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Phonological Codes are Assembled Before Word Fixation: Evidence from Boundary Paradigm in Sentence Reading

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This experiment employed the boundary paradigm during sentence reading to explore the nature of early phonological coding in reading. Fixation durations were shorter when the parafoveal preview was the correct word than when it was a spelling control pseudoword. In contrast, there was no significant difference between correct word and pseudohomophone previews. These results suggest that the phonological codes are assembled before word fixation and are used for lexical access. Moreover, there was evidence that orthographic codes influence the activation of word meaning. We found that fixation durations were shorter for orthographically similar parafoveal previews, and this orthographic priming effect is limited to pseudohomophones. Thus, it seems that both the orthographic and the phonological similarities of the parafoveal preview to the target play a part in the facilitative effects of the preview.

Key Words: parafoveal information ; assembled phonology ; eye movements ; reading ; boundary paradigm

INTRODUCTION

During reading, the eyes do not move smoothly across the printed page. Instead, the eyes make short and rapid movements, called saccades. Between saccades, the eyes remain stationary for brief periods of time (typically 200-250 ms) called fixations (Javal, 1906; Huey, 1908). Visual information is extracted from the printed page only during fixations - no useful information is extracted during the saccade (Wolverton & Zola, 1983). During a fixation, the eyes have access to three areas for viewing information: the foveal, parafoveal, and peripheral regions. The foveal region is the area where visual acuity is maximal and includes 2 degrees of visual angle around the point of fixation, where 1 degree is generally equal to three or four letters in experiments (thus, six to eight letters are in focus). The parafoveal region extends to about 15 to 20 letters, and the peripheral region includes everything in the visual field beyond the parafoveal region. Because acuity drops off steadily from the center of fixation, words presented in parafoveal vision are harder to identify accurately (Henderson, Dixon, Petersen, Twilley & Ferreira, 1995). However, the importance of this parafoveal vision in reading was clearly demonstrated in the classic *moving window* studies (McConkie & Rayner, 1975 ; Rayner, Well, Pollatsek & Bertera, 1982). In these experiments, a "window" of normal text was defined around the letter that the subject was fixating; outside this window, the text was mutilated. Whenever the eyes moved, a new window was defined around the next fixation point. One finding is that the reading rate is slower when only the fixated word is visible in the window. But when readers have the currently fixated word plus either the next word or the beginning letters of the next word available, the reading rate is almost equally as fast as when readers have the whole line of text. These results clearly demonstrate that both types of information - foveal and parafoveal - are important in reading.

There are two major ways in which parafoveal information can be used during eye fixations in reading. First, it can be used to help readers determine where to look next. McConkie & Rayner (1975) found that readers use the word length information (marked by the spaces between words) in parafoveal vision to program where their next saccade will go. This result was confirmed by a great deal of research (Liversedge & Underwood, 1998; Pollatsek & Rayner, 1982; Rayner, Fischer & Pollatsek, 1998; Vonk, Radach & van Rijn, 2000). Second, parafoveal information can be used to aid word-recognition processes. When a parafoveal word was previewed, the result was a shorter fixation duration when that word became the next fixated word (Rayner, 1975). This parafoveal preview benefit may be due to a movement of the attention toward the parafoveal word before the eye movement, as in the "sequential attention shift" models (for example the E-Z Reader model, Reichle, Pollatsek, Fisher & Rayner, 1998) in which attention is allocated serially, from one word to the next. It also may be due to the processing in parallel of more that one word as in the "guidance by attentional gradient" models (for example the Mr. Chips model, Klitz, Legge & Tjan, 2000).

It has been demonstrated that orthographic processing of a word can begin prior to the word being fixated (Balota, Pollatsek & Rayner, 1985 ; Binder, Pollatsek & Rayner, 1999). Moreover, this parafoveal preview benefit is not due to retention of visual-feature information since all the letters can change from fixation to fixation (e.g. MaNgRoVe changed to mAnGrOvE) with virtually no disruption of the reading process; therefore, the source of preview seems to be due to abstract letter codes (McConkie & Zola, 1979). It seems also that phonological codes are extracted from a word that has yet to be fixated. According to Pollatsek, Lesch, Morris & Rayner (1992), phonological codes can be extracted from parafoveal field of vision. These authors used the *boundary paradigm* introduced by Rayner (1975). In this paradigm, a boundary location is specified just to the left of a target word. This boundary is not visible in the text. Prior to the reader's eye movement crossing the boundary, an initially display stimulus (the preview) is presented, and when the reader's saccade crosses the boundary, the computer replaces the preview with the target word (see Figure 1). Thus, in foveal vision, the readers always see the correct target word (fixation n). The readers are unaware of the display change because it occurs during the saccade (according to Wolverton & Zola, 1983, there is no useful information extracted during the saccade). One benefit of this paradigm is that there is minimal disruption of normal reading.

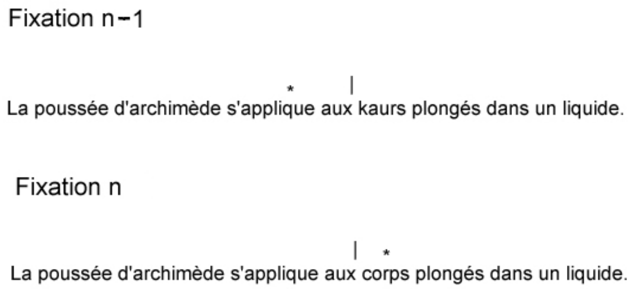

Figure 1: Illustration of the boundary technique. The top line represents the line before the boundary is crossed. The fixation point is represented by an asterisk and the boundary (invisible to the subject) is represented by the vertical line. The second line represents the text after the boundary has been crossed and the preview *kaurs* (pseudohomophone) has changed to *corps*. Other possible previews are *kanrs* (pseudocontrol) and *corps* (correct word).

In the experiment lead by Pollatsek and his colleagues, the reading of the target word was faster when the preview was a homophone than when the preview was a non-homophonic control word that was as visually similar to the target word as was the homophone. So the authors came to the conclusion that phonological information is extracted from the parafoveal word and is used for word identification. These results indicate that the preview has its beneficial effect through graphemic codes such as abstract letters and phonological codes such as phonemes. However, the mechanism for the integration process is unclear. Two different scenarios are possible to explicate the preview benefit. Either the phonological and orthographical information are used to narrow down the set of potential candidates or they are used to activate partial word information then perceptual and lexical analyses that have been executed parafoveally are omitted during the following fixation. According to the first hypothesis, parafoveally available word information that greatly limits the set of potential word candidates should be more effective than parafoveally obtained information that only loosely limits this set. Lima and Inhoff (1985) tested this by using previews that either strongly or loosely constrained the number of potential word candidates. However, they found that constraints imposed by the word initial letter sequence on potential word candidates did not affect the benefit obtained from a parafoveal preview. In the light of these results, it seems to us that the parafoveal preview benefit is due to a partial activation of the target word rather than a narrowing of the set of candidates. One possibility is that the orthographic information is extracted from the beginning of the parafoveal letter-string and this activates a neighborhood of lexical entries. Phonological information is also automatically activated on the basis of sub-lexical units for those units that follow the initial orthographic information. The preview benefit will be determined by the degree of orthographic and phonological excitation of the lexical entry of the target word caused by the preview. If the preview is physically identical to the target, then one would expect that both the visual and phonological lexical entries would be maximally excited. If the preview is a homophone of the target word, the phonological lexical entry will be maximally excited, but the visual entry less so. For visually similar preview, there will be some excitation in the visual lexicon causing some preview benefit, but less than for the homophone.

Although Pollatsek et al. (1992) results provide good evidence for an influence of phonological representations upon preview benefit, they do not specify the origin of this influence: are these phonological representations *addressed* (in the sense of obtained globally from a complete orthographical representation of the word) or *assembled* (in the sense of obtained from sublexical information or from Grapheme-Phoneme Correspondences) ? Lesch & Pollatsek (1998, experiment 2) tried to answer this question by using a variant of the boundary paradigm. In this study, the authors used false homophones as previews. A false homophone is not a homophone of the true associate word, but it could be pronounced like the true associate word by some process of assembled phonology (for example : BEAD is a false homophone of BED because if BEAD was pronounced with the spelling-to-sound correspondences of its neighbor HEAD, then the pronunciation /bɛd/ would result). If visual word recognition is phonologically mediated and if all the phonological representations allowed by a letter string are computed automatically, then presentation of a letter string like BEAD should result both in the activation of the meaning "bead" associated with the actual phonological representation of the word (/bid/) and the meaning "bed" associated with the phonological representation that results if an alternative spelling-to-sound correspondence is applied (/bɛd/). Participants judged whether two simultaneous presented words were semantically related. Thus, they were to respond "yes" when presented with the words PILLOW and BED, and "no" when presented with the words PILLOW and HOOK. The semantic associate (e.g., PILLOW) appeared centered in the fixation point while the target word (e.g., correct word: BED, false homophone: BEAD, visually similar control: BEND, or different: HOOK) appeared to the right . Participants were instructed to look at the word appearing in the fixation point first and then to look at the second word and judge whether the two words were semantically related in some way. The word on the right was changed from a preview word displayed when the participant was fixating the first word to the target word on the second fixation. There were four parafoveal preview conditions: identical, true associate, different, biasing preview (e.g., HEAD as a preview for BEAD). Participants were slower to reject false homophones than to reject visually similar controls. Moreover, response times were quicker the more orthographically and/or phonologically similar the preview and target words were. The authors argued that assembled phonological representations are extracted from parafovea. However, false homophones are real words so they may produce interfering lexical activation. Moreover, the authors used a semantic judgment task with isolated words and in foveal vision participants see foils, which is not the most common way of reading. It is possible that the subjects were not performing the majority of psycholinguistic processes that would normally occur during reading. In addition, the dependent variable was time needed to press the response key, which is longer than fixation duration and so which allows specific strategies. Therefore, the question of the nature of the phonological code that is involved in parafoveal benefit remains open.

The main goal of the present study was to test whether non-word primes can produce the preview benefit effects. Specifically, we wanted to know whether there was a phonological priming effect that was due to pseudohomophone primes. The use of pseudohomophones is advantageous : they are typically compared to non-homophone pseudowords, which do not sound like words. The comparison between these stimuli is interesting because it potentially provides a way to diagnose the activation of phonological information in reading. Pseudohomophones are novel stimuli that the subjects will not have encountered before; hence they will not have formed any associations between their spellings and specific meanings. For homophone previews, phonological representations may be addressed. It is not the case for pseudohomophone previews. So, we think that the use of pseudohomophones is useful because the facilitation induced by the pseudoword prime is necessarily due to assembled codes. We addressed this question by using boundary paradigm in sentence reading with pseudowords (pseudohomophones and pseudocontrols) as preview stimuli and by recording first fixation and gaze durations. The major advantage of this paradigm is that it can be used to study word identification in the silent reading of sentences, with minimal disruption of normal reading. If phonological information assembled from parafoveal preview aids word-recognition processes, there should be more preview benefit for pseudohomophones than for pseudocontrols.

A secondary focus was to examine the role of orthographic similarity between the prime and the target word. It has been demonstrated that orthographic processing can also begin prior to the word being fixated (Balota et al., 1985; Binder et al., 1999). Thus, although the main focus was on assessing whether assembled phonological coding is involved in the process of integration of information across saccades, we wanted to determine whether orthographic codes were involved as well and how they interact with phonological codes. Hence, the spelling similarity between the preview and the target was varied. We think that both orthographic and phonological parafoveal information aid word-recognition processes in an additive way. Thus, fixation durations should be shorter for high spelling similarity previews than for low spelling similarity previews. Moreover, we expected preview benefit was maximal when pseudowords were homophone and visually similar.

A third focus was to examine the influence of frequency in parafoveal priming. Inhoff and Rayner (1986) found that high frequency words receive shorter first fixations than low frequency words when parafoveal previews are available but not when only the foveal word was available. Thus, when parafoveal preview benefits have been obtained, first fixation on a word apparently reflects lexical processing of that word. We expected an effect of target-word frequency on first fixation durations when launch site is close to the target word (when parafoveal processing is possible) but not when it is faraway (in this case, parafoveal preview is not available). It seems to us also interesting to investigate how phonological and orthographic preview benefits would interact with frequency, especially with non-word primes. We think that phonological and orthographical similarity between the parafoveal prime and the foveal word aid the word recognition processes but even pseudohomophone primes with high spelling similarity are different from correct word. We suppose that these differences between the parafoveal and the foveal items disrupt the lexical activation : pseudoword parafoveal primes should provide less activation of the correct word than correct word primes. Thus, we expected no frequency effect on first fixation durations with pseudoword primes.

METHOD

Participants.

15 unpaid graduate students participated in this experiment. All were native French speakers and had normal uncorrected vision. All subjects considered themselves fluent readers and were naïve with respect to the purpose of the experiment.

Materials and design.

60 target words were inserted in sentences in such a way that they were near the middle of the line. For each target word, 3 preview items were possible : an identical preview, a spelling control pseudoword preview or a homophone pseudoword preview (for example : chaise, choise and cheise, see appendix 1). Target words and associate pseudowords have the same number of letters. The frequency of correct words and the spelling similarity between pseudowords and correct words were manipulated. Correct words could be sorted into a high (30) and a low (30) frequency group. The mean frequency count was 33 828 occurrences per 100 million for high frequency words and 2 195 occurrences for low frequency words (Content, Mousty & Radeau, 1990). For each frequency group, half (15) pseudohomophones and half (15) controls were orthographically similar to their corresponding target story-word. There were two measures for orthographic similarity : the index used by Van Orden (1987, see appendix 2) and the number of identical first letters. Mean orthographic similarity (Van Orden's index) for the similarly spelled foils was 0.78 (≥ 3 in term of identical first letters) for pseudohomophones and 0.79 for controls. The other 15 pseudohomophones and their yoked controls were orthographically less similar to their corresponding target story-word: mean orthographic similarity was 0.23 for pseudohomophones and 0.27 for controls (no identical first letters).

The word length was controlled across the groups. The target words ranged from 4 to 12 letters in length with mean length equal to 7.08. Four different lists of sentences were constructed. We accomplished counterbalancing of sentences across the four lists in such a way that a participant was presented only one version of each sentence. In each list, one half of the previews were correct words, one quarter were pseudohomophones and one quarter were pseudocontrols.

Balota, Pollatsek, & Rayner (1985) showed that the effective use of parafoveal information during the following fixation on the word is a function of the contextual constraints. Parafoveal information was used more effectively when the predictability of the parafoveal word was high than when the predictability was low. So, in our experiment, contextual constraints are held constant. The word *context* can apply to a multitude of phenomena. In reading, one might distinguish between the contributions of (1) syntax, (2) the semantic relatedness of individual words, and (3) higher order variables such as schemata. Such distinctions are not central to our concerns. Instead, we deal with context (and contextual constraint) largely in terms of a word predictability given the prior text. A group of 10 graduates who did not participate in the experiment were presented the sentence frames up to the target word and were asked to produce the next word in the sentence. Target word predictability was not different between all item groups [$F(3,56) = 0.53$, $p > .65$, high frequency - high spelling similarity: 19.33 %, high frequency - low spelling similarity: 29.33 %, low frequency - high spelling similarity: 18.66 %, low frequency - low spelling similarity: 22.66 %].

Procedure.

Subjects were tested in a dimly illuminated room. They were seated at a distance of 75 cm from the monitor. At that distance, approximately 3.4 characters subtended 1° of visual angle. Participants were instructed to read the sentences at as normal a pace as possible, paying attention to meaning. The sentences were displayed on a 17-inch View Sonic monitor in conventional upper- and lowercase. Each sentence was presented on a single line with a maximum of 68 characters and could be refreshed in less than 20 ms. The boundary location was always the last letter of the word immediately to the left of the target word. Luminance of the monitor was adjusted to a comfortable level and held constant throughout the experiment. An ET4 of AMtech pupil tracking system was used to record reader's eye movements. The eye tracker has a spatial resolution of 2 min of arc, and its signal was sampled every three millisecond. Viewing was binocular, with eye movements recorded from the right eye. At the beginning of the experiment, the eye-tracking system was calibrated for the subject. Each trial was initiated by the appearance of a cross on the left of the line. Before reading each sentence, the subject looked at the fixation cross that marked the first character position in the sentence. This cross was a warning signal and a calibration check (if the calibration was inaccurate, the eye-tracking system was calibrated anew). When the cross was fixated, the experimenter presented the sentence. When the reading of the sentence was finished (fixation of a cross at the right of the sentence) the sentence disappeared and a new calibration check cross appeared. At the end of the experiment, we asked the participants if they had perceived anything particular and the participants who declared they had seen some flickering were excluded from the analysis. It was the case for two participants. Thus the results of 13 participants were analysed.

RESULTS

The key question was whether the type of preview would affect the time needed to process the target word. The parafoveal preview benefit is revealed by shorter fixation durations when the target word is later fixated. The two measures of processing time used most frequently for assessing the time to identify a word are the mean first fixation duration and the mean gaze duration. First fixation duration (FFD) is an average of the first fixations made on a word, disregarding any additional fixations. Gaze duration (GD) is the sum of all consecutive fixations on a word prior to an eye movement to another word. First fixation and gaze durations are calculated only from the fixated words. However, the words which are completely identified from parafoveal information will be skipped. Thus skipped words may be considered to be words with a fixation duration being equal to zero (and a parafoveal preview benefit being maximal). However, in contrast to fixation durations, the skipping rate is a dichotomic variable. So, we expected that skipping rate is less statistically sensitive to the effects of parafoveal preview benefit than the fixation duration index. Fixation durations recorded in our study were not longer than fixation times recorded in other eye-tracking studies. So, we think that the reading has not been disrupted by the boundary paradigm.

Trials on which a fixation duration was below 55 ms or over 400 ms were excluded from the analysis. After the experiment, we determined the launch sites which are the letter positions, relative to the target word beginning, from which the eye movement started. With alphabetic text, readers can progress at a more-or-less normal rate when the window extends 14-15 characters spaces to the right (McConkie & Rayner, 1975 ; Rayner & Bertera, 1979). However it seems that word encoding probably does not extend to more than 7-8 characters to the right of fixation; beyond this distance, only low-spatial frequency information about letter shape and word length is extracted from the page (see Rayner, 1998). We could not use this limit of 7-8 characters because we don't have enough data for the analysis (27 % of the overall data). Thus, if the saccade started from 1 to 15 letters before the target word (4,40° of angle), we considered the launch site close and if it started from more than 15 letters, we considered the launch site faraway. The main objective of this experiment is to study the influence of parafoveal information in reading. So we were focused on the data with close launch sites which allowed parafoveal processing of the target words and which represented 77.5 % of the overall data. The saccades that started from a close launch site, arrived at approximately 37 % of the target word (between the beginning and the middle of the word). This initial landing site corresponded to the classical *preferred viewing location* (Rayner, 1979).

A 3 (preview type: pseudohomophone, pseudocontrol, identical) x 2 (frequency of corresponding word: high, low) analyse of variance (ANOVA) based on subject variability (F1) and item variability (F2) was carried out on the dependant variables.

TABLE 1
First fixation durations and gaze durations (in milliseconds)

	Correct words		Pseudohomophones		Pseudocontrols	
	FFD	GD	FFD	GD	FFD	GD
HF	223	260	233	266	242	282
LF	234	285	246	303	262	315
Mean	228	272	239	284	252	299

Note. FFD = First fixation duration ; GD = gaze duration ; HF = High frequency ; LF = Low frequency.

ANOVA showed a significant main effect of preview on the first fixation durations [$F1(2,24) = 3.74$, $p < .05$; $F2(2,168) = 3.02$, $p < .05$]. On gaze durations the main effect of preview was significant by subjects [$F1(2,24) = 5.55$, $p < .05$] but not by items [$F2(1,167) = 1.67$, $p > .10$]. This discrepancy may be due to the fact that gaze durations include some refixations on the correct foveal words and so are a little less sensitive to the preview effect. Paired comparisons revealed that first fixation durations with pseudocontrol previews (252 ms) were longer than those with correct word previews (228 ms) [$F1(1,12) = 9.80$, $p < .01$; $F2(1,168) = 5.41$, $p < .05$]. In contrast, the first fixation durations were not significantly different between pseudohomophone previews (239 ms) and correct word previews [$F1(1,12) = 2.32$, $p > .15$; $F2(1,168) = 2.09$, $p > .15$]. The gaze durations showed the same pattern of results. Gaze durations were longer with pseudocontrol previews (299 ms) than with correct word previews (272 ms) but this effect only approached significance by items [$F1(1,12) = 13.42$, $p < .005$; $F2(1,167) = 3.27$, $p < .07$], there was no difference between pseudohomophone previews (284 ms) and correct word previews [$F1(1,12) = 1.35$, $p > .25$; $F2(1,167) = 1.25$, $p > .25$].

The main effect of frequency was significant on first fixation durations [$F1(1,12) = 6.83$, $p < .05$; $F2(1,168) = 4.97$, $p < .05$] and on gaze durations [$F1(1,12) = 11.40$, $p < .01$; $F2(1,167) = 8.06$, $p < .01$]. Planned comparisons revealed that fixation durations on high frequency words with correct preview were shorter (223 and 260 ms for first fixation and gaze durations respectively) than low frequency words with correct preview (234 and 285 ms) for both first fixation durations and gaze durations [FFD : $F1(1,12) = 7.71$, $p < .05$; $F2(1,168) = 4.03$, $p < .05$; GD : $F1(1,12) = 7.83$, $p < .05$; $F2(1,167) = 5.49$, $p < .05$]. In contrast, frequency effect was not significant with pseudocontrol previews [FFD : $F1(1,12) = 3.06$, $p > .10$; $F2(1,168) = 0.52$, $p > .40$; GD : $F1(1,12) = 1.60$, $p > .20$; $F2(1,167) = 1.14$, $p > .25$] and pseudohomophone previews [FFD : $F1(1,12) = 0.86$, $p > .30$; $F2(1,168) = 1.28$, $p > .25$; GD : $F1(1,12) = 4.51$, $p > .05$; $F2(1,167) = 2.25$, $p > .10$].

A first 2 (homophony: pseudohomophone, pseudocontrol) x 2 (orthographic similarity: high, low) analyse of variance (ANOVA) was carried out to determine the role of orthographic information from parafovea. In this analysis, orthographic similarity was assessed by the index used by Van Orden (1987).

TABLE 2

First fixation durations and gaze durations (in milliseconds)

	Pseudohomophones		Pseudocontrols	
	FFD	GD	FFD	GD
OS+	242	270	249	292
OS-	237	299	255	306
Mean	239	284	252	299

Note. FFD = First fixation duration ; GD = gaze duration ; OS- = Less similarly spelled ; OS+ = similarly spelled. Spelling similarity calculated with Van Orden's index.

The main effect of spelling similarity was not reliable on first fixation durations [$F1(1,12) = 0.63$, $p > .40$; $F2(1,110) = 0.25$, $p > .60$] but was statistically significant on gaze durations by subjects [$F1(1,12) = 5.36$, $p < .05$; $F2(1,110) = 0.58$, $p > .40$]. With pseudohomophone previews, gaze durations on words with high spelling similarity preview were shorter (270 ms) than on words with low spelling similarity preview (299 ms) [only significant by subjects; $F1(1,12) = 6.20$, $p <.05$; $F2(1,110) = 1.22$, $p > .20$]. This effect of spelling similarity was not found with pseudocontrol previews [$F1(1,12) = 1.75$, $p >.20$; $F2(1,110) = 0$, $p > .95$].

For the former analysis, degree of spelling similarity was calculated with Van Orden's index (1987). However, the Van Orden's index is a global index assessing the orthographic similarity with all the letters of the items (see appendix 2). Because of the distance of some launch sites considered here (from 1 to 15 characters), we think that, in the majority of cases, only the first letters of parafoveal words were processed. We can also estimate the orthographic similarity between two items by estimating the number of common initial letters (the beginning letters of the prime yield preview benefit; Inhoff, 1989). Thus we made an analysis in which we considered that primes which were identical to the target in at least the first three letter positions were orthographically similar primes, and that primes which were different from the target in the first letter position were dissimilar primes. The set of items used in the analysis with the Van Orden's index contained 60 items. The set of items used in the analysis with the number of common initial letters contained 43 items (high spelling similarity - high frequency : 11 out of 15 ; high spelling similarity - low frequency : 10 out of 15 ; low spelling similarity - high frequency : 10 out of 15 ; low spelling similarity - low frequency : 12 out of 15). High spelling similarity pseudowords for which one of the three first letters was different from the correct word were excluded from this analysis. In the same way, low spelling similarity pseudowords for which the first letter was identical to the correct word were excluded from this analysis. All the similarly spelled items in regard to the number of common initial letters are similarly spelled with the Van Orden's index.

All the less similarly spelled items in regard to the number of common initial letters are less similarly spelled with the Van Orden's index.

TABLE 3

First fixation durations and gaze durations (in milliseconds)

	Pseudohomophones		Pseudocontrols	
	FFD	GD	FFD	GD
OS+	217	251	236	284
OS-	255	309	252	301
Mean	236	280	244	293

Note. FFD = First fixation duration ; GD = gaze duration ; OS- = Less similarly spelled ; OS+ = similarly spelled. Spelling similarity in term of number of common initial letters.

With this index, the main effect of spelling similarity was reliable on first fixation durations [$F1(1,12) = 5.44$, $p < .05$; $F2(1,82) = 3.84$, $p < .05$] and on gaze durations [$F1(1,12) = 5.20$, $p < .05$; $F2(1,82) = 5.50$, $p < .05$]. With pseudohomophone previews, first fixation durations and gaze durations on words with high spelling similarity preview were shorter than on words with low spelling similarity preview [$F1(1,12) = 6.07$, $p <.05$; $F2(1,82) = 4.69$, $p < .05$; and $F1(1,12) = 9.80$, $p <.01$; $F2(1,82) = 4.01$, $p < .05$ respectively]. These effects were not found with pseudocontrol previews.

An additional 3 (preview type: pseudohomophone, pseudocontrol, identical) x 2 (frequency of corresponding word: high, low) analyse of variance was made on the percentage of skipped target-words. We observed main effect of preview type on the skipping rate [$F1(2,24) = 4.48$, $p < .05$; $F2(2,174) = 3.85$, $p < .05$]. Skipping rate was significantly higher for correct word previews (20.1 %) than for pseudoword previews (8.63 % for pseudohomophone previews and 7.74 % for pseudocontrol previews) [$F1(1,12) = 7.11$, $p < .05$; $F2(1,174) = 7.57$, $p < .01$]. Moreover, the frequency effect with correct word previews observed on fixation durations was also found on the skipping rate. High frequency words were skipped more often (25,9 %) than low frequency words (14,2 %) [$t(12) = 2.36$, $p < .05$].

In the cases for which parafoveal processing was not possible (faraway launch sites, 11 % of the overall data), the results were different. There was no longer a parafoveal preview benefit for correct words in comparison with pseudocontrols. There was no difference on first fixation and gaze durations between correct word previews and pseudocontrol previews [FFD : $t(12) = 1.87$, $p > .05$; GD : $t(12) = 1.21$, $p > .20$]. Moreover, first fixation and gaze durations on low-frequency targets did not differ from fixation durations on high-frequency targets [FFD : $t(12) = 0.17$, $p > .80$; GD : $t(12) = 0.47$, $p > .60$], in contrast with the cases for which the parafoveal preview was available.

DISCUSSION AND CONCLUSION

The principal finding of the study is that a significant phonological priming was obtained with pseudowords. We found that a pseudohomophone parafoveal preview of a target facilitated the subsequent fixation on this target more than a non-homophone pseudoword preview equated on visual similarity to the target. This result indicates, in agreement with Pollatsek et al. (1992), that phonological codes are extracted in reading even before the word is fixated and aid word identification. The present study provides direct positive evidence for the use of assembled phonological representations in preview benefit (that is consistent with Lesch & Pollatsek, 1998). One may objected that even if an assembled phonological code is generated for pseudowords, this does not mean that an addressed code is not generated for words. However, in our study the subject is never aware of the presence of these pseudoword previews while reading. The fact that the subject does not know in advance whether the prime is a word or a pseudoword (half of the previews presented to the subjects are correct words) implies that the information is extracted from the preview via a common universally used stage of processing in word identification (rather than a stage used in the production of an experimentally unique response). So, the code generated for the preview should be the same one both for pseudoword and word.

The main issue of this experiment was to investigate whether parafoveally extracted phonological codes are addressed (in the sense of obtained globally from a complete orthographical representation of the word) or assembled (in the sense of obtained from sublexical information or from Grapheme-Phoneme Correspondences). Our main conclusions are that phonological codes are extracted in reading even before the word is fixated, that these codes aid word identification and that these codes are assembled. However, our results not allow us to give a verdict on the locus, prelexical or lexical, of these parafoveally assembled phonological codes. This assembling may be see as prelexical if we consider that the lexicon contains the representation of the word only as a whole, or as lexical if we consider that sublexical information is a part of the orthographic and phonological components.

Even if the present data suggest that phonological codes play an important role in meaning activation during silent reading, there was also evidence that orthography influences processing. In our study, with identical first letters index, we found that first fixations were shorter for orthographically similar primes. One possible mechanism for this facilitation is that the letters of the parafoveal preview partially activate a neighborhood of lexical entries, including the entry of the word visible in foveal vision, so that the resulting excitation speeds lexical access to this word. Another possibility is that abstract letters are identified parafoveally, which facilitates lexical access on the subsequent fixation (cf. Rayner &

Pollatsek, 1989). One piece of our data that suggests that the facilitation is in terms of partially activated word detectors, rather than fully activated letter detectors, is that the orthographic priming effect on first fixations is limited to pseudohomophones. An orthographically similar prime will facilitate the early stages of accessing the phonological code by providing greater support for the component letters. As parafoveal information is, in most cases, insufficient to activate the word completely (there is very little word skipping with pseudowords as previews), pseudohomophone previews will have an advantage over the orthographically similar non-homophone items because they are better primes for the phonological code of the word that will be visible in the fovea.

In contrast, when the orthographic similarity was calculated with the Van Orden (1987) index of orthographic similarity, we found a different pattern of results: we obtained a difference between orthographic similar and dissimilar primes only for gaze durations. There is a possible explanation for this discrepancy. First fixations have been proved to be sensitive to the initial processing of a word (Inhoff, 1984). Gaze durations which include refixations are more global indicators of word processing and are likely to include postlexical processing operations. As orthographic similarity - estimated with Van Orden index - affected only gaze durations, it must be reasonably admitted that this factor affected postlexical stages. These data appear to be compatible with a model of lexical access, such as the verification model (Van Orden, Johnston & Hale, 1988; Rayner, Pollatsek & Binder, 1998), in which the initial stage of lexical access is the activation of the relevant phonological code, followed by a verification stage, in which the orthographic code is subjected to further processing. If we use the verification model as an explanatory mechanism, then our observed pattern of data makes sense: initial letters of the parafoveal preview partially activate a neighborhood of lexical entries at an early stage of processing (effect on first fixation durations) and global similarity between items (estimated by Van Orden's index) influences gaze durations, that is, later stages of processing such as the verification process.

On the other hand, there was not as much priming from pseudowords as from real-words in this study, even if pseudohomophones may produce a stronger priming effect than non-homophone pseudocontrols. When parafoveal preview was the target word, we found a frequency effect on first fixation durations and gaze durations. No such effect was found when the preview was a pseudoword. When parafoveal previews were not available (faraway launch sites), first fixation and gaze durations on a low-frequency target did not differ from fixations on a high-frequency target. This finding supports the position that parafoveal word processing is sensitive to the lexical characteristics of the parafoveal word (Inhoff & Rayner, 1986) and that high-frequency parafoveal words are processed more effectively than low-frequency parafoveal words. Another piece of data supporting this hypothesis was the fact that the probability of word skipping was higher when the preview was the correct word. In addition, we found a frequency effect : word skipping was more frequent for high frequency targets than for low frequency targets. If a word is skipped, it has been processed on the prior fixation.

There is now a wide variety of paradigms that argue for early phonological involvement in word identification. These include misclassification of homophones or pseudohomophones in categorization task (Van Orden, 1987; Van Orden et al., 1988), semantic priming by homophones of associates (Lesch & Pollatsek, 1993; Lukatela & Turvey, 1994), masked phonological priming by homophones (Humphreys, Evett & Taylor, 1982), omission in proofreading task (Daneman & Stainton, 1991; Van Orden, 1991) and release from backward masking by homophones (Perfetti, Bell & Delaney, 1988). In addition, there is a number of relevant eye movement studies that are consistent with the notion that phonological codes are activated early during eye fixation. These include boundary paradigm (Pollatsek et al., 1992), boundary paradigm with lexical decision task (Henderson et al., 1995) or semantic judgement task (Lesch & Pollatsek, 1998), fast priming paradigm (Rayner, Sereno, Lesch & Pollatsek, 1995; Lee, Binder, Kim, Pollatsek and Rayner, 1999; Lee, Rayner and Pollatsek, 1999), sentence reading with pseudohomophones (Inhoff & Topolski, 1994) or homophones (Rayner et al., 1998; Folk, 1999; Folk & Morris, 1995) embedded in sentences and text reading (Jared, Levy and Rayner, 1999; Sparrow & Miellet, 2002). The fact that in our study, parafoveal preview benefits are systematically more important for pseudohomophones confirm these data.

Numerous authors argue that semantic codes directly receive activation from the phonological codes. However, even if the phonology of a word is automatically activated during silent reading and aid word recognition, this does not mean that it is necessary to get to meaning via the phonological component. According to an alternative explanation, phonology may be automatically activated sublexically, but this in turn, can activate the orthography of the homophonic partner. It can then be this orthographic representation that makes contact with semantics (see Taft & van Graan, 1998). Although, we support the former (direct activation of semantic from phonology), our results not allow us to decide positively between these two hypothesis.

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APPENDIX 1

Stimuli used in the experiment

PH: pseudohomophones ; PC: pseudocontrols ; SO: Van Orden's (1987) index

Words	frequency	Nb letters	PH	Nb letters	same first letters	SO	PC	Nb letters	same first letters	SO
			Similarly spelled foils							
High frequency										
maison	50652	6	maizon	6	3	0,82	mailon	6	3	0,82
raison	48197	6	raizon	6	3	0,82	raiton	6	3	0,82
chambre	33851	7	chembre	7	2	0,847	chamble	7	5	0,847
conscience	33375	10	consciance	10	6	0,901	conscionce	10	6	0,95
d'action	29503	8	d'acsion	8	2	0,82	d'aclion	8	2	0,82
chemins	21161	7	chemain	7	4	0,672	chemoin	7	4	0,672
caractère	20084	9	caraktère	9	4	0,874	carantère	9	4	0,874
rêves	19893	5	reive	5	2	0,582	rêpes	5	2	0,78
d'étrange	13707	9	d'étranje	9	5	0,847	d'étrampe	9	4	0,764
camarade	10682	8	camarhad	8	5	0,695	camarode	8	5	0,86
direction	10520	9	direksion	9	4	0,817	dirention	9	4	0,882
réflexions	9925	10	réflection	10	5	0,857	réflendion	10	5	0,857
position	9470	8	posiçion	8	4	0,805	posilion	8	4	0,805
hontes	9236	6	hontte	6	4	0,725	hontle	6	4	0,643
chaise	8168	6	cheise	6	2	0,82	choise	6	2	0,82
Mean	21894,93	7,60		7,60	3,67	0,79		7,60	3,80	0,81
SD	14211,95					0,09				0,08
Low frequency										
l'atmosphère	5190	12	l'atmosfaire	12	5	0,781	l'atmoslaire	12	5	0,781
croyance	4492	8	croïance	8	3	0,866	cropance	8	3	0,866
excès	4360	5	exsès	5	2	0,84	exnès	5	2	0,78
pression	3416	8	préscion	8	2	0,718	préstion	8	2	0,718
remords	3343	7	remaurs	7	3	0,69	renours	7	2	0,75
morne	2620	5	mohrn	5	2	0,6	moirn	5	2	0,6
soupçons	2339	8	soupsons	8	4	0,926	souprons	8	4	0,864
faubourgs	2195	9	fauxbours	9	3	0,828	fautourgs	9	3	0,882
d'alcool	1969	8	d'alcohl	8	4	0,79	d'alcoil	8	4	0,79
supplice	1696	8	suplisse	8	3	0,776	supliffe	8	3	0,776
singe	1646	5	sinje	5	3	0,78	sinpe	5	3	0,78
sorcières	1497	9	sorciairs	9	5	0,761	sorgières	9	3	0,88
chimères	1263	8	chimairs	8	4	0,735	chimoirs	8	4	0,735
docilités	727	9	dossilité	9	2	0,675	dospilité	9	2	0,675
gravats	233	7	gravâds	7	4	0,753	gravûds	7	4	0,753
Mean	2465,73	7,73		7,73	3,27	0,77		7,73	3,07	0,78
SD	1434,42					0,08				0,08

Words	frequency	Nb letters	PH	Nb letters	same first letters	SO	PC	Nb letters	same first letters	SO
			Less similarly spelled foils							
High frequency										
l'autre	248359	7	l'ôttre	7	0	0,49	l'utrie	7	0	0,51
femme	85995	5	phame	5	0	0,317	plome	5	0	0,317
têtes	63793	5	taite	5	1	0,418	toite	5	1	0,418
assez	55497	5	açait	5	1	0,327	adait	5	1	0,327
corps	54417	5	kaurs	5	0	0,062	kanrs	5	0	0,062
fort	47010	4	phor	4	0	0,231	plor	4	0	0,231
l'objet	32252	7	l'aubjé	7	0	0,19	l'auplé	7	0	0,07
compte	22079	6	kontes	6	0	0,18	rontes	6	0	0,18
espèce	18978	6	aispès	6	0	0,267	eispot	6	1	0,453
hasard	12635	6	azzart	6	0	0,152	avlart	6	0	0,152
oiseaux	11205	7	hoizots	7	0	0,16	hoitous	7	0	0,174
d'aspect	10259	8	d'haspai	8	0	0,262	d'haspoi	8	0	0,262
enfance	9206	7	anfense	7	0	0,501	onfense	7	0	0,416
morceaux	7708	8	maurçots	8	1	0,429	meurçats	8	1	0,369
péchés	7028	6	paiché	6	1	0,553	procha	6	1	0,453
Mean	45761,40	6,13		6,13	0,27	0,30		6,13	0,33	0,29
SD	61212,86					0,15				0,14
Low frequency										
enfer	4360	5	anfer	5	0	0,61	onfer	5	0	0,61
fantôme	4245	7	phentom	7	0	0,174	plentom	7	0	0,174
harmonie	3922	8	armaunit	8	0	0,289	armaunat	8	0	0,217
caresses	2616	8	karaices	8	0	0,423	daraices	8	0	0,423
haleine	2352	7	alhaîne	7	0	0,508	alhande	7	0	0,438
noeud	2327	5	nheux	5	1	0,48	nille	5	1	0,36
l'embarras	2156	10	l'hambarat	10	0	0,378	l'imbarale	10	0	0,389
bâtiment	2016	8	batimand	8	1	0,495	batimond	8	1	0,495
hideuse	1352	7	idheuze	7	0	0,438	idheupe	7	0	0,438
quête	1250	5	kaite	5	0	0,37	foite	5	0	0,37
tonneaux	991	8	teaunods	8	1	0,525	tainnoue	8	1	0,501
chaux	859	5	schot	5	0	0,19	schol	5	0	0,19
crépi	246	5	krépy	5	0	0,31	orépy	5	0	0,31
gibet	140	5	jibai	5	0	0,19	pibou	5	0	0,19
ammoniaque	55	10	hamauniack	10	0	0,264	haumeuniat	10	0	0,226
Mean	1925,80	6,87		6,87	0,20	0,38		6,87	0,20	0,36
SD	1426,22					0,14				0,13

APPENDIX 2

Van Orden's (1987) index

Van Orden adapted an estimate from Weber (1970). Weber's measure of graphic similarity (GS) is computed as follows:

$$GS = 10 ([(50\,F + 30\,V + 10\,C) / A] + 5\,T + 27\,B + 18\,E)$$

F = number of pairs of adjacent letters in the same order shared by word pairs :

HOUSE / HORSE F = 2

EVERY / VERY F = 3

V = number of pairs of adjacent letters in reverse order shared by word pairs:

WAS / SAW V = 2

C = number of single letters shared by word pairs:

SPOT / PUFF C = 1

FAMILY / FUNNY C = 2

A = average number of letters in the two words:

EVERY / VERY A = 4.5

T = ratio of number of letters in the shorter word to the number in the longer:

EVERY / VERY T = 4 / 5

B = 1 if the first letter in the two words is the same; otherwise, B = 0.

E = 1 if the last letter in the two words is the same; otherwise, E = 0.

Van Orden's (1987) index of orthographic similarity (OS) was defined by the following ratio:

OS = (GS of the two items) / (GS of the correct word and itself)