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Evidence for the Use of Phonological Representations During Transsaccadic Word Recognition

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The authors explored the role of phonological representations in the integration of lexical information across saccadic eye movements. Study participants executed a saccade to a preview letter string that was presented extrafoveally. In Experiment 1, the preview string was replaced by a target string during the saccade, and the participants performed a lexical decision. Targets with phonologically regular initial trigrams benefited more from a preview than did targets with irregular initial trigrams. In Experiment 2, words with regularly pronounced initial trigrams were more likely to be correctly identified from the preview alone. In Experiment 3, participants were more likely to detect a change across a saccade from regular to irregular initial trigrams than from irregular to regular trigrams. The results suggest that phonological representations are activated from an extrafoveal preview and that this phonological information can be integrated with foveal information following a saccade.

Models of visual word recognition traditionally have been concerned with the nature of the representations that mediate between perceptual information and lexical knowledge. For example, according to one type of model, encoding of the graphemic information present in the visual stimulus directly activates lexical representations without the need for phonological encoding (e.g., Seidenberg & McClelland, 1989). In other models, visual information necessarily activates a phonological representation prior to activating semantic representations (e.g., Lukatela & Turvey, 1991; Perfetti, Bell, & Delaney, 1988; Van Orden, 1987; Van Orden, Johnston, & Hale, 1987). Most common, however, are the so-called dual-route models of word recognition, which allow activation of lexical representations both directly from graphemic information and via intermediate phonological representations (Baron, 1973; Carr & Pollatsek, 1985; Coltheart, 1978; Paap & Noel, 1991). Most of the evidence concerning the use of phonological representations in word recognition derives from paradigms examining foveally presented words. While a great deal of useful information has been collected from such paradigms, the situation is more complex in natural reading because word recognition is typically distributed over several eye fixations and information from one fixation must be integrated with information from another. The present research is concerned with the nature of the representations used in this transsaccadic integration and specifically with whether phonological representations may mediate the integration process.

Two interrelated concepts central to framing the problem of transsaccadic integration in word recognition are the perceptual span in reading and extrafoveal preview benefit. The *perceptual span* is that region of text from which useful information is acquired during a given eye fixation in the course of natural reading. Research indicates that the perceptual span extends from a maximum of about 4 characters to the left of the currently fixated character (McConkie & Rayner, 1976; Rayner, Well, & Pollatsek, 1980; N. R. Underwood & McConkie, 1985) to a maximum of about 15 characters to the right (McConkie & Rayner, 1975; Rayner, Inhoff, Morrison, Slowiaczek, & Bertera, 1981). This translates into a perceptual span covering the word in foveal vision (word *n*), as well as the next one or two words (words $n + 1$ and $n + 2$).

The type of information acquired within the perceptual span varies as a function of distance from the point of

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fixation. For example, information leading to identification will likely be acquired from word *n*, while only information about the boundaries between words is likely to be acquired at extrafoveal distances corresponding to word *n* + 2. Information acquired from word *n* + 1, which falls spatially between these two extremes, is more variable. Sometimes word *n* + 1 will be identified during fixation on word *n*, in which case no fixation on word *n* + 1 will occur. However, more often word *n* + 1 will be partially analyzed but not completely identified during fixation on word *n*. In other words, during reading of connected text, readers will obtain an extrafoveal preview of word *n* + 1 while they are fixated on word *n*. The partial information acquired from this preview must subsequently be integrated with the information that is acquired once the eyes move to bring word *n* + 1 into foveal vision.

Extrafoveal Preview Benefit in Word Recognition

Transsaccadic integration has been studied by comparing word identification with and without extrafoveal preview. If a reader is given an extrafoveal preview of word *n* + 1 prior to fixation on that word, then identification time is faster once that word is fixated in comparison with a condition in which either no or incorrect preview information has been presented. This facilitation of identification due to the correct extrafoveal preview is referred to as a *preview benefit* and has been demonstrated in a number of paradigms.[1] In an early study, Dodge (1907) showed that readers required more time to begin naming a word presented at the fovea than to begin naming a word that had been presented in the parafovea prior to an eye movement to the word. Because the naming latency was measured from the time that the word occupied foveal vision in both cases, Dodge concluded that in the latter case the word must have been partially analyzed in the parafovea prior to the eye movement.

Dodge's (1907) findings notwithstanding, the most compelling studies examining preview benefits in word identification have used the eye-contingent display-change technique. With this technique, the experimenter uses an eye movement monitor interfaced with a computer and display system to change the display in real time contingent on where the reader is looking. In a variant of this technique similar to Dodge's original paradigm, Rayner (1978) had readers fixate a central point until a letter string appeared extrafoveally. The reader was asked to execute a saccade to the extrafoveal string as soon as it appeared. During the saccade, the preview string was replaced by a target word that the reader was to name aloud as quickly as possible. Because the display change took place during the saccade, the change was usually not detected by the readers. The primary manipulation concerned the relationship between the preview string and the target word. Rayner found that readers were significantly faster to name the target word when the preview string contained the same first and last letters as the target word and also had the same overall word shape.

Subsequent work using Rayner's (1978) paradigm has led to further insight into the preview benefit observed during word recognition. First, the effect is not an artifact of the naming task, because it is also found using semantic categorization (Rayner, McConkie, & Zola, 1980). Second, the effect is due to facilitation from a similar preview rather than inhibition from a dissimilar preview (Rayner, McConkie, & Ehrlich, 1978). Third, the preview benefit does not depend on readers' expectations concerning likely word candidates (Balota & Rayner, 1983). Fourth, the preview benefit seems to be due primarily to encoding of information from the first two or three letters of the preview string (Rayner, McConkie, & Zola, 1980).

The preview benefit is also observed in a more natural reading situation. Two variations of the eye-contingent display-change technique allow participants to read connected text. In the *boundary paradigm* (Rayner, 1975), a preview string is displayed in one location in the text until the eyes cross an invisible boundary located to the left of that string. Once the eyes cross the boundary, the preview string is changed to the target word. In the *moving-window paradigm* (McConkie & Rayner, 1975), the text displayed to the reader is mutilated (e.g., replaced by *x*s) everywhere except within a limited region, or window, around the reader's point of fixation, while the text within the window is displayed normally. The window moves with the participant's eyes, so that the window region is always at the point of fixation. The dependent measure in both paradigms is either overall reading rate or fixation time on the target word as a function of the preview condition. Results from these paradigms are consistent with the naming paradigm in suggesting that the preview benefit is due primarily to information acquired from the first few letters of the extrafoveal word (Henderson & Ferreira, 1990; Inhoff, 1989a, 1989b; Lima & Inhoff, 1985; Rayner, Well, Pollatsek, & Bertera, 1982; N. R. Underwood & McConkie, 1985), though gross featural information from other letters may also play some role (Inhoff, 1989b; Lima & Inhoff, 1985; Rayner et al., 1982).

Integration of Information Across Eye Movements

Although the preview benefit in reading is clearly a robust phenomenon, it is less clear what type of information is integrated across the eye movement to produce this benefit. To date, several hypotheses have been considered (Rayner & Pollatsek, 1989). The first, and perhaps intuitively most appealing, hypothesis is that integration occurs at a relatively low perceptual level. According to one version of this hypothesis, the visual system acquires and stores featural information from beyond the fovea in a visual integrative buffer and aligns and integrates this information with fea-

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[1] We prefer to use the term *preview benefit* rather than *priming* because the latter suggests the acceptance of a particular type of process and the former is process neutral (see Kahneman, Treisman, & Gibbs, 1992). Preview benefits observed across eye movements may be due to type priming in long-term memory, token maintenance in short-term memory (Irwin, 1991), or both (Henderson & Anes, 1994).

tural information acquired from the fovea following the saccade (McConkie & Rayner, 1976). According to this view, the system aligns information across the saccade by keeping track of the spatial extent of the saccade and "shifting" information in the buffer the appropriate distance, as well as by relying on the similarity of the patterns acquired before and after the saccade.

A great deal of evidence now indicates that the visual integrative buffer hypothesis is incorrect as an account of information integration across saccades in reading. First, changes in position of the text during the saccade do not reduce the preview benefit, as would be expected if the system were using saccadic extent to compute featural alignment (McConkie, Zola, & Wolverton, 1980; O'Regan, 1981). Second, integration can occur even without an intervening saccade, again suggesting that saccadic extent is not used to compute feature overlap in the integration process (Rayner et al., 1978). Third, a change in visual features from fixation to fixation brought about by changing the case of text during the saccade (e.g., *AlTeRnAtE* to *aLtErNaTe*) has no effect on the integration process (McConkie & Zola, 1979; Rayner, McConkie, & Zola, 1980). Finally, there is similarly no evidence supporting the view that low-level visual information is integrated across eye movements when other types of stimuli are used, such as contrast gratings (Irwin, Zacks, & Brown, 1990), dot patterns (Irwin, 1991; Irwin, Yantis, & Jonides, 1983; Rayner & Pollatsek, 1983), or line drawings of objects (Henderson, Pollatsek, & Rayner, 1987; Pollatsek, Rayner, & Collins, 1984; Pollatsek, Rayner, & Henderson, 1990).

A second hypothesis concerning integration across saccades is that word $n + 1$ is semantically "preprocessed" prior to fixation. There are actually two variants of this hypothesis. According to the first, word $n + 1$ is unconsciously processed to a semantic level prior to fixation (Marcel, 1983; G. Underwood, 1980, 1981). The evidence discussed above suggesting that integration primarily involves the first few letters of the preview does not support this hypothesis, nor does evidence derived from studies directly examining the possibility of semantic activation from the preview string (Inhoff, 1982; Inhoff & Rayner, 1980; Rayner, Balota, & Pollatsek, 1986). According to the second variant, the beginning of word $n + 1$ may often form a morpheme, and processing this morpheme in the parafovea may reduce the number of word candidates that have to be considered once the eyes land on the word. This hypothesis has been investigated in a number of experiments, and again the evidence has been negative. For example, the preview benefit is no greater for prefixed words than for pseudoprefixed words (Lima, 1987) or for compound words than for pseudocompound words (Inhoff, 1987, 1989a).

A third hypothesis is that orthographic information is integrated across eye movements. According to this hypothesis, abstract information about the orthography of the preview string is encoded, and this partial information is integrated with additional information following the saccade. Again, several versions of this hypothesis have been proposed. According to what we might call the *orthographic constraint* version, the initial letters identified in the parafovea constrain the potential word candidates that must be considered by the word-recognition process once the word is fixated. This notion was tested by Lima and Inhoff (1985), who used the moving-window paradigm and found no difference in preview benefit for words highly constrained by the initial letters (e.g., *dwarf*) in comparison with less constrained words (e.g., *clown*). According to the *abstract letter identities* version, an abstract (e.g., case invariant) representation of the first few letters of word $n + 1$ is maintained across the saccade. Once the eyes land, this information is integrated with new information concerning the identities of the other letters in the word. To date, the abstract letter identity hypothesis has been adopted somewhat by default (e.g., Rayner & Pollatsek, 1989).

A final hypothesis concerning transsaccadic integration is what we call the *partial phonological coding hypothesis*. According to this hypothesis, identification of the first few letters of word $n + 1$ prior to fixation allows activation of a phonological code for the beginning of the word. This partial phonological code allows speeded identification of the word once it is fixated. The partial code could be facilitative in several ways. For example, the partial code may be integrated with a phonological code derived from the remaining letters once the word is fixated. Alternatively, the partial code could allow a reduction of the number of potential word candidates that must be considered once the word is fixated. Two studies have examined the partial phonological coding hypothesis. In the first, Rayner, McConkie, and Zola (1980) used the Rayner (1978) naming paradigm to contrast preview strings that shared both the initial letter and the initial phoneme as the target word (e.g., *brand–bread*) with preview strings that shared only the initial letter (e.g., *phone–plane*). If the partial phonological coding hypothesis were correct, then one would expect a larger preview benefit for the pair that shared the same initial phoneme. Instead, the preview benefit did not differ for these two conditions. Unfortunately, as Rayner and Pollatsek (1989) have pointed out, no preview benefit at all was observed for either condition, calling into doubt the adequacy of the test for the phonological coding hypothesis.

In a more recent study examining the phonological coding hypothesis, Pollatsek, Lesch, Morris, and Rayner (1992) contrasted preview strings that were both visually similar and homophonous with the target word with preview strings that were only visually similar. In the first experiment, Pollatsek et al. used the Rayner (1978) naming paradigm and found that the homophonous preview strings produced a larger preview benefit. However, as Pollatsek et al. admitted, it is difficult to make firm conclusions about the phonological coding hypothesis from a naming task, because positive effects may be due to integration at the output preparation stage rather than at the word-recognition stage. Therefore, in a second experiment, they used the boundary paradigm to examine the issue in silent sentence reading. Again, they contrasted preview strings visually similar and homophonous to the target words (e.g., *foul–fowl*) with visually similar (*foil–fowl*) and different (*tint–fowl*) controls. They found that the strings that were both visually similar and homophonous to the target words produced a larger preview benefit than did the strings that were only visually similar.

The Pollatsek et al. (1992) results are important because they are the first demonstration that phonological codes may play a role in the integration of word information across saccades. At the same time, there are a number of questions that remain unanswered. For example, as discussed above, there is a good deal of evidence suggesting that it is mainly information derived from the first few letters of a word that is integrated across saccades. Yet, the homophony of the Pollatsek et al. stimuli was defined over the entire word. Thus, one may ask whether a phonological code derived from the initial part of a word alone would play a role in transsaccadic integration. Second, a majority of the stimuli used in the Pollatsek et al. reading experiment were relatively short words: 54% (13 of 24 words) were four letters in length, and an additional 38% (9 of 24 words) were five letters in length; 1 word had six letters and one had seven letters. Because the words were relatively short, it is possible that information from the entire preview string was obtained prior to the saccade to that string. This may at least partially explain why they found that the homophony of the entire word played a role in the magnitude of the preview benefit. A remaining question, however, is whether the use of phonological codes across saccades could be demonstrated for longer words, a situation in which the entire word is unlikely to be coded prior to the eye movement.

In Experiment 1, we examined whether a phonological code derived from the initial trigram of a six-letter word would mediate the integration of word information across a saccade. In Experiment 2, we examined the nature of the phonological code derived from an extrafoveal preview alone. Finally, in Experiment 3 we attempted to determine the degree to which readers could detect our display changes, and we examined whether phonological codes would influence transsaccadic integration in a task that did not explicitly require lexical access.

Experiment 1

In this experiment we used a variant of the Rayner (1978) paradigm to explore the issue of phonological coding in transsaccadic integration. Figure 1 illustrates the main aspects of the paradigm. Participants began each trial fixated on a central cross. A preview string was then displayed to the right of fixation. The reader was instructed to execute an eye movement to the preview string as quickly as possible once it appeared. During the saccade, the preview string was changed to a target string. The reader's task was to make a lexical decision about the target string as rapidly as possible following the saccade.

Our use of the lexical decision task is a compromise among several considerations. On the one hand, lexical decisions can be influenced by processes that occur following lexical access, such as response generation (e.g., Balota & Chumbley, 1984). On the other hand, in the exploration of phonological effects on transsaccadic integration, other tasks may be even more problematic. For example, the naming task may overestimate the influence of a phonological manipulation because the phonological characteristics of the preview may allow the participant to begin to prepare a specific motor program for vocalization (see Pollatsek et al., 1992, for similar concerns). The advantage of the lexical decision task is that any effects of phonological similarity between the preview string and the target string on the magnitude of the preview benefit can be attributed to stages prior to output generation. Fixation paradigms (e.g., Pollatsek et al., 1992) do not suffer from the vocalization problem. However, other factors such as the eccentricity and viewing time of the preview string cannot be controlled. Given these clear difficulties with the naming and fixation paradigms, we considered the lexical decision task most appropriate for our purposes. Our view is that converging evidence from several paradigms will ultimately provide us with the best hope of discovering the underlying nature of the transsaccadic integration process.

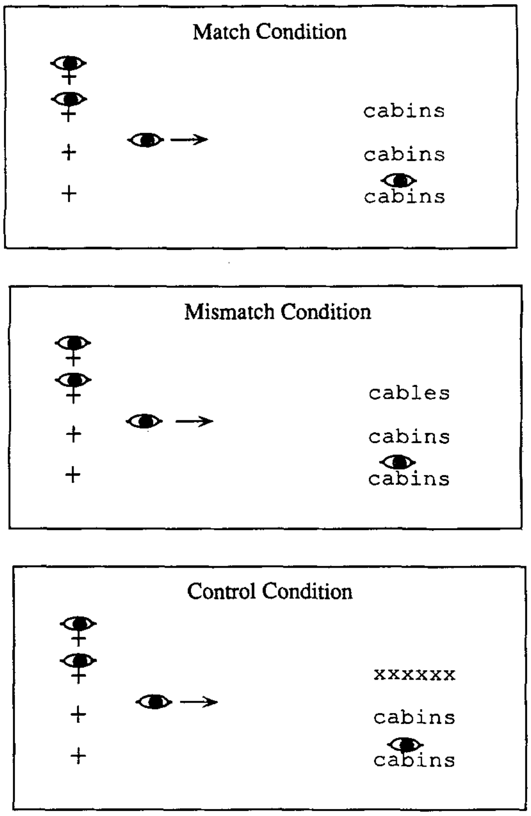

Figure 1. An illustration of the main aspects of the experimental paradigm used in Experiment 1.

Our main goal in this experiment was to determine whether a phonological code derived from the initial part of a preview string would mediate transsaccadic integration and hence the magnitude of the preview benefit. To examine this question, we contrasted six-letter target words that had initial trigrams that were either regularly or irregularly pronounced within the context of the entire word. For example, in the pair *button–butane,* the first word would be considered regular and the second word would be considered irregular. We should highlight that, in contrast to normal usage, we are using the terms *regular* and *irregular* to refer only to the pronunciation of the first three letters and not to the pronunciation of the entire word. The main question we asked was whether the preview benefit produced by a word with a regularly pronounced initial trigram would be larger than that produced by a word with an irregularly pronounced initial trigram. The logic of using this contrast is as follows: According to the partial phonological coding hypothesis, when a preview string appears in parafoveal vision, the first few letters are identified and a phonological code is generated. This code will correspond to the regular pronunciation of those letters, because the last few letters of the word (which might modulate the pronunciation of the initial trigram) are likely to be too eccentric to be identified. If this phonological code then turns out to be correct within the context of the entire word, identification of the word will be facilitated once it is fixated. If the code turns out to be incorrect (i.e., the initial trigram is pronounced irregularly in the context of the word, as *but-* is in *butane*), then the code generated from the preview will be less useful, and the preview benefit will be reduced. Thus, the partial coding hypothesis predicts a larger preview benefit for regular words than for irregular words.

In addition to this predicted effect of regularity, we generated a second set of related predictions from the partial phonological coding hypothesis. If only the first few (e.g., three) letters of a preview string are typically encoded, then the context within which those letters appear in the preview should not affect the phonological code generated for the initial part of the word. For example, a preview consisting of the word *butane* should generate the same phonological code for the initial trigram as a preview consisting of the word *button,* because in both cases only the first few letters will be encoded. Therefore, the partial phonological coding hypothesis predicts that the preview benefit should be larger for regular target words than for irregular target words regardless of whether the last three letters in the preview match the target or not. In other words, preview–target pairs such as *butane–button* and *button–button* should produce larger preview benefit effects than would pairs such as *button–butane* and *butane–butane.* To test these predictions, we assessed preview benefits in both match- and mismatch-preview conditions, as well as in a control condition in which the preview consisted of a string of *x*s.

Method

Participants. Eighteen University of Alberta undergraduate students participated in the study for credit toward their introductory psychology class. All had normal vision or corrected-to-normal vision with contact lenses, were native speakers of Canadian English, and were naive with respect to the hypotheses under investigation.

Apparatus. Eye movements were monitored via an ISCAN RK-416 high-speed eyetracker. The eyetracker and display monitor were interfaced with a Zenith 80286 microcomputer that controlled the experiment. Eye movements were monitored from the right eye, and viewing was binocular. The computer recorded saccade latencies and response latencies. Signals were generated by the eyetracker at a frequency of 120 Hz, and the computer changed the display contingent on detecting an eye movement of greater than 0.5°. Because a saccade to the center of the target (5°) required approximately 35 ms and because a maximum of 22 ms were required to change the display (8 ms to detect the saccade and 14 ms to refresh the monitor), the display change was accomplished during the saccade, when vision is suppressed.

Letter strings were white on a black background and were displayed in lowercase on a high-resolution, flat-screen monitor. The participant's eyes were 36 cm from the display monitor, so that a six-character string subtended about 4°52′ of visual angle. The room was illuminated normally with overhead lighting.

Stimuli. The target stimuli consisted of 102 pairs of six-letter words. The members of each pair shared the same first three letters. For one member of each pair of words, the pronunciation of the first three letters was regular, while for the other member of the pair, the pronunciation of the first three letters was irregular. To determine which pronunciation should be considered regular, we used three criteria. First, we designated a word as regular if the pronunciation of the first three letters was deemed by us to correspond to the pronunciation of those letters in isolation. Second, we conducted a type-frequency count, taking as regular those words whose first three letters were pronounced in the same way as the majority of words beginning with those letters. Finally, we conducted a norming study using 6 members of the University of Alberta community (undergraduate and graduate students and faculty). In this study we presented letter strings containing the first three letters of each potential stimulus word followed by three *x*s (e.g., *butxxx*) and asked the reader to generate the first six-letter word that came to mind. The letter strings were presented in lists on paper, and the participant wrote responses in a self-paced manner. We took the most commonly produced pronunciation of the first three letters in the generated six-letter words as the regular pronunciation. From the entire sample of word pairs that passed all three criteria, a set of 102 pairs was chosen. Generally, the regular pronunciation contained a short vowel. Examples of regular/irregular word pairs are *batter/bathed, button/butane, cannon/canine, chunks/chutes, pastor/pastry, nickel/nicest,* and *tracks/traced.* The pairs were chosen so that the two levels of regularity were equated on lexical frequency, bigram frequency, letter frequency, and number of syllables, as is shown in Table 1.

Stimulus validation: Completion study. As a check on the manipulation of regularity in our stimulus set, a second group of 7 volunteers from the University of Alberta community generated words from the initial trigrams of the target set. This generation task was similar to the norming study and served three purposes. First, it allowed a validation of our regularity manipulation: Readers should generate more of our regular targets than our irregular targets from the initial three letters. Second, it provided a baseline concerning how lexical access might proceed on the basis of the first three letters only, and this baseline can be used to assess the results of the integration task. Third, it allowed us to assess whether the effects of regularity, if observed, would interact with stimulus factors such as frequency and syllable structure.

Participants in this study were native speakers of Canadian English and were naive with respect to the hypotheses under investigation. The materials presented to the participants consisted of columns of letter strings printed on a page of paper. These strings were the initial trigrams from all of our target word pairs, followed by three *x*s that replaced the final trigram of each word. For example, *cabxxx* was presented for the pair *cabins–cables.* Each initial trigram represented in our stimulus set was presented

Table 1
Means and Standard Deviations of Lexical Frequencies, Bigram Frequencies, Letter Frequencies, and Number of Syllables for Regular and Irregular Target Words

	Lexical frequency		Bigram frequency		Letter frequency		Number of syllables	
Word type	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Regular	45.0	146.1	1167	795	7016	2028	1.75	0.48
Irregular	63.7	125.5	1273	790	7231	1827	1.82	0.57

Note. Lexical frequencies are count per million words from Kucera and Francis (1967); bigram and letter frequencies are means of position-specific counts per million words from Massaro, Taylor, Venezky, Jastrzembski, and Lucas (1980).

once regardless of the number of times that trigram appeared in the set. Readers were given the pages containing the letter strings and were asked to write in the blank space next to each string the first six-letter word that came to mind given the letters provided. Participants were encouraged to respond to all of the strings and were allowed unlimited time in which to finish the study.

To score the completions, we considered a target as correctly identified when the participant's response was the target word from which the three-letter cue was derived. In this analysis, we included two additional items factors (in addition to our regularity factor), lexical frequency (Kucera & Francis, 1967) and syllable structure. For the frequency factor, items were classified as high or low frequency in relation to the median frequency for the set (four words at the median were excluded). For the syllable structure factor, we grouped words on the basis of number of syllables; in our corpus, there were 54 words with one syllable, 137 with two syllables, and 13 with three syllables, divided with roughly equal frequency between the regular and irregular words. Because there were so few words with more than two syllables, we designated the latter two categories together as "polysyllabic" words. The completion data, shown in Table 2, produced significant effects of regularity, $F(1, 192) = 25.76$, $p < .001$, $MS_e = 0.0534$, and of syllable structure, $F(1, 192) = 5.03$, $p < .05$, $MS_e = 0.0534$. Both of these effects reflect the tendency for completions to be generated phonologically. That is, participants seem to have pronounced the three-letter stem to themselves (with a regular pronunciation) and attempted to find a word that began with that sound. The effect of syllable structure suggests either that readers have a bias to generate polysyllabic completions or that monosyllabic completions are difficult to produce. In any event, the regularity effect did not interact with either frequency or syllable structure, and there was no overall effect of frequency ($Fs < 1$).

Experimental materials. For each target word, there were three possible parafoveal preview conditions. The match preview condition consisted of the word itself (e.g., preview–target pairings of *button–button* and *butane–butane*). The mismatch preview condition consisted of the other member of the word pair as the preview for a given target (e.g., *butane–button* and *button–butane*). Finally, in the control condition a row of six *x*s was presented as the preview (e.g., *xxxxxx–button* and *xxxxxx–butane*).

Table 2
Proportion of "Correctly Identified" Words in Completion Study, Experiment 1

	Monosyllabic		Polysyllabic	
Word type	Low frequency	High frequency	Low frequency	High frequency
Regular	.21	.23	.26	.39
Irregular	.06	.05	.09	.14

The 102 word pairs were divided into two stimulus lists. In List 1, half of the regular words and half of the irregular words were defined as targets. In List 2, the other half of the regular and irregular words were defined as targets. Each participant saw both lists, once each, with the order of list presentation counterbalanced across participants. Across lists, each participant saw each target word once (i.e., in only one preview condition). Across participants, each target word was seen with each preview an equal number of times.

In addition to the word stimuli, 102 pairs of pronounceable nonwords were created by changing the final three letters of each target word. The same three preview conditions were generated for these nonwords as were used for the words, and the nonword pairs were assigned to one of the two stimulus lists in the same manner as were the word pairs. Thus, each participant judged 102 words and 102 nonwords in each stimulus list.

Procedure. The participant was seated in a comfortable chair and was supported by a chin and forehead rest to minimize body and head movements. At the beginning of the experiment, the eye-tracking system was calibrated, a procedure that took less than 5 min. At the beginning of the session, the participant was given 20 practice trials consisting of items not included in the experiment. After the practice trials, the participant saw 102 word trials and 102 nonword trials in the first block. After a short rest, the second block consisting of a new set of 102 words and 102 nonwords was presented. Stimuli were randomized for each participant in each block.

A trial consisted of the following events: First, the experimenter checked the calibration accuracy of the eye-movement system by displaying three calibration crosses and a fourth cross that indicated where the system estimated the fixation point to be. The participant was asked to fixate each calibration cross, and if the estimated fixation point was within one character position of each cross, calibration was determined to be accurate. The system was recalibrated whenever this criterion was not satisfied. Second, the participant was asked to fixate a cross to the left of the center of the screen when ready for a trial to begin. When the participant had fixated the cross, the experimenter initiated the trial, and a preview letter string was presented to the right of the fixation point, with 4°8′ of visual angle between the cross and the first letter of the string. The participant immediately initiated a rightward horizontal eye movement toward this string. During the saccade, the preview string was replaced by the target string, and after fixating the target, the participant executed a lexical decision for this string as quickly and as accurately as possible. The computer recorded the latency of the eye movement and the accuracy and latency of the lexical decision, timed from when the eye crossed the 0.5° boundary. Figure 1 illustrates the important components of an experimental trial. The experiment was completed in a single session that lasted about 45 min.

Results

The following analyses excluded trials on which the eye-movement latency was less than 100 ms; on which the lexical decision latency was less than 100 ms, greater than 2,000 ms, or greater than 3 standard deviations from the mean latency for that participant; and on which the participant's response to the lexical decision was incorrect. The percentage of trials eliminated was 15% for the word stimuli and 16% for the nonword stimuli. The percentage of trials included did not differ across conditions. The mean eye-movement latency was 200 ms for the included trials. For the lexical decision data reported below, analyses of variance (ANOVAs) were conducted treating both participants (F_1) and items (F_2) as random effects. In the participants analyses, list order was included as a between-subjects factor, and list, regularity, and preview were included as within-subjects factors. Neither the list nor list order factor mediated the effects of interest, and they are not discussed further here.

Word stimuli. Figure 2 presents the mean correct lexical decision latencies for the word stimuli as a function of regularity and preview condition. As can be seen, the regularity of the first three letters of the target word affected word-recognition processes, such that regular words were responded to faster than were irregular words, $F_1(1, 16) = 67.1$, $p < .001$, $MS_e = 1630$, and $F_2(1, 101) = 22.1$, $p < .001$, $MS_e = 18104$. Consistent with previous studies, we also found an effect of preview condition on lexical decision latency, $F_1(2, 32) = 15.7$, $p < .001$, $MS_e = 2040$, and $F_2(2, 202) = 9.72$, $p < .001$, $MS_e = 7802$. As can be seen in Figure 2, latencies were faster in the match condition than in the mismatch and control conditions. Thus, it appears that an extrafoveal preview was beneficial when the preview did not change during the saccade.

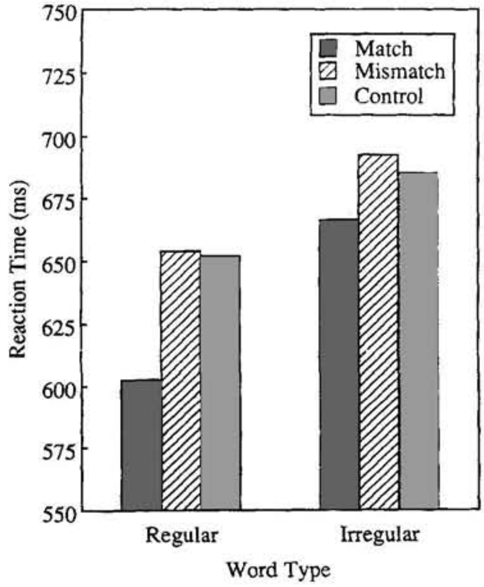

Figure 2. Mean correct lexical decision latencies for the word targets as a function of preview condition and regularity in Experiment 1.

The crucial test for determining whether phonological codes computed from the word–initial trigrams mediated the preview benefit was the Regularity × Preview interaction. In the omnibus analysis, this interaction did not reach significance, $F_1(2, 32) = 2.10$, $p = .14$, $MS_e = 2368$, and $F_2(2, 202) = 2.27$, $p = .10$, $MS_e = 6946$. However, a closer inspection of the data indicated that the mismatch condition was noisier than the other two conditions. For example, response-time distributions computed for each participant by condition indicated more variability (i.e., larger standard deviations) in the mismatch condition. This variability seems to be due to a mixture of response tendencies in that condition (see Experiment 3 below). Given this variability along with the lack of a preview benefit in the mismatch condition, we conducted a second set of analyses in which we included only two levels of preview (match vs. control) along with the two levels of regularity (regular vs. irregular). In this analysis, the main effect of regularity was significant, $F_1(1, 16) = 23.7$, $p < .001$, $MS_e = 3560$, and $F_2(1, 101) = 22.2$, $p < .001$, $MS_e = 14{,}595$, as was the main effect of preview, $F_1(1, 16) = 34.5$, $p < .001$, $MS_e = 1195$, and $F_2(1, 101) = 17.2$, $p < .001$, $MS_e = 7097$. In addition, there was a significant interaction between regularity and preview, $F_1(1, 16) = 6.08$, $p < .05$, $MS_e = 1419$, and $F_2(1, 101) = 5.29$, $p < .05$, $MS_e = 4323$. The preview benefit was a significant 50 ms (652 vs. 602 ms) for the regular words, $F_1(1, 16) = 35.8$, $p < .001$, $MS_e = 1224$, and $F_2(1, 101) = 28.1$, $p < .001$, $MS_e = 4469$, but only a marginally significant 19 ms (685 vs. 666 ms) for the irregular words, $F_1(1, 16) = 4.34$, $p = .05$, $MS_e = 1390$, and $F_2(1, 101) = 2.82$, $p = .09$, $MS_e = 6952$. Thus, these data provide evidence that phonologically regular word–initial trigrams provide a greater preview benefit than phonologically irregular trigrams, consistent with the hypothesis that preview benefit in word identification is partially mediated by phonological codes.

Word stimuli: Additional analyses. Exploratory analyses indicated that the effects of regularity and preview condition were mediated by two properties of the stimuli: word frequency and number of syllables. To assess these effects more systematically, we classified words as high or low frequency (on the basis of median split) and as either monosyllabic or polysyllabic. (Four words that had precisely the median frequency were eliminated.) These variables, together with preview condition (match vs. control) and regularity, were tested in an ANOVA using items as a random effect. The results are shown in Figure 3. There were main effects of frequency, $F(1, 192) = 18.74$, $p < .001$, $MS_e = 13{,}458$; regularity, $F(1, 192) = 9.40$, $p < .005$, $MS_e = 13{,}458$; and preview condition, $F(1, 192) = 18.56$, $p < .001$, $MS_e = 5624$. There were significant interactions between regularity and syllabicity, $F(1, 192) = 8.52$, $p < .005$, $MS_e = 13{,}458$, and among preview condition, frequency, and regularity, $F(1, 192) = 4.07$, $p < .05$, $MS_e =$

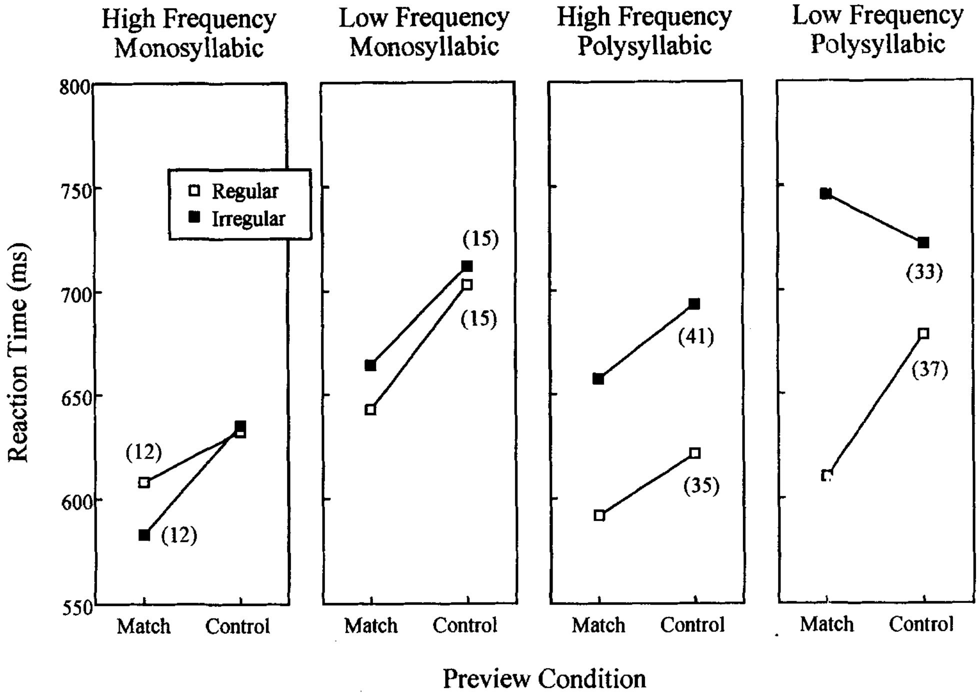

Figure 3. Mean correct lexical decision latencies for the word targets as a function of preview condition (match and control only), regularity, lexical frequency, and syllable structure in Experiment 1. (Number of targets in each condition are shown in parentheses.)

5624. The four-way interaction, although apparent in Figure 3, failed to reach significance. However, subsidiary analyses confirmed that the interaction between regularity and preview condition was confined to low-frequency polysyllabic words: When the monosyllabic words were analyzed separately, only effects of frequency and preview condition were found, $F(1, 50) = 8.01$, $p < .01$, $MS_e = 14{,}307$, and $F(1, 50) = 8.17$, $p < .01$, $MS_e = 6897$, respectively; regularity produced no effect. Among the polysyllabic words, there were main effects of frequency, $F(1, 142) = 12.78$, $p < .001$, $MS_e = 13{,}159$; regularity, $F(1, 142) = 34.07$, $p < .001$, $MS_e = 13{,}159$; and preview condition, $F(1, 142) = 10.37$, $p < .005$, $MS_e = 5176$. Importantly, there were significant interactions between regularity and preview condition, $F(1, 142) = 6.52$, $p < .05$, $MS_e = 6.52$, and among regularity, preview condition, and frequency, $F(1, 142) = 8.40$, $p < .005$, $MS_e = 5176$. Further analyses indicated that there was a significant interaction between regularity and preview conditions among low-frequency polysyllabic words only, $F(1, 68) = 13.79$, $p < .001$, $MS_e = 5366$; no such interaction was found among high-frequency polysyllabic words, $F(1, 74) < 1$, $MS_e = 5001$.

Exploratory analyses were also conducted using a variety of other stimulus characteristics. Although a number of variables were found to affect performance in one way or another, these variables were largely unrelated to the interaction between regularity and preview condition shown in Figures 2 and 3. For example, consider the effect of bigram frequency. Items with a low bigram frequency count produced less preview benefit (i.e., less of a difference between the control and match conditions) than items with a high bigram frequency (16 ms vs. 53 ms). However, regular items always produced more preview benefit than irregular items, and the size of this difference was about the same for both levels of bigram frequency. For low bigram frequency words, the regular items produced a 30-ms preview benefit, and the irregular items produced a 2-ms preview benefit. For the high bigram frequency words, the regular items produced a 71-ms preview benefit, and the irregular items produced a 35-ms preview benefit. We also examined the effect of syllable length. In this case, there was a substantial correlation between regularity and the length of the initial syllable in polysyllabic words: Although irregular polysyllabic words were divided between those beginning with a two-letter syllable and those beginning with a three-letter syllable, almost all regular polysyllabic words began with a three-letter syllable. However, the regular words produced more preview benefit even when consideration was limited to words beginning with three-letter syllables (58-ms vs. 26-ms preview benefit for the regular and irregular targets, respectively). Thus, the observed effects of regularity cannot be ascribed in any simple way to bigram frequency or initial syllable length. Our tentative conclusion is that these variables produce effects that are orthogonal to the interaction between regularity and preview condition.

Nonword stimuli. An important question concerning transsaccadic integration is whether integration occurs prelexically (prior to activation of lexical representations) or within the lexicon itself. If the preview benefit that we observed for the words was mediated by the use of a prelexical phonological code, then we might expect a preview benefit for nonwords as well. The mean correct lexical decision latencies for the nonword stimuli as a function of preview condition were 751 ms in the match condition, 777 ms in the mismatch condition, and 788 ms in the control condition, $F_1(2, 32) = 12.0$, $p < .001$, $MS_e = 2206$, and $F_2(2, 202) = 11.9$, $p < .001$, $MS_e = 6179$. The 37-ms preview benefit in the match condition was significant, $F_1(1, 16) = 27.9$, $p < .001$, $MS_e = 1782$, and $F_2(1, 101) = 22.9$, $p < .001$, $MS_e = 6379$, while the 11-ms difference in the mismatch condition was significant only by items, $F_1(1, 16) = 1.39$, $p > .10$, $MS_e = 2859$, and $F_2(1, 101) = 3.95$, $p < .05$, $MS_e = 6506$.

To examine whether there was any additional preview benefit for words in comparison with nonwords, we analyzed the match and control conditions for both words and nonwords together. In this analysis, regularity for the nonwords was a dummy factor referring to the regularity of the word from which the nonword was derived. As we would expect, there was an interaction between regularity and the lexical status of the stimulus, $F_1(1, 16) = 17.6$, $p < .001$, $MS_e = 2872$, and $F_2(1, 101) = 16.7$, $p < .001$, $MS_e = 12{,}592$. The regularity effect was relatively large for the words (49 ms) but was nonexistent for the nonwords (−4 ms). Most important, the size of the preview benefit effect was similar for the word and nonword stimuli, and the interaction of lexical status and preview condition was nonsignificant (both F_1 and $F_2 < 1$). As can be seen in Figure 4, the amount of preview benefit derived for the nonwords was roughly intermediate between the amount derived for the words in the regular and irregular conditions. The results for nonwords can most easily be accommodated by a model in which either an orthographic or a phonological sublexical representation is activated and maintained across the saccade.

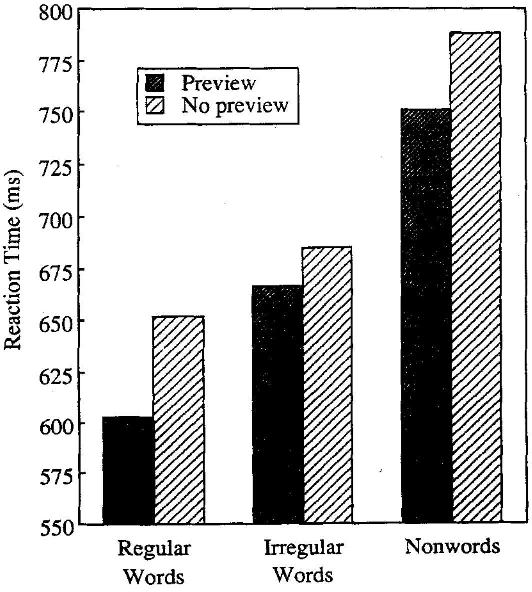

Figure 4. Mean correct lexical decision latencies for the word and nonword targets as a function of preview condition (match and control only) and regularity in Experiment 1.

Discussion

The main question addressed in Experiment 1 was whether the phonological regularity of a word–initial trigram would affect the integration of information across a saccadic eye movement. We found that when the preview and target were identical, a greater preview benefit was derived from a word with a regularly pronounced initial trigram than one from a word with an irregularly pronounced trigram. This result strongly suggests that sound-based representations play a role in the integration of word information across eye movements.

The findings involving target frequency and syllable structure must be viewed with caution, given that these analyses were conducted post hoc and involved variables that were not directly manipulated. Given this caveat, it is interesting to note that the phonological regularity of the preview appeared to play less of a role for high-frequency target words than for low-frequency target words, particularly when the preview and target matched (see Figure 3). This finding is consistent with previous research showing similar effects with foveally presented words (e.g., Seidenberg, Waters, Barnes, & Tanenhaus, 1984). The finding that lexical frequency mediated the effects of phonological regularity on the preview benefit is also consistent with the view that phonological codes are more important for recognition of low-frequency words. More specifically, these results suggest that for low-frequency polysyllabic words, the phonological code derived from the preview is very useful if the initial trigram is regular and is harmful if the trigram is irregular. For high-frequency polysyllabic words, on the other hand, integration appears to be unaffected by the phonological regularity of the initial trigram. This latter result suggests that the preview benefit for high-frequency words is not mediated by phonological representations and therefore is likely to be orthographically based.

The finding that low-frequency polysyllabic words produced a Regularity × Preview interaction while low-frequency monosyllabic words did not provides mixed support for the partial phonological coding hypothesis. On the one hand, when the target word was low frequency and polysyllabic, a phonological code derived from the initial few letters of that word clearly played a role in transsaccadic integration, as was predicted by the hypothesis. On the other hand, when the target word was low frequency and monosyllabic, the regularity of the initial trigram had no effect even though a clear preview benefit was observed. This interaction suggests that the benefit of extrafoveal preview may be mediated by a phonological code for the first syllable of the target word. For polysyllabic words, our manipulation of regularity generally ensured that a phonological code for the first syllable in isolation would be correct for regular words and incorrect for irregular words; thus, regular polysyllabic words benefited more from the preview than did irregular polysyllabic words. In this view, however, our manipulation of regularity would not apply to monosyllabic words. Because the first syllable of a monosyllabic word is the entire word, a phonological code for the initial syllable would be the same as a phonological code for the entire word and would always be correct. In other words, the irregular words in our materials were defined as irregular because the initial part of the word was pronounced differently in isolation than in the context of the entire word. But if "initial part of the word" is taken to be the first syllable rather than the first three letters, all monosyllabic words would have to be regular.

We had initially predicted from the partial phonological coding hypothesis that a trigram preview would provide greater preview benefit if the target word was regular and would provide less (or no) preview benefit if the target word was irregular, regardless of the context in which the preview trigram appeared. That is, we predicted that the mismatch preview condition would show more facilitation given a regular target word than given an irregular target word. This prediction followed because we expected that only the initial trigram would play a role in the preview benefit. The notion was that the initial trigram of the preview would be encoded and that a regular phonological code for that trigram would be generated regardless of the preview context. The data from our experiment did not support this aspect of the partial phonological coding hypothesis. Instead, a word-initial trigram in the context of a word different from the target provided no preview benefit regardless of the regularity of the trigram.

We suspect that the failure to find a preview benefit in the mismatch condition occurred because the word-recognition system was sensitive to the discrepancy in the final three letters between the preview and target strings. The detection of a visual change (as might occur in the mismatch and control conditions) may have caused the system to reevaluate the target once it was fixated, thereby making the preview irrelevant. In this case, when a change was noted, the system discarded the preview and began anew with the foveally available target. While this reevaluation would not be detrimental in the control condition (the preview was of no use in any case), it would tend to undermine whatever preview information had been acquired in the mismatch condition.

If this explanation is correct, then the question arises why the physical change disrupted integration in our experiment when disruption did not seem to occur in previous research using naming and fixation time paradigms. Part of the answer may be that the amount of disruption depends on the type of change that occurs. In the experiments that have examined the preview benefit derived from the initial trigram alone, the benefit is larger when the other letters of the preview are replaced with visually similar letters than when they are replaced by visually dissimilar letters (Inhoff, 1989b; Lima & Inhoff, 1985; Rayner et al., 1982). Our experiment may have produced minimal preview benefit in the mismatch condition because the final letters changed in an uncontrolled fashion and were often visually dissimilar between preview and target. Furthermore, it may be that letter changes affect the lexical decision task more than other word-recognition paradigms. For example, the need to make word–nonword decisions may sensitize the word-recognition system to visual changes or may increase the likelihood that the input is reevaluated whenever a change is noted. Alternatively, detection of a change may have biased the system toward a nonword response. Consistent with this latter hypothesis, a mismatching preview produced an 11-ms preview benefit for nonwords, but a 5-ms preview interference for words. In Experiment 3, we attempted to test this hypothesis by determining how often participants could detect the display changes.

Overall, the results of Experiment 1 suggest that phonological representations play a central role in transsaccadic integration during word recognition. Converging evidence for the role of phonological codes was provided by Experiment 2, in which participants identified words from an extrafoveal preview alone.

Experiment 2

In Experiment 2 we collected further evidence concerning the processing of extrafoveal previews by examining how accurately participants could identify the target from an extrafoveal preview alone. Participants' ability to accomplish this task provides us with evidence concerning the nature of the phonological codes that are generated from preview information. For example, an influence of phonological regularity on word recognition from previews alone would provide further support for the view that readers compute phonological codes from extrafoveal information. In addition, a comparison of the results of Experiment 2 with the trigram completion study in Experiment 1 will indicate whether the extrafoveal preview provides more or less information than can be obtained from the initial trigram by itself. Finally, the experiment provides evidence bearing on the possibility that participants were simply identifying or guessing the target words from the previews in Experiment 1.

Method

Participants. Ten students from the same pool as in Experiment 1 participated. All had normal vision or wore contact lenses in the experiment, were native speakers of Canadian English, and were naive with respect to the hypotheses under investigation. None had participated in Experiment 1.

Apparatus and materials. The apparatus and materials were the same as those used in Experiment 1, with the exception that only the word targets were used (both regular and irregular) and the control preview condition was not used.

Procedure. The eye-movement calibration was the same as that used in Experiment 1. Each experimental trial was also similar to those in Experiment 1, with the following differences: First, the preview string was always a word (either regular or irregular). The participant was again instructed to execute an eye movement as rapidly as possible to the location of the preview once it appeared on the screen. During the eye movement, the preview word was replaced with a mask consisting of six *x*s (*xxxxxx*). The participants were asked to say aloud the preview word following the eye movement. When they were not sure about the identity of the word, they were encouraged to guess. Each participant saw only one of the two stimulus lists. The experiment was completed in a single session that lasted about 20 min.

Results

Table 3 presents the proportion of correctly identified words as a function of word frequency (high or low), syllable structure (monosyllabic or polysyllabic), and regularity. "Correctly identified" was defined in terms of the word that was actually present; a response other than the word that was presented as the preview was scored as incorrect.

In light of the importance of syllable structure and lexical frequency in determining the preview benefit in Experiment 1, we analyzed the Experiment 2 data over items using a regression model so that we could include these factors. First, among polysyllabic words, regular words were easier to identify than irregular words. This led to a marginal overall effect of regularity, $F(1, 192) = 2.77$, $p < .10$, $MS_e = 0.0416$, and an interaction between regularity and syllable structure, $F(1, 192) = 5.90$, $p < .05$, $MS_e = 0.0416$. Second, among monosyllabic words, there was little evidence for an effect of regularity, and instead word frequency was important. Thus, there was an overall effect of word frequency, $F(1, 192) = 8.16$, $p < .005$, $MS_e = 0.0416$, with high-frequency items being identified more often than low-frequency items, and a marginal interaction between word frequency and number of syllables, $F(1, 192) = 2.84$, $p < .10$, $MS_e = 0.0416$.

Discussion

The results of Experiment 2 can be understood by assuming that participants used the extrafoveal preview to generate a phonological code for the first syllable. When the target word was polysyllabic, the first syllable was a good clue to the identity of regular words but a misleading clue for irregular words; thus, regular items have an advantage over irregular items. Presumably, there was little effect of word frequency in this case, because what is important in retrieving the target item is the frequency of the target given the first syllable rather than overall frequency in the language. In contrast, when the word is monosyllabic, the first syllable will be the entire word. Thus, if readers succeed in generating a first-syllable code, they will be able to identify the target correctly, regardless of whether the initial trigram was classified as regular or irregular. The large frequency effect for monosyllabic words may reflect the greater likelihood of being able to generate such a code with high-frequency items.

Table 3
Proportion of Correctly Identified Words in Experiment 2

	Monosyllabic		Polysyllabic	
Word type	Low frequency	High frequency	Low frequency	High frequency
Regular	.03	.22	.23	.26
Irregular	.09	.20	.09	.13

The results of this experiment also bear on an alternative interpretation of the results of Experiment 1. It might be suggested that participants were fully identifying or simply guessing the identities of the target words from the preview alone on some proportion of the preview trials rather than integrating partial information across saccades. In that case, we would have found a larger preview benefit for the regular words because the proportion of correctly identified and/or guessed targets increased as a function of the regularity of the initial trigram. We believe that this explanation is unlikely for four reasons. First, participants were generally unable to report the words in Experiment 2. This was true even though the average saccade latencies were longer in Experiment 2 (338 ms) than in Experiment 1 (200 ms). Second, the results of Experiment 2 indicate that overall, readers are more likely to be able to identify or guess high-frequency words than low-frequency words whereas the preview benefit in Experiment 1 was as large or larger for low-frequency regular words. Third, if the preview benefit derives in part from the readers' ability to identify (or guess) quickly the target item, one would expect those items that are easy to identify to show the largest preview benefit. However, there was no correlation between the magnitude of the preview benefit observed in Experiment 1 and the probability of correct identification in Experiment 2, $r(202) = .02$. Finally, this account implies that the distribution of match response times in Experiment 1 should be the mixture of two distributions, one for foveal identifications and another, much faster, distribution for identifications based on extrafoveal preview. However, there is no evidence for this kind of mixture: No bimodality is apparent in the reaction time distribution, and the variance in the match condition is similar to that for the control condition, in which distribution mixing would not be expected. In short, we believe that guessing based on the preview alone does not provide a viable account of the results of Experiment 1.

Experiment 3

In Experiment 3, readers participated in trials that were identical to those of Experiment 1, with the exception that the task was to indicate whether the stimulus had changed between the preview and the target. There were two main purposes of the experiment. First, we wanted to determine how often participants could detect the type of display changes that occurred in Experiment 1. As discussed above, we suspected that the overall reason for the lack of a preview benefit and the increase in latency variability in the mismatch condition in Experiment 1 was that participants were occasionally detecting the display change in that condition. We wanted to have some indication of how often participants could detect the changes in order to assess the viability of this explanation.

Second, we were interested in whether we could find an effect of phonological regularity in a task in which explicit word-recognition processes would not be required. For example, if regularity were to influence the ability to detect a display change, then this result would provide further evidence that the generation of a phonological code is a general feature of parafoveal word processing and is not a process invoked only during tasks involving deliberate word identification.

Method

Participants. Six students from the same pool as in Experiment 1 participated. All had normal vision or wore contact lenses in the experiment, were native speakers of Canadian English, and were naive with respect to the hypotheses under investigation. None had participated in Experiments 1 or 2.

Apparatus and materials. The apparatus and materials were identical to those used in Experiment 1.

Procedure. The eye-movement calibration, practice trials, and presentation of materials were identical to those in Experiment 1. A trial was also identical with the following exception: After the eye movement to the target, the participant was asked to press one button if he or she noticed any change between the preview and the target and to press another button if he or she noticed no such change. The experiment was completed in a single session that lasted about 45 min.

Results

Table 4 presents the proportions of trials on which the participant responded that no change had been detected, for the word and nonword stimuli, by preview condition. To ascertain how sensitive participants were to changes across saccades, we used these data to calculate A', a nonparametric measure of sensitivity. A' can be interpreted as the probability of a correct response in a two-alternative forced-choice task (Grier, 1971; Pollack & Norman, 1964). The factors in this analysis were the lexical status of the target (word or nonword) and the type of change (either the final trigram in the mismatch condition or the entire word in the control condition). The tendency to respond "change" in the match condition provided a false alarm rate against which detection rates in the mismatch and control conditions were compared. The A' values for the means are also shown in Table 4. The analysis revealed an effect of type of change, $F_1(1, 5) = 12.71, p < .05, MS_e = 0.0186$, and $F_2(1, 404) = 288.76, p < .001, MS_e = 0.025$, with changes in the control condition being detected more often than changes in the mismatch condition.

Table 4

Proportion of Trials on Which "No Change" Was Reported and A′ Values for Word and Nonword Stimuli as a Function of Preview Condition, Experiment 3

		Mismatch		Control	
Stimuli	Match	Prop.	A'	Prop.	A'
Words					
Regular	.85	.47	.79	.02	.96
Irregular	.92	.40	.86	.03	.97
Nonwords	.82	.38	.82	.03	.95

Note. Mismatch condition changes are changes from one word to another (e.g., *button–butane* and *butane–button*). Control condition changes are changes from the control string to a word (e.g., *xxxxxx–butane* and *xxxxxx–button*). Prop. = proportion.

We also examined the effects of regularity (shown in Table 4) on the A' values for the word stimuli. In this analysis, there was an effect of type of change, $F_1(1, 5) = 18.95, p < .01, MS_e = 0.0061$, and $F_2(1, 202) = 171.74, p < .001, MS_e = 0.026$; an effect of regularity, $F_1(1, 5) = 12.50, p < .05, MS_e = 0.0006$, and $F_2(1, 202) = 3.96, p < .05, MS_e = 0.0488$; and a marginal interaction between regularity and type of change, $F_1(1, 5) = 4.10, p < .10, MS_e = 0.008$, and $F_2(1, 202) = 5.20, p < .05, MS_e = 0.026$. These effects arose because changes to the final trigram (mismatch condition) were detected better with irregular targets than with regular targets, $F_1(1, 5) = 13.28, p < .05, MS_e = 0.0008$, and $F_2(1, 202) = 4.91, p < .05, MS_e = 0.0659$, while detection of changes to the entire string (control condition) was not significantly affected by regularity (F_1 and $F_2 < 1$).

Discussion

The first issue addressed in this experiment was the degree to which participants could detect display changes across the preview conditions. The results suggest that changes were almost always detectable in the control condition but only sometimes detectable in the mismatch condition (when just the final trigram in the word changed). These data are consistent with our assumption that in Experiment 1, detection of a change in the mismatch condition could have interfered with integrating information across an eye movement. Furthermore, these results suggest a reason for the increased variability of the mismatch condition in comparison with the other conditions in Experiment 1 and lend support to our argument that the mismatch condition in Experiment 1 may not have offered a fair test of the phonological coding hypothesis.

There are two reasons why performance in the present experiment may overestimate the degree to which participants were sensitive to display changes in Experiment 1. First, unlike as in Experiment 1, readers were told at the outset of Experiment 3 that display changes would occur and that they should attend to them. This kind of information may have caused participants to be sensitive to aspects of the visual display to which they would have paid little attention under other circumstances. Second, despite instructions to move their eyes as quickly as possible, the mean eye-movement latencies in Experiment 3 were 270 ms, 70 ms longer than in Experiment 1. Thus, participants had a longer look at the extrafoveal preview stimulus in Experiment 3 than in Experiment 1. Presumably, a longer look would lead to a better representation of the preview string and should serve to make the display changes more noticeable. Keeping these caveats in mind, the results of Experiment 3 suggest that the change was detectable on some of the trials in Experiment 1 and therefore support our suggestion that the longer average response latencies and higher variability in the mismatch condition of Experiment 1 were due to a mixture of response latencies from trials on which the change was and was not noted.

The second issue addressed in this experiment was whether phonological regularity would play a role in a word-processing task that did not require recognition. The fact that we did observe an effect of regularity in this experiment indicates that participants' decisions in the change-detection task were influenced by phonological aspects of the stimuli. Furthermore, the interaction between regularity and the type of preview shown suggests that a phonological code derived from the preview was instrumental in the task. This finding is interesting given that word-recognition processes per se were not required to perform the task. That is, participants could have responded by comparing only visual information between the preview and foveally viewed strings. The fact that the phonological match between the preview and the target strings influenced change detection when the preview string was a word provides additional evidence that phonological representations are automatically activated from an extrafoveal preview of a word.

Finally, the finding that changes were detected better with irregular than with regular targets in the mismatch condition provides some support for our original partial phonological coding hypothesis. That is, participants were more likely to detect a change when the preview was a regular word and the target was an irregular word than vice versa. On the partial coding account, given an irregular preview, participants would be likely to generate a regular code for the initial trigram (because the rest of the letters would not be encoded), and when the regular target was then viewed foveally, the code for the initial trigram would match the code for the target. Given a regular preview, participants would again generate a regular phonological code for the initial trigram. However, when the irregular target was then viewed foveally, the mismatch between the codes for the initial trigram would provide an additional source of information indicating that the preview and target were different.

General Discussion

In this study we sought to specify the nature of the representation mediating transsaccadic word recognition. More specifically, we tested the partial phonological coding hypothesis, according to which transsaccadic integration during word recognition involves the use of phonological representations derived from the initial few letters of an extrafoveally previewed word. We found that the phonological regularity of the initial trigram of a six-letter word mediated the integration process: In Experiment 1, the amount of benefit derived from a preview of the target word was greater when the initial trigram of the word was regularly pronounced in the context of the word than when it was irregularly pronounced. This strongly suggests that phonological representations play a role in word recognition across saccades. In Experiment 3, the ability to detect that a word viewed extrafoveally had changed to another word following an eye movement was also affected by the phonological similarity between the two words. Words whose initial trigrams were visually identical but did not match phonologically were more readily detected as having changed than were words whose trigrams did match phonologically. This result suggests that the computation of a phonological code from an extrafoveally viewed word is not specific to the recognition task and that it occurs even when such a code is not useful. Furthermore, detection of change was greater when the preview was regular and the target irregular than vice versa, consistent with the partial coding hypothesis. Finally, in Experiment 2, participants found it very difficult to identify or guess the identities of the target words from an extrafoveal preview alone, correctly responding on only about 15% of the trials. Furthermore, performance in Experiment 2 was most accurate for high-frequency, regular words. This latter result contrasts with the results of Experiment 1, in which it was found that the largest preview benefits accrued for low-frequency, regular words. Together, these results indicate that the pattern of benefits observed in Experiment 1 was not due to identification or guessing of the targets from the previews alone.

Models of Word Recognition

A number of different types of models have been proposed to account for the role of phonological representations in word recognition. The most popular of these models, the dual-route model, proposes that both orthographic and phonological representations are computed from a letter string input and that either of these types of representations can lead to lexical access (Carr & Pollatsek, 1985). Other models suggest that either orthographic representations alone (Humphreys & Evett, 1985) or phonological representations alone (Lukatela & Turvey, 1991; Perfetti et al., 1988; Van Orden, Pennington, & Stone, 1990) are sufficient to account for lexical access under all circumstances. Our study was not designed to decide between these classes of models. Instead, our purpose was to determine whether phonological representations play a role in transsaccadic word recognition. The results of Experiment 1 indicated that when orthographic similarity between the preview and target is held constant (i.e., when the preview and target are identical), a preview of a target word with a regularly pronounced initial trigram provides more benefit than a preview of a target word with an irregularly pronounced initial trigram. This result suggests that phonological representations do play a role given the type of input that the word-recognition system normally acquires in the course of natural reading, which consists of a parafoveal preview of a word during one fixation followed by a central view on a subsequent fixation (Rayner & Pollatsek, 1989). Furthermore, the results of Experiment 3 suggest that phonological representations are activated whether or not word recognition is explicitly called for by the task. These results appear to be compatible with models of word recognition that include a role either for phonological representations alone or for both phonological and orthographic representations but not with models in which phonological representations play no role.

One way to conceptualize our results is within the context of the covariant-learning hypothesis (Van Orden et al., 1990). According to this view, word recognition involves a process of settling into an "attractor" state within a hyperspace defined over a set of subsymbolic output features. Attractors are initially located in the hyperspace during learning via covariations between input and output subsymbols (e.g., position-coded orthographic and phonological units; Seidenberg & McClelland, 1989; Van Orden, 1987). According to the covariant-learning hypothesis, effects that have traditionally been taken as evidence for the dual-route model can be accounted for with a single mechanism. For example, the Regularity × Frequency interaction, often taken as support for the dual-route model, can be accounted for within a covariant-learning model by using covariation coding alone (Seidenberg & McClelland, 1989). Within these models, high-frequency words have relatively strong attractors because the covariations between the input and output subsymbols are seen relatively often during learning. This is true for both regular and irregular high-frequency words. Low-frequency regular words also have relatively strong attractors because they benefit from the covariations between the same subsymbols in the high-frequency words. Low-frequency irregular words, in contrast, have relatively weak attractors because they benefit from neither repetition in learning nor "spillover" from covariations among the subsymbols of other words.

Such a model could account for our results on the hypothesis that the entire word is more likely to offer a context within which to interpret the initial trigram in the preview when the word is monosyllabic rather than polysyllabic. That is, if we maintain the assumption that the initial trigram alone of the preview string is more likely to be the input to the system (from the preview) when the word is polysyllabic rather than monosyllabic, then the input of the initial trigram is more likely to lead to a coding closer to an attractor corresponding to a regular pronunciation than an irregular pronunciation given a polysyllabic word. If the word then turned out to contain a regular initial trigram, a preview benefit based on phonology would be obtained. If the word turned out to contain an irregular initial trigram, we might then expect some cost in comparison with the control condition, because the coding would have to be deflected away from the regular attractor and toward the irregular attractor (presumably on the basis of the presence of the other letters making up the word). Finally, continuing with our main assumption, if the input to the system from the preview is more likely to be the entire word given a monosyllabic word, then the coding of the initial trigram will be influenced by the orthographic units activated by the rest of the word. That is, the orthographic context provided by the other orthographic subsymbols will constrain the phonological coding of the orthographic subsymbols that compose the initial trigram (see, e.g., Kawamoto, 1993, for an example of how inclusion of additional input subsymbols can serve as context within which other subsymbols are interpreted in a covariant-learning model). In other words, regularity for the initial trigram alone will no longer be relevant.

On the above analysis, the lack of a Regularity × Preview interaction for the high-frequency polysyllabic words presents somewhat of a problem. One possible solution is to suppose that for these high-frequency words, the attractor for the entire word is strong enough that when the word is seen centrally, an initial incorrect coding of the trigram from the preview is not too important (the coding is easily deflected from the incorrect to the correct attractor). Another possibility is that the initial trigram in these words is likely to be coded within the context of the entire word (as with the monosyllabic words). Support for this second possibility derives from the finding that more information can be acquired from a high- rather than low-frequency extrafoveal word (Inhoff & Rayner, 1986). The issue, then, would be to explain why a main effect of regularity is still observed with the high-frequency, polysyllabic words.

In summary, the interaction of preview and regularity observed for the low-frequency polysyllabic words suggests that phonological codes play a role in integrating lexical information across a saccade. Either a dual-route or a covariant-learning account of word recognition could account for this finding. At the same time, it is important to note that the preview benefits observed in the other conditions (the first three panels of Figure 3) could be accommodated by assuming that the information about a word that is carried across a saccade is based on orthographic information alone. That is, the results are consistent with a model in which phonological codes are functional only in the integration process given low-frequency, polysyllabic words.

Transsaccadic Word Recognition

As discussed in our introduction, Pollatsek et al. (1992) have also reported evidence consistent with phonological mediation of transsaccadic integration. In their study, preview benefits were larger for homophonic preview–target pairs than for visually matched but nonhomophonic preview–target pairs. The words used by Pollatsek et al. were generally monosyllabic, and therefore the phonological representation mediating integration in their study may have involved a code for the entire word. Because Pollatsek et al. defined homophony over the entire word, their interpretation of the phonological representation mediating transsaccadic integration in their stimuli is consonant with our present proposal. As we pointed out earlier, many authors have suggested that the representation mediating integration from fixation to fixation in reading involves primarily information from only the first few letters of the previewed word. Both our work and that of Pollatsek et al. suggest that information from larger segments of the extrafoveal word may be involved in some instances. Our suggestion is that this finding is particularly likely when the first syllabic unit is longer than the initial few letters.

Pollatsek et al. (1992) concluded that in addition to phonological codes, orthographic representations probably mediate transsaccadic integration. They conducted several post hoc analyses showing that the effect of phonological similarity (homophony) in their study increased as visual similarity between the preview and target decreased. From these results, Pollatsek et al. concluded that phonological and graphemic codes cooperate in the identification of words across saccades. However, it is important to note that our results showed an effect of phonological integration when the preview and target were visually identical to each other. Therefore, our results suggest that phonological codes are used in the integration process even when graphemic codes would be maximally useful. This issue clearly requires further empirical scrutiny.

Given that phonological regularity exerts an influence on transsaccadic integration, at what level of representation is this influence produced? We consider two possibilities. First, the phonological code derived from the preview may initiate lexical processing immediately. In this view, the preview benefit is due to integration of activation within the lexicon, with a preview providing earlier activation of a neighborhood of lexical entries. Given the importance of the initial letters in producing a preview benefit (Henderson & Ferreira, 1990; Inhoff, 1989a, 1989b; Lima & Inhoff, 1985; Rayner et al., 1982; N. R. Underwood & McConkie, 1985), the initial letters may be weighted more heavily during extrafoveal processing, perhaps because they form the initial phonological syllable. This view can be seen as generally consistent with models of auditory word recognition in which initial phonemes play a central role (Marslen-Wilson, 1989). Second, it could be that a prelexical phonological code is generated from the preview and held in a short-term store. Presumably, when the word is foveally fixated, further information would be added to this code until a representation capable of supporting access to the word-recognition system is created. The initial letters would be important in this case because they generally would form a syllabic unit capable of supporting a unitized, easily maintained phonological code. Our finding that the magnitude of the preview benefit was as large for nonwords as for words provides some limited evidence against the direct lexical activation account. If the preview benefit were due to activation within the lexicon, then we would not expect a large preview benefit for nonwords.

Conclusion

In summary, our most important finding was that the phonological regularity of the initial trigram of an extrafoveal preview affected several aspects of extrafoveal word processing. First, the regularity of the preview mediated the benefit derived from that preview in transsaccadic word recognition. Second, extrafoveal regularity influenced the identifiability of a word from the preview alone. Importantly, regularity interacted differently with word frequency in these two tasks: In the integration task, a low-frequency regular preview provided the most benefit, while in the task of identifying words from a preview alone, a high-frequency regular preview was most useful. Finally, the regularity of the extrafoveal preview mediated the detectability of changes to a letter string across saccades. Together, these results suggest that phonological representations are computed for a word viewed extrafoveally prior to a saccade and that these representations are often integrated with phonological representations derived from that word following the saccade.

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