal-nonword context. Finally, participants' reading speeds were expected to correlate with the magnitude of vowel-length effects. Previous studies show that slower readers are most affected by phonology (Coltheart, 1978; Coltheart et al., 1979). Therefore, slower readers were expected to display stronger vowel-length effects.

Method

Subjects. Fifty-six introductory psychology students at Arizona State University participated for course credit. All were right-handed, native speakers of English, and all had normal or corrected vision.

Stimulus materials. The 264 monosyllabic stimuli used in Experiment 1 included 88 words, 88 legal nonwords, and 88 pseudohomophones. Half of each type of stimuli had long vowels and half had short vowels (as determined by subsequent voiced or voiceless consonants). Equal numbers of four- and five-letter stimuli were used. Half of the words were of low frequency (<10 per million) and half were of high frequency (>20 per million; Kučera & Francis, 1967). All words, however, were previously rated as familiar (above 5 on a 7-point scale; Nusbaum, Pisoni, & Davis, 1984), and were well balanced in terms of neighborhood size and neighborhood frequency (using the "N metric"; Coltheart, 1978; Grainger, O'Regan, Jacobs, & Segui, 1989). Appendix A shows all stimuli except for the words and nonwords used in 10 practice trials.

Procedure. Students were tested in a lexical decision task in groups of 4. A mixed analysis of variance (ANOVA) design was used, with all variables except nonword type manipulated within subjects. Half of the groups received words and legal nonwords; half received words and pseudohomophones. The subjects were seated approximately 50 cm from computer monitors. Each trial began with a row of asterisks (*****) in the center of the screen. After 400 msec, a word or nonword replaced the asterisks. These stimuli were presented in uppercase letters, approximately 4 mm wide and 5 mm high, with approximately 2 mm of space between letters. Each letter subtended a visual angle of about 22′ horizontal and 50′ vertical. The stimulus remained visible for 750 msec or until everyone responded. The subjects indicated the lexical status of each stimulus with a response box, pressing the right button for "word" or the left button for "nonword." They were instructed to respond as quickly and accurately as possible. If a response was not registered within 2 sec, the trial was counted as an error. All groups were given 10 practice trials before the experimental trials. A 2- to 3-min rest period separated the first 88 experimental trials and the last 88.

After the lexical decision task, the subjects were individually tested for reading speed on a separate computer. A short story was presented across seven screens on the computer monitor. The subjects read each screen, pressing the space bar to continue until the story was finished and a blank screen appeared. Then a short story comprehension test was administered. The computer collected display times for each screen, thus providing an estimate of reading speed for each participant.

Results and Discussion

Before data analysis, all outlier trials (RTs < 200 msec or > 2,000 msec) were removed. These accounted for less than 1% of the data. The RT and accuracy data were first analyzed in omnibus ANOVAs that examined the entire experimental design. These were followed by ANOVAs conducted on the words across both nonword types to assess frequency effects.

All items: Response times. The analyses on all items included the variables vowel length, lexicality, and nonword type. All analyses included separate ANOVAs conducted on subject and item means (Clark, 1973).[2] The upper panel of Figure 1 displays mean RTs and the lower panel displays mean error rates. Both panels show the data as a function of vowel length, lexicality, and nonword type. Short-vowel items (M = 570.9 msec) were classified faster than long-vowel items (M = 600.9 msec) [F(1,54) =

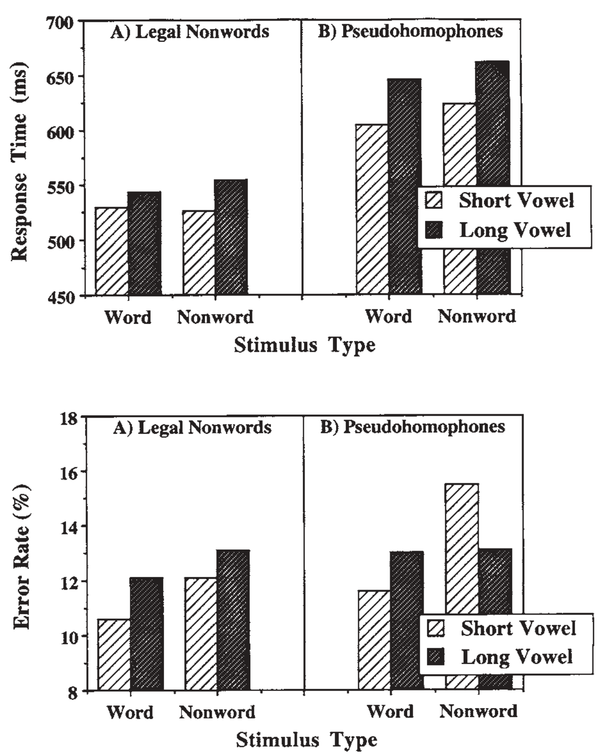

Figure 1. Experiment 1: Mean response times (upper panels) and error rates (lower panels) for all stimulus items, as a function of vowel length, lexicality, and nonword type.

186.40, $p < .0001$]. Responses were also faster in the legal-nonword condition ($M = 537.9$ msec) than in the pseudohomophone condition ($M = 633.9$ msec) [$F(1,54) = 21.91, p < .0001$]. Also, words ($M = 580.3$ msec) were classified as faster than nonwords ($M = 591.6$ msec) [$F(1,54) = 25.16, p < .0001$], although further analysis showed that this was reliable only in the pseudohomophone condition [$F(1,27) = 30.58, p < .0001$] and not in the legal-nonword condition [$F(1,27) = 1.56, p = .2218$]. This pattern emerged along several other dimensions: The lexicality effect was larger in the pseudohomophone condition (18.9 msec) than in the legal-nonword condition (3.7 msec) [$Fs(1,54) = 11.49, p < .002$]. The vowel-length effect was also larger in the pseudohomophone condition (39.6 msec) than in the legal-nonword condition (20.4 msec) [$F(1,54) = 19.18, p < .0001$]. No significant interaction was observed between vowel length and lexicality [$F(1,54) = 1.21, p = .3219$], despite a trend toward a stronger vowel-length effect for legal nonwords (27.5 msec) than for words (13.3 msec).

All items: Error rates. As shown in the lower half of Figure 1, fewer errors were made to words ($M = 11.9\%$) than to nonwords ($M = 13.5\%$) [$F(1,54) = 8.22, p < .01$], primarily due to the pseudohomophone condition. No main effects of nonword type [$F(1,54) = 0.93, p = .3393$] or vowel length [$F(1,54) = 0.22, p = .6389$] and no interactions involving these factors were observed.

Words only: Response times. The upper half of Figure 2 shows mean RTs and the lower half shows mean error rates, each as a function of vowel length, frequency, and nonword type. Short-vowel words ($M = 567.1$ msec) were classified faster than long-vowel words ($M = 595.5$ msec) [$F(1,54) = 51.49, p < .0001$]. Words were classified faster in the legal-nonword condition ($M = 536.2$ msec) than in the pseudohomophone condition ($M = 625.3$ msec) [$F(1,54) = 17.67, p < .0001$]. Also, high-frequency words ($M = 558.7$ msec) were classified faster than low-frequency words ($M = 602.8$ msec) [$F(1,54) = 136.43, p < .0001$].

The vowel-length effect was considerably stronger for low-frequency words (47.2 msec) than for high-frequency words (7.5 msec) [$F(1,54) = 28.10, p < .0001$]. The vowel-length effect was stronger for words in the pseudohomophone condition (42.9 msec) than in the legal-nonword condition (11.7 msec) [$F(1,54) = 16.76, p < .0001$]. The frequency effect was also stronger for words in the pseudohomophone condition (55.6 msec) than for those in the legal-nonword condition (32.6 msec) [$F(1,54) = 9.22, p < .01$]. The three-way interaction of vowel length, frequency, and nonword type was not significant [$Fs(1,54) = 0.28, p = .6005$]. Accuracy analyses on the words showed no reliable main effects or interactions.

Reading speed. Each subject's reading speed was estimated via the mean RT for the five middle screens of the reading test. (Because subjects often forgot to press the space bar after the first and last screens, RTs to screens 1 and 7 were not included.) The magnitude of the vowel-length effect for each participant was determined by subtracting mean short-vowel RTs from mean long-vowel RTs. Correlations of reading speed and the vowel-length effect were then examined. Significant positive correlations were found for the legal nonwords [$r(54) = .40, p < .05$] and the pseudohomophones [$r(54) = .54, p < .01$], showing that vowel-length effects in these stimuli were larger for slower readers. Despite trends in the same direction, no significant correlations were found for words in the legal-nonword [$r(54) = .06, p = .76$] or the pseudohomophone context [$r(54) = .09, p = .93$].

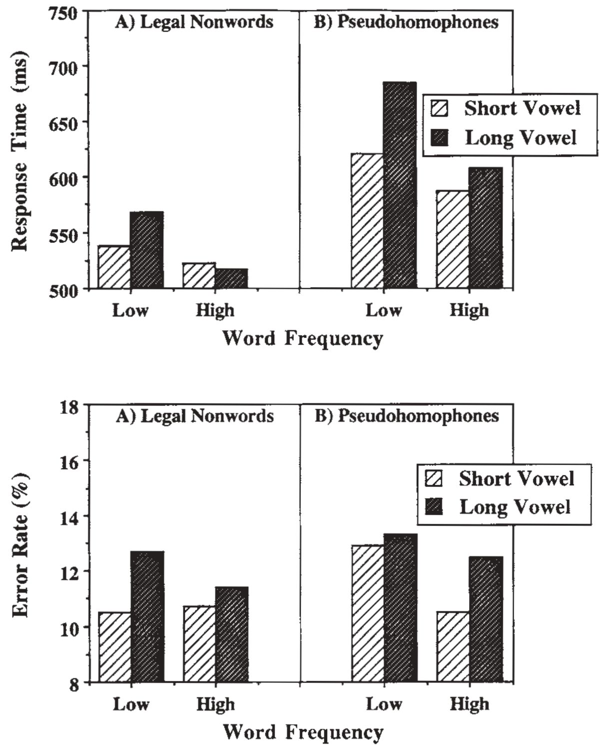

Figure 2. Experiment 1: Mean response times (upper panels) and error rates (lower panels) for words, as a function of vowel length, word frequency, and nonword type.

The effects typically observed in lexical decision were observed in Experiment 1. Words were classified faster and more accurately than nonwords.[3] High-frequency words were classified faster than low-frequency words. Words and nonwords were classified faster in the legal-nonword context than in the pseudohomophone context. There were also predictable interactions of nonword type and lexicality, and of nonword type and frequency. As in previous research (Lewellen et al., 1993; Stone & Van Orden, 1993), all effects were magnified in a context of pseudohomophones relative to a context of legal nonwords.

Of primary importance were the observed vowel-length effects. In general, short-vowel stimuli were classified faster than long-vowel stimuli, suggesting that silent reading activates inner speech. If phonological representations were purely abstract codes, they would not exhibit this characteristic of overt speech. In addition to this main effect, the vowel-length effect was stronger for low-frequency words than for high-frequency words. Previous research shows that low-frequency words are more susceptible to phonological variables, such as spelling–sound consistency, than are high-frequency words (Jared et al., 1990; Waters & Seidenberg, 1985). The vowel-length effect was also stronger when pseudohomophones were used than when legal nonwords were used. This was likely due to the increased difficulty of discrimination in the pseudohomophone context (Balota & Chumbley, 1984). Surprisingly, vowel length did not interact with lexicality, showing equivalent effects in words and nonwords.

The correlations observed between reading speed and vowel length suggest that slower readers are more affected by inner speech, at least when processing nonwords. These data resemble previous findings that phonology has stronger effects in slower readers and for less familiar stimuli (Coltheart et al., 1979). This does not mean that readers were unaffected by vowel length in words; the main effect was robust (see Figure 2). However, participants' reading fluency predicted their sensitivity to vowel length only when correctly rejecting nonwords. Less skilled readers may have a particularly difficult time discriminating between nonwords and low-frequency words (Lewellen et al., 1993). This may lead to the "extra analysis" suggested by Balota and Chumbley (1984) and therefore increase the vowel-length effect for these readers.

Overall, Experiment 1 suggested that phonological representations activated in silent reading might be inner speech, which behaves like overt speech. Because vowel-length effects are coarticulatory in nature, these data suggest that inner speech occurs in reading. One would not expect coarticulation effects in abstract phonological codes. Because consonants surrounding the vowels are inherent to this effect, the effects of word-initial consonant length, along with vowel length, were assessed in Experiment 2.

EXPERIMENT 2

Another phonetic variable that affects spoken-word duration is the length of initial consonants. In speech, certain consonants (e.g., *s*, *sh*, *ch*, *r*, *f*) are longer than others (e.g., *p*, *k*, *t*; see Ladefoged, 1975). On average, fricatives are about 79 msec longer than stop consonants. Stops in word-initial position are almost immeasurable, although voiceless stops have a voice onset time (VOT) of up to 30 msec. There is no measurable VOT for voiced stops in word-initial position (Port, 1979; Umeda, 1977). Stop consonants in word-initial position, therefore, have a durational range approximating 0–30 msec, whereas fricatives, liquids, and glides have a range approximating 70–115 msec (Umeda, 1977). If inner speech resembles overt speech, this is another source of phonetic variation that we may detect in lexical decision. Moreover, this manipulation might augment the effects observed in Experiment 1. Previous research suggests that inner speech is "articulated" faster than overt speech (Anderson, 1982; MacKay, 1981; Weber & Castleman, 1970).

Apparently, inner speech clearly "articulates" only word beginnings (Sokolov, 1972), which may be sufficient to activate meaning (Marslen-Wilson & Welsh, 1978). Dell and Repka (1993) found evidence for such inner-speech truncation by studying "slips of the tongue" in overt and inner speech. Half of their participants said phrases aloud; half *imagined* saying them. Some phrases were tongue twisters (e.g., "a bucket of blue bug's blood"), some were pseudo tongue twisters (e.g., "my nice new nightshirt"), and some were not tongue twisters (e.g., "many new candlesticks"). (The pseudo tongue twisters were used to reduce demand characteristics.) If both the inner- and overt-speech groups primarily made slips to the tongue twisters, it would seem that bona fide inner speech occurs when people imagine speaking. Although Dell and Repka found more overt slips than self-reported inner-speech slips, the majority of both kinds of slips occurred on the tongue twisters. Also, inner-speech slips occurred mostly at word beginnings, suggesting that inner speech was characterized more by word beginnings than by complete words. Given the prominence of word beginnings in inner speech, this was examined directly in Experiment 2.[4]

In Experiment 2, word-initial consonant length was manipulated in addition to vowel length, word frequency, lexicality, and stimulus context. As in Experiment 1, reading speeds were assessed and were expected to correlate with the magnitudes of consonant- and vowel-length effects. Slower readers were expected to show greater sensitivity to both phonetic manipulations.

Method

Subjects. Forty-four introductory psychology students participated for class credit. All were right-handed native speakers of English and had normal or corrected vision.

Stimulus materials. The 360 monosyllabic stimuli used in Experiment 2 included 120 words, 120 legal nonwords, and 120 pseudohomophones. Half of the words were of low frequency (<10 per million), and half were of high frequency (>20 per million; Kučera & Francis, 1967). All words met the familiarity criterion used in Experiment 1, and were balanced in terms of neighborhood characteristics. One fourth of each type of stimulus had short initial consonants and short vowels, one fourth had short initial consonants and long vowels, one fourth had long initial consonants and short vowels, and one fourth had long initial consonants and long vowels. All stimuli were monosyllabic and four letters long. Appendix B lists all stimuli and shows descriptive statistics for the words. Ten practice stimuli are not listed in Appendix B.

Procedure. The design and procedures were the same as in Experiment 1. Nonword type was a between-subjects variable, with all other variables manipulated within subjects. Half of the groups received words with legal nonword foils; half received the same words with pseudohomophone foils. The experiment began with 10 practice trials, followed by 120 experimental trials. After a 2- to 3-min rest period, the subjects completed the remaining 120 experimental trials. After the lexical decision task, participants were individually tested in the reading task used in Experiment 1.

Results and Discussion

Before data analysis, all outlier trials (mean RTs < 200 msec or >2,000 msec) were removed. These trials constituted less than 2% of the data. As in Experiment 1, omnibus ANOVAS were first conducted on the entire design. Next, separate ANOVAs examined only the "word" trials across both nonword types so that frequency effects could be assessed.

All items: Response times. The all-item analyses included the variables consonant length, vowel length, lexicality, and nonword type. The upper half of Figure 3 displays all mean RTs, and the lower half shows all mean error rates. Regarding first the new manipulation, short-consonant items (M = 558.4 msec) were classified slightly faster than long-consonant items (M = 567.0 msec) [$F(1,42) = 11.89$, $p < .002$]. However, this was reliable only in the legal-nonword condition [$F(1,21) = 9.33$, $p < .01$]. No interactions were observed between consonant length and nonword type [$F(1,42) = 0.24$, $p = .6261$] or between consonant length and lexicality [$F(1,42) = 0.67$, $p = .4192$].

As in Experiment 1, short-vowel items (M = 549.9 msec) were classified faster than long-vowel items (M = 573.2 msec) [$F(1,42) = 102.35$, $p < .0001$], and this effect was larger in the pseudohomophone condition (28.0 msec) than in the legal-nonword condition (18.6 msec) [$F(1,42) = 4.14$, $p < .05$]. No interactions were observed between vowel length and lexicality [$F(1,42) = 0.08$, $p = .7724$] or between vowel length and consonant length [$F(1,42) = 0.64$, $p = .4266$]. Responses were faster to words (M = 545.3 msec) than to nonwords (M = 580.1 msec) [$F(1,42) = 131.74$, $p < .0001$]. Responses were also faster in the legal nonword condition (M = 524.9 msec) than in the pseudohomophone condition (M = 598.2 msec), [$F(1,42) = 13.10$, $p < .001$]. No interaction emerged between lexicality and nonword type [$F(1,42) = 0.01$, $p = .9063$].

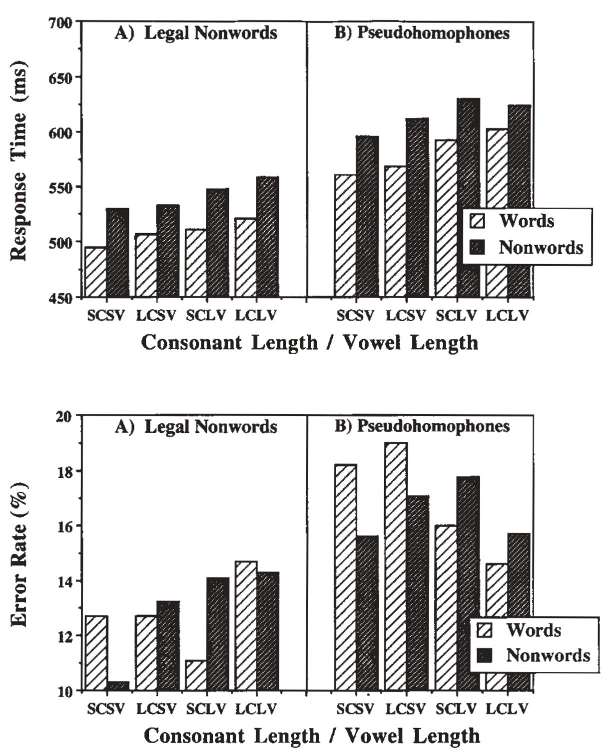

Figure 3. Experiment 2: Mean response times (upper panels) and error rates (lower panels) for all stimulus items, as a function of consonant length, vowel length, lexicality, and nonword type. The abbreviations SC, LC, SV, and LV denote short consonant, long consonant, short vowel, and long vowel, respectively.

All items: Error rates. As shown in the lower half of Figure 3, error rates were higher in the pseudohomophone condition (M = 15.8%) than in the legal nonword condition (M = 12.2%) [$F(1,42) = 5.94$, $p < .02$]. The main effects of vowel length [$F(1,42) = 0.01$, $p = .9403$] and lexicality [$F(1,42) = 0.20$, $p = .8850$] were both unreliable. Collapsing over consonant length, most errors were made to short-vowel items in the pseudohomophone condition (M = 17.4%), followed by long-vowel items in the pseudohomophone condition (M = 16.0%), long-vowel items in the legal-nonword condition (M = 13.6%), and short-vowel items in the legal-nonword condition (M = 12.2%) [$F(1,42) = 4.70$, $p < .05$]. Neither the main effect of consonant length [$F(1,42) = 1.18$, $p = .2844$] nor any of its interactions were reliable.

Words only: Response times. The upper half of Figure 4 displays mean RTs for words as a function of consonant length, vowel length, frequency, and nonword type. The lower half of Figure 4 shows mean error rates. Regarding first the new manipulation, responses were faster to short-consonant words (M = 539.5 msec) than to long-consonant words (M = 549.5 msec) [$F(1,42) = 6.50$, $p < .02$]. The consonant length effect was larger for low-frequency words (16.5 msec) than for high-frequency words (3.4 msec) [$F(1,42) = 4.96$, $p < .05$]. As before, high-frequency words (M = 533.8 msec) were classified faster than low-frequency words (M = 555.2 msec) [$F(1,42) = 10.44$, $p < .01$], and words were classified faster in the legal nonword condition (M = 508.01 msec) than in the pseudohomophone condition (M = 581.0 msec) [$F(1,42) = 13.54$, $p < .001$]. No interactions were observed between consonant length and nonword type [$F(1,42) = 0.08$, $p = .7846$] or between frequency and nonword type [$F(1,42) = 0.63$, $p = .4330$].

Responses were faster to short-vowel words (M = 532.5 msec) than to long-vowel words (M = 556.5 msec) [$F(1,42) = 45.31$, $p < .0001$]. As before, the vowel length effect was greater in the pseudohomophone condition (32.6 msec) than in the legal-nonword condition (15.4 msec) [$F(1,42) = 5.85$, $p < .02$], and it was greater for low-frequency words (33.3 msec) than for high-frequency words (14.7 msec) [$F(1,42) = 8.73$, $p < .01$]. No interaction was observed between vowel length and consonant length [$F(1,42) = 0.01$, $p = .9042$].

Words only: Error rates. As shown in the lower half of Figure 4, more errors were made to words in the pseudohomophone condition (M = 16.0%) than to words in the legal-nonword condition (M = 12.8%) [$F(1,42) = 5.28$, $p < .05$]. The main effects of frequency [$F(1,42) = 0.24$, $p = .6232$], vowel length [$F(1,42) = 2.76$, $p = .1039$], and consonant length [$F(1,42) = 0.91$, $p = .3444$] were all unreliable. Collapsing over consonant length, most errors were made to short-vowel high-frequency words (M = 20.5%), followed by short-vowel low-frequency words

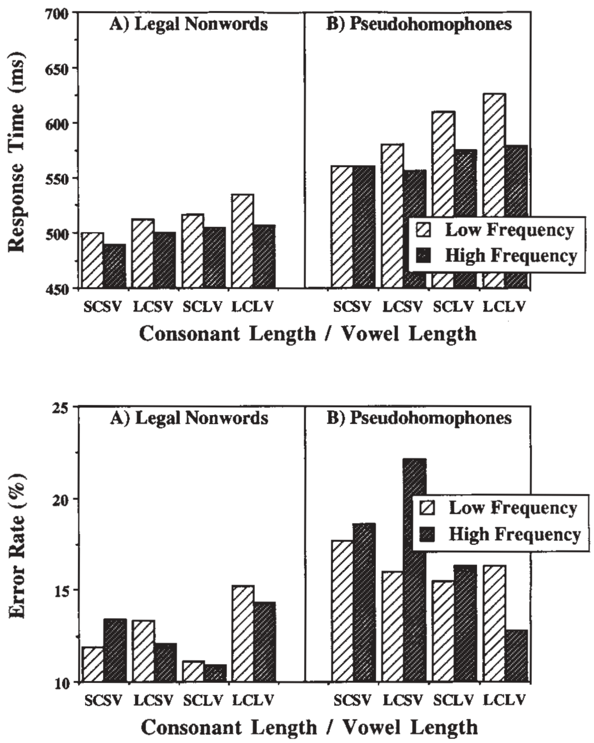

Figure 4. Experiment 2: Mean response times (upper panels) and error rates (lower panels) for words, as a function of consonant length, vowel length, word frequency, and nonword type. The abbreviations SC, LC, SV, and LV denote short consonant, long consonant, short vowel, and long vowel, respectively.

(M = 16.8%), long-vowel low-frequency words (M = 15.9%), and long-vowel high-frequency words (M = 14.6%) [$F(1,21) = 4.78, p < .05$].

Reading speed. As in Experiment 1, each participant's reading speed was estimated by mean RTs for the five middle screens of the reading test. The magnitude of each participant's vowel- and consonant-length effects were determined by subtraction. As in Experiment 1, significant positive correlations were found between reading speed and the vowel-length effect for the legal nonwords [$r(42) = .55, p < .05$] and for the pseudohomophones [$r(42) = .53, p < .01$]. There was also a smaller, significant correlation for words in the pseudohomophone condition [$r(42) = .35, p < .05$], but not for words in the legal nonword condition [$r(42) = .01, p = .99$]. Thus, in responding to most stimuli, slower readers were more strongly affected by the vowel-length manipulation.

A positive correlation between reading speed and the consonant-length effect approached significance for legal nonwords [$r(42) = .41, p = .07$], and a significant correlation was observed for words in the pseudohomophone condition [$r(42) = .49, p < .05$]. There were no significant correlations of reading speed and the consonant-length effect for words in the legal-nonword condition [$r(42) = .08, p = .81$] or for pseudohomophones [$r(42) = -.05, p = .90$]. Slower readers were thus slightly more affected by the consonant-length manipulation.

As in Experiment 1, the lexicality, nonword type, and frequency variables all displayed their expected effects. The vowel-length effect found in Experiment 1 was replicated in Experiment 2, although it was slightly less robust. For example, vowel length interacted with frequency and nonword type, but neither interaction was significant by items in Experiment 2. The consonant-length effect was significant, but there was only a 9-msec difference between short- and long-consonant items. In real speech, the durational range of initial consonants is small relative to that of vowels[5] (Port, 1979; Umeda, 1975, 1977). Thus, the relatively small consonant-length effect may reflect this smaller range of natural variation. The consonant-length effect was slightly stronger for low-frequency words, although this interaction was not reliable by the item analysis. In terms of reading speeds, the data again suggested that slower readers and less familiar items were more sensitive to phonological manipulations (Coltheart et al., 1979).

GENERAL DISCUSSION

The present data suggest that phonological representations activated in silent reading are best characterized as inner speech. In general, lengthening the vowel or initial consonant of words and nonwords increased lexical decision times, although vowel-length effects were much stronger than consonant-length effects. Most likely, consonant-length effects are small because consonants are much shorter than vowels in real speech, and their range of variation is smaller (Port, 1979; Umeda, 1975, 1977). The vowel- and consonant-length effects resemble previously reported phonological effects, as they were stronger for lower frequency words and stronger in a context of pseudohomophones relative to legal nonwords. Previous research has shown that lower frequency words are more affected by phonological variables (Jared et al., 1990; Waters & Seidenberg, 1985), and that stimulus effects in lexical decision are strongest when pseudohomophone foils are used (Lewellen et al., 1993; Stone & Van Orden, 1993). The predicted interaction between nonword type and consonant length did not emerge, presumably because the consonant-length effect was so small. Perhaps, by increasing the task difficulty, the consonant effect would increase and the predicted interaction could be measured.

Prior research has shown that phonological variables, such as spelling–sound consistency, affect slower readers more than faster readers (Coltheart, 1978; Coltheart et al., 1979). This correlation also held true for vowel- and consonant-length effects. In Experiment 1, the magnitude of vowel-length effects positively correlated with reading speed, at least for pseudohomophones and legal nonwords. These results were replicated in Experiment 2, with an additional positive correlation for words in the pseudohomophone condition. The magnitude of the consonant-length effect also correlated positively with reading time, at least for words in the pseudohomophone condition and for legal nonwords. (Naturally, in both experiments, correlations combining all stimuli were significant. We reported the stimulus categories separately to provide a complete view of the data.) According to dual-route theory, these data reflect a greater reliance on phonology when items are unfamiliar or when readers are relatively unskilled. By extension, we may predict that phonetic length effects would be stronger in children who are just beginning to read than in the college students tested in the present study.

Although the present data suggest that silent reading entails inner speech, a few caveats are in order. Our lexical decision task was quite difficult, especially relative to normal silent reading. Participants had to quickly discriminate words from nonwords. Often the nonwords sounded like real words, and the real words were often uncommon (although familiar). The relatively high error rates in each experiment, especially in the pseudohomophone conditions, attest to this difficulty. It remains to be seen if these inner-speech effects will generalize to more natural reading tasks. Also, the data do not imply that inner speech is *necessary* for reading; it may simply be epiphenomenal to word perception and/or reading.

Moreover, the present results do not uniquely support any model of reading or word perception. Although our results are consistent with dual-route theory (Coltheart, 1978; Coltheart et al., 1979; Donnenworth-Nolan et al., 1981; McCusker et al., 1981; Seidenberg et al., 1984), they are equally consistent with other prevailing models of reading, such as connectionist (McClelland & Rumelhart, 1981; Seidenberg & McClelland, 1989) or adaptive resonance models (Van Orden & Goldinger, 1994). It is interesting, however, that all participants, regardless of reading skill, were somewhat affected by vowel and consonant length, which appears contrary to a strong version of dual-route theory.

Huey (1908/1968) proposed that inner speech occurred in silent reading, primarily in unskilled readers. The present study tested this idea, combining well-known speech-production phenomena with visual word perception. It appears that phonological representations activated in silent reading share some characteristics with overt speech, at least in durational factors. It remains to be seen if other similarities exist between inner and overt speech, and if these effects generalize to normal silent reading. "Inner voices" may provide information about phonological representation that the term "phonological recoding" left unclear.

REFERENCES

Anderson, R. D. (1982). Speech imagery is not always faster than visual imagery. *Memory & Cognition*, **10**, 371-380.

Baddeley, A. D., Thomson, N., & Buchanan, M. (1975). Word length and the structure of short-term memory. *Journal of Verbal Learning & Verbal Behavior*, **14**, 575-589.

Balota, D. A., & Chumbley, J. I. (1984). Are lexical decisions a good measure of lexical access? The role of word frequency in the neglected decision stage. *Journal of Experimental Psychology: Human Perception & Performance*, **10**, 340-357.

Chen, M. (1970). Vowel length variation as a function of the voicing of the consonant environment. *Phonetica*, **22**, 129-159.

Chomsky, N., & Halle, M. (1968). *Sound patterns of English*. New York: Harper & Row.

Clark, H. H. (1973). The "language as fixed effect" fallacy: A critique of language statistics in psychological research. *Journal of Verbal Learning & Verbal Behavior*, **12**, 335-359.

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., Besner, D., Jonasson, J. T., & Davelaar, E. (1979). Phonological encoding in the lexical decision task. *Quarterly Journal of Experimental Psychology*, **31**, 489-505.

Dell, G. S., & Repka, R. J. (1993). Errors in inner speech. In B. J. Baars (Ed.), *Experimental slips and human errors: Exploring the architecture of volition* (pp. 237-262). New York: Plenum.

Donnenworth-Nolan, S., Tanenhaus, M., & Seidenberg, M. S. (1981). Multiple code activation in word recognition: Evidence from rhyme monitoring. *Journal of Experimental Psychology: Human Learning & Memory*, **7**, 170-180.

Faaborg-Anderson, K., & Edfeldt, A. W. (1958). Electromyography of intrinsic and extrinsic laryngeal muscles during silent speech correlate with reading activity. *Acta Otolaryngology*, **49**, 478-482.

Foss, D. J., & Hakes, D. T. (1978). *Psycholinguistics: An introduction to the psychology of language*. Englewood Cliffs, NJ: Prentice-Hall.

Fredriksen, J., & Kroll, J. (1976). Spelling and sound: Approaches to the internal lexicon. *Journal of Experimental Psychology: Human Perception & Performance*, **2**, 361-379.

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

Gough, P. B. (1972). One second of reading. In J. F. Kavanagh & I. G. Mattingly (Eds.), *Language by ear and by eye* (pp. 331-358). Cambridge, MA: MIT Press.

Grainger, J., O'Regan, K. J., Jacobs, A. M., & Segui, J. (1989). On the role of competing word units in visual word recognition: The neighborhood frequency effect. *Perception & Psychophysics*, **45**, 189-195.

Hanson, V. L., Goodell, E. W., & Perfetti, C. A. (1991). Tongue-twister effects in the silent reading of hearing and deaf college students. *Journal of Memory & Language*, **30**, 319-330.

Hardyck, C. D., & Petrinovich, L. F. (1970). Subvocal speech and comprehension level as a function of difficulty level of the reading material. *Journal of Verbal Learning & Verbal Behavior*, **9**, 647-652.

Healy, A. F. (1976). Detection errors on the word *the*: Evidence for reading units larger than letters. *Journal of Experimental Psychology: Human Perception & Performance*, **2**, 235-242.

House, A. S., & Fairbanks, G. (1953). The influence of consonant environment upon secondary acoustical characteristics of vowels. *Journal of the Acoustical Society of America*, **25**, 106-113.

Huey, E. B. (1968). *The psychology and pedagogy of reading*. Cambridge, MA: MIT Press. (Original work published 1908)

Jared, D., McRae, K., & Seidenberg, M. S. (1990). The basis of consistency effects in word meaning. *Journal of Memory & Language*, **29**, 687-715.

Klapp, S. T. (1971). Implicit speech inferred from response latencies in same-different decisions. *Journal of Experimental Psychology*, **91**, 262-267.

Klatt, D. H. (1976). The linguistic uses of segmental duration in English: Acoustic and perceptual evidence. *Journal of the Acoustical Society of America*, **59**, 1208-1221.

Klima, E. S., & Bellugi, U. (1979). *The signs of language*. Cambridge, MA: Harvard University Press.

Kučera, H., & Francis, W. N. (1967). *Computational analysis of present-day American English*. Providence, RI: Brown University Press.

Ladefoged, P. (1975). *A course in phonetics*. New York: Harcourt Brace Jovanovich.

Lewellen, M. J., Goldinger, S. D., Pisoni, D. B., & Greene, B. G. (1993). Lexical familiarity and processing efficiency: Individual differences in naming, lexical decision, and semantic categorization. *Journal of Experimental Psychology: General*, **122**, 316-330.

Luce, P. A., & Charles-Luce, J. (1985). Contextual effects on vowel duration, closure duration, and the consonant/vowel ratio in speech production. *Journal of the Acoustical Society of America*, **78**, 1949-1957.

Lukatela, G., & Turvey, M. T. (1993). Phonemic similarity effects and prelexical phonology. *Memory & Cognition*, **18**, 128-152.

MacKay, D. G. (1981). The problem of rehearsal or mental practice. *Journal of Motor Behavior*, **13**, 274-285.

Marslen-Wilson, W. D., & Welsh, A. (1978). Processing interactions and lexical access during spoken word recognition in continuous speech. *Cognitive Psychology*, **10**, 29-63.

Massaro, D., Venezky, R., & Taylor, G. (1979). Orthographic regularity, positional frequency, and visual processing of letter strings. *Journal of Experimental Psychology: General*, **108**, 107-124.

McClelland, J. L., & Rumelhart, D. E. (1981). An interaction activation model of context effects in letter perception: Part 1. An account of basic findings. *Psychological Review*, **88**, 375-407.

McCusker, L., Hillinger, M., & Bias, R. (1981). Phonological recoding and reading. *Psychological Bulletin*, **89**, 217-245.

McCutchen, D., & Perfetti, C. (1982). The visual tongue-twister effect: Phonological activation in silent reading. *Journal of Verbal Learning & Verbal Behavior*, **21**, 672-687.

McGuigan, F. J. (1984). How is linguistic memory accessed? A psychophysiological approach. *Pavlovian Journal of Biological Science*, **19**, 119-138.

Meyer, D. E., Schvaneveldt, R. W., & Ruddy, M. G. (1974). Functions of graphemic and phonemic codes in visual word recognition. *Memory & Cognition*, **2**, 309-321.

Nusbaum, H. C., Pisoni, D. B., & Davis, C. K. (1984). *Sizing up the Hoosier mental lexicon: Measuring the familiarity of 20,000 words* (Research on Speech Perception Progress Report No. 10). Bloomington: Indiana University Press.

Perfetti, C. A., Zhang, S., & Berent, I. (1992). Reading in English and Chinese: Evidence for a "universal" phonological principle. In R. Frost & L. Katz (Eds.), *Orthography, phonology, morphology, and meaning* (pp. 227-248). Amsterdam: North-Holland.

Peterson, G., & Lehiste, I. (1960). Durations of syllabic nuclei in English. *Journal of the Acoustical Society of America*, **32**, 693-703.

Port, R. (1979). Relation between voice onset time and vowel duration. *Journal of the Acoustical Society of America*, **66**, 654-662.

Port, R. (1981). Linguistic timing factors in combination. *Journal of the Acoustical Society of America*, **69**, 262-274.

Reed, H. B. (1916). The existence and function of inner speech in thought processes. *Journal of Experimental Psychology*, **1**, 365-392.

Rohrman, N. L., & Gough, P. B. (1967). Forewarning, meaning, and semantic decision latency. *Psychonomic Science*, **9**, 217-218.

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

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

Sharf, D. (1962). Duration of post-stress intervocalic consonants and preceding vowels. *Language & Speech*, **5**, 25-30.

Smith, S. M., Brown, H., Toman, J., & Goodman, L. S. (1947). The lack of cerebral effects of d-tubocararine. *Anesthesiology*, **8**, 1-14.

Sokolov, A. N. (1972). *Inner speech and thought*. New York: Plenum.

Spoehr, K., & Smith, E. (1971). The role of orthographic and phonotactic rules in perceiving letter patterns. *Journal of Experimental Psychology: Human Perception & Performance*, **104**, 21-34.

Stevens, K. N., & House, A. S. (1963). Perturbations of vowel articulations by consonantal context: An acoustical study. *Journal of Speech & Hearing Research*, **6**, 111-128.

Stone, G. O., & Van Orden, G. C. (1993). Strategic processes in printed word recognition. *Journal of Experimental Psychology: Human Perception & Performance*, **19**, 744-774.

Stricker, S. S. (1880). *Studien über die Sprachvorstellungen* [Studies of imagined speech]. Vienna: Braumiller.

Umeda, N. (1975). Vowel duration in American English. *Journal of the Acoustical Society of America*, **58**, 434-445.

Umeda, N. (1977). Consonant duration in American English. *Journal of the Acoustical Society of America*, **61**, 846-858.

Van Orden, G. C. (1987). A ROWS is a ROSE: Spelling, sound and reading. *Memory & Cognition*, **15**, 181-198.

Van Orden, G. C., & Goldinger, S. D. (1994). Interdependence of form and function in cognitive systems explains perception of printed words. *Journal of Experimental Psychology: Human Perception & Performance*, **20**, 1269-1291.

Van Orden, G. C., Pennington, B. F., & Stone, G. O. (1990). Word identification in reading and the promise of subsymbolic psycholinguistics. *Psychological Review*, **97**, 488-522.

Waters, G. S., & Seidenberg, M. S. (1985). Spelling-sound effects in reading: Time course and decision criteria. *Memory & Cognition*, **13**, 557-572.

Watson, J. B. (1919). *Psychology from the standpoint of a behaviorist*. Philadelphia: J. B. Lippincott.

Weber, R. J., & Castleman, J. (1970). The time it takes to imagine. *Perception & Psychophysics*, **8**, 165-168.

Whaley, C. P. (1978). Word-nonword classification time. *Journal of Verbal Learning & Verbal Behavior*, **17**, 143-154.

Zhang, S., & Perfetti, C. A. (1993). The tongue-twister effect in reading Chinese. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, **19**, 1082-1093.

NOTES

1. Clearly, by virtue of their pronunciations, pseudohomophones are most similar to real words. This difference cannot be quantified but is supported by many published data (e.g., Stone & Van Orden, 1993). With respect to measurable properties, the pseudohomophones and legal nonwords were well matched. For example, in Experiment 1, mean bigram frequencies (Massaro, Venezky, & Taylor, 1979) for legal nonwords and pseudohomophones were 1,030.4 and 1,016, respectively [$F(2,261) = 0.64$, $p = .723$]. In Experiment 2, these were 1,334.9 and 1,402.6, respectively [$F(2,357) = 1.19$, $p = .346$].

2. As in all word-perception research, we conducted item analyses commensurate with all subject analyses. In both experiments, the profiles of results were nearly identical across tests. Therefore, for brevity, we report only F ratios from the subject analyses. The handful of effects with insignificant item-analysis values are duly noted.

3. This lexicality effect is nearly always observed in lexical decision (Whaley, 1978). Unfortunately, the present observation is inconclusive, as the "word" response was always mapped to the subject's favored hand. However, the key result of Experiment 1 (vowel-length effect) was equally evident among words and nonwords.

4. This emphasis on word beginnings in inner speech may resolve an issue in Experiment 1. In real speech, closure durations of final consonants often adjust in a direction opposite to vowel length, keeping overall word duration relatively constant (Luce & Charles-Luce, 1985; Sharf, 1962). Thus, it should be difficult to observe vowel-length effects. But if word endings are truncated in inner speech, potential adjustments in word-final consonants would not occur and would not affect RTs.

5. For purposes of comparison, we recorded a naive volunteer speaking all stimulus materials for Experiment 2. Acoustic analyses conducted on her digitized speech generally replicated these prior reports. We observed a 47-msec consonant-length effect [$t(178) = 9.13$, $p < .001$] and a 162-msec vowel-length effect [$t(178) = 18.21$, $p < .001$].

(*Continued on next page*)

APPENDIX A
Stimulus Materials for Experiment 1

High Frequency						Low Frequency					
Short Vowel			Long Vowel			Short Vowel			Long Vowel		
W	L	P	W	L	P	W	L	P	W	L	P
wake	wape	wate	ward	warg	worz	wart	wark	worf	wade	wame	waze
trip	trit	trik	trim	trin	tril	smut	smuk	shok	smug	smum	shel
tape	tate	taik	lane	labe	lade	swap	swak	trak	swan	swaz	swel
slip	slif	slik	slid	slig	skan	slap	slaf	slak	slab	slaz	stil
pipe	pite	pype	ride	ribe	ryde	moat	moak	mote	moan	moab	mone
lake	lape	laik	lean	leam	leag	lark	lart	lait	lard	larn	lern
grip	grif	crok	barn	barv	barz	brat	brak	bate	brag	boim	boam
gate	gake	gayt	gain	gaib	gane	glut	glup	gruf	glum	glub	gluv
curt	curp	kert	code	cobe	coam	clap	clat	klap	clan	clag	klam
coat	coaf	coap	card	carm	kard	cart	cark	kart	curb	curg	kerb
chip	chet	chak	chin	chid	chil	hook	hoat	hupe	hood	hoog	hoze
sweep	sweek	swepe	steam	steeb	steem	swipe	swite	swype	swine	swime	swyne
speak	speat	speek	speed	speem	spede	spike	spipe	spyke	spine	spibe	spyne
shape	shate	shaip	shade	shabe	shaid	gripe	grite	grype	groom	groob	grume
shake	shafe	shaik	shame	shube	shaim	flake	flate	flaik	fling	fline	flawg
price	prite	pryce	stage	stame	staze	swoop	swook	swupe	purge	purbe	perge
plate	plape	playt	prime	prine	pryme	pleat	pleak	pleet	plead	pleam	pleed
creak	creaf	kreak	cream	creeb	kream	crate	crake	krate	crane	crade	krane
chart	chark	shurt	charm	charb	chern	grope	groke	groap	grime	gride	grone
brief	breep	breef	trade	trabe	traid	trait	traik	trate	bleed	bleeg	blede
brake	brate	braik	green	greeb	greev	cleat	cleek	kleet	creed	creeb	crede
black	blafe	bleek	clean	cleam	kleen	stork	storp	sleak	stain	staig	stane

Note—W, words; L, legal nonwords; P, pseudohomophones.

APPENDIX B
Stimulus Materials for Experiment 2: High-Frequency Words and Associated Foils

SCSV			SCLV			LCSV			LCLV		
W	L	P	W	L	P	W	L	P	W	L	P
tape	tate	taip	game	gade	gaim	sake	sape	saik	wage	wuge	waze
cape	cate	kape	tone	tove	toan	hate	hape	hayt	hang	hong	heer
gate	gayk	gayt	gain	gaib	gane	fate	foop	fayt	wide	wibe	wyde
curt	curp	kert	burn	burv	burd	luck	leck	loap	warm	warv	worp
coat	carf	cote	code	cobe	coam	note	noke	noat	mine	mibe	myne
pack	poik	purk	king	kang	karv	sick	seck	seak	song	seng	seez
date	dake	dayt	dead	derm	deam	lake	lape	laik	lane	lage	lade
deep	deet	deap	torn	torb	toon	ship	shik	shok	yard	yarm	yung
type	tyfe	tipe	tube	tuve	toob	heat	heak	heet	ride	ribe	ryde
cope	cofe	coap	coal	coag	cole	hope	hote	hoap	hide	hibe	hyve
cook	coof	koop	cold	colb	kold	loop	loof	lupe	hold	holn	smal
book	boop	bote	corn	corb	korn	shut	shup	shak	lose	loze	luze
beat	bick	bete	team	teab	teel	seat	seaf	seet	mean	merm	meen
cast	cark	kast	calm	caln	kalm	late	leet	lait	harm	harn	herl
park	parp	purt	barn	barv	barz	wake	wape	wate	ward	warg	worz
tart	tark	terk	curd	curn	kurd	wart	wark	worf	lard	larn	lern
tack	tafe	teek	bang	barg	birn	swap	swak	swop	swan	swaz	swel
toot	teep	tute	tame	tane	taim	rack	reet	reck	loom	leeb	lume
duck	dack	chuk	dung	deeb	deen	smut	smuk	smok	smug	smum	smal
bike	bipe	byke	bide	bibe	byde	ripe	rike	rype	shin	shim	shur
poke	pook	poak	pose	pove	poze	vase	wase	veel	haze	hane	hays
goat	goap	gote	goad	goab	gode	moat	moak	mait	slum	slub	flem
gape	gafe	gayp	dame	dage	daim	fake	fape	faik	lame	labe	laim
coke	kife	coak	toad	teev	tode	mope	mook	moap	hose	hobe	hoze
dope	doke	doap	bode	bove	boad	sock	sook	shuk	flog	flom	flud
duke	dute	doat	daze	dabe	dayz	wick	woot	weet	wade	wame	waid
beak	baip	beek	bead	beal	beed	seep	saip	seap	mead	meam	meed
boot	boof	bate	bard	barm	beem	mart	marp	meak	lewd	leme	lude
burp	burf	berp	curb	curg	kerb	jerk	jert	jurk	germ	jerb	jerm
carp	corf	karp	curl	curm	kurl	lark	lart	rait	slab	slan	smyl

Note—SCSY, short consonant, short vowel; SCLV, short consonant, long vowel; LCSV, long consonant, short vowel; LCLV, long consonant, long vowel. TW, words; L, legal nonwords; P, pseudohomophones.

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