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Is emotional content obtained from parafoveal words during reading? An eye movement analysis

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An eye-movement-contingent display change technique was employed to study whether adult readers extract semantic information from parafoveal words during reading. Three types of parafoveal preview conditions were contrasted: an emotional word, a neutral word, and an identical word condition. To have a maximally effective parafoveal manipulation, high-arousal emotional words (sex- and threat-related and curse words) were used as parafoveal previews. Readers' eye fixation patterns around the target word revealed no evidence for parafoveal semantic processing. Furthermore, the pupil size showed no signs for an emotional response triggered by an emotional word previewed parafoveally. These results are consistent with the view that, as a rule, only the fixated word is processed to a semantic level during reading.

Key words: Eye movements, reading, attention span.

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INTRODUCTION

Eye movement research has significantly advanced our understanding of the attentional processes related to reading (for a review, see Rayner, 1998). Despite the significant progress made, the issue of the scope of the attentional span during reading is still controversial. Specifically, researchers differ in their views on how much semantic information is assumed to be simultaneously processed. The serial attention view advocated by Rayner and colleagues (see Rayner, White, Kambe, Miller & Liversedge, 2003; Reichle, Pollatsek, Fisher & Rayner, 1998; Reichle, Rayner & Pollatsek, 2003) holds that typically only one word at a time is processed to a semantic level (i.e., an access to the word meaning is achieved). Once the identity of the foveal word is accessed, attention is shifted to the parafoveal word. Parafoveal preprocessing is assumed to be restricted to the orthographic and visual information. An exception to this rule is made for cases when a word is skipped (i.e., is read without making an eye fixation on it). The meaning of the skipped words is assumed to be accessed during the fixation preceding the skipping (this typically happens when the word is short, high-frequency, and/or contextually highly predictable).

The competing view does not consider the attentional span in reading to be limited to a single word at a time. Thus, according to the attentional gradient view (Inhoff, Radach, Starr & Greenberg, 2000a; Kliegl & Engbert, 2003) attention can spread to the neighboring words so that semantic processing of two adjacent words may be carried out. In support of this view, Inhoff *et al*. reported that when a word to the right of the fixated word was a semantic associate of the fixated word, the fixated word received less fixation time than when the word to the right was unassociated. Murray (1998) also reported results in support of parafoveal semantic processing. When the parafoveal word was semantically implausible in the sentence, the fixation time on the word to the left of the parafoveal word was inflated (see also Kennedy, 1998; Kennedy, Murray & Boissiere, 2004). Thus, in the sentence "The uranium smacked the child" fixation time on *uranium* was inflated in comparison to a sentence where *uranium* was replaced by a more pragmatically plausible word such as *savages*. However, Murray did not use a normal reading task, but a task where the participants scanned pairs of sentences to judge whether or not they were physically identical. Rayner *et al.* (2003) reported that when the study of Murray (1998) was replicated using a normal reading task no evidence was found to support the existence of parafoveal semantic processing in reading. The same conclusion was made by Rayner, Warren, Juhasz and Liversedge (2004). They presented semantically implausible and anomalous sentences to the readers to see at what point in time implausibility was detected. They found no compelling evidence to support the view that semantic anomaly would be detected parafoveally. Only when a fixation was closer than three character spaces to the left of the anomalous expression, potential evidence for anomaly detection was observable in the eye movement record. However, Rayner *et al.* (2004) interpreted this finding to reflect a saccadic undershoot, that is, on some trials the eyes were intended to land on the anomalous word, but fell slightly short. In other words, this finding was not taken as evidence for parafoveal semantic processing.

To date, Rayner and colleagues have consistently failed to find evidence to support the existence of parafoveal semantic

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processing (Altarriba, Kambe, Pollatsek & Rayner, 2001; Balota, Pollatsek & Rayner, 1985; Rayner, Balota & Pollatsek, 1986). In these studies, an eye-movement-contingent display change paradigm was employed (Rayner, 1975). In this paradigm, changes are introduced in the word to the right of the fixated word; during the saccade made to the parafoveal word, the letter string is changed to its intended form. As vision is significantly reduced during saccadic eye movements (due to saccadic suppression), the actual change is not perceived by the readers. On the other hand, if semantic information is obtained of the word from the parafovea in the changed form, it should have consequences for its subsequent foveal processing (when foveated, the word appears in its intended form). For example, for the target word *song* Rayner *et al*. (1986) presented in the parafovea a semantically related word (*tune*) or an unrelated word (*door*). No processing difference occurred between these two conditions, which led them to conclude that no semantic information is obtained from the parafovea during reading.

The present study was conducted as a further test of parafoveal semantic processing. We reasoned that the lack of parafoveal semantic effect observed in many of the previous reading studies may be due to the semantic manipulation being insufficiently strong to induce an effect. Therefore, in the present study we opted for a manipulation that would maximize the chances to find an effect. We thought emotional words with a negative valence and a high arousal value, such as obscene, sex-related and curse words, would meet this criterion. In a repetition priming study, Calvo and Castillo (2005) presented simultaneously a prime word in the parafovea and a probe word in the fovea. The words were either emotionally positive, threat-related, or neutral. The participants made lexical decisions to the probe words. In Experiments 1–3, the parafoveal primes were identical to the foveal probes, except that the letter case was changed (from lower-case to upper-case). Their priming results supported the view that a word's emotional content, particularly when it is threat-related (e.g., *coffin*, *tumor*, *murder*), may be obtained from the parafovea. Lexical decision times for threat-related probes were speeded up by the presence of a threat-related identity prime in the parafovea. We wanted to further strengthen the emotional content to increase the likelihood that if an emotional word is recognized parafoveally, the effect would be traced in readers' eye movement records. Therefore, the majority of our emotional words were sex-related and curse words that are likely to induce an emotional arousal when recognized (we also included a set of threat-related and other negatively valenced words in the set of emotional words).

In the present experiment, we employed the eye-movement-contingent display change technique (see Rayner, 1975) to study parafoveal semantic processing in reading. Three different parafoveal preview conditions were included: (a) an emotional word preview, (b) a neutral word preview, and (c) an identical word condition where no change was made to the target word. In the two change conditions the preview was changed to the original form during the incoming saccade to the target word. Thus, when foveally inspected, the target word was identical across the three experimental conditions; they only differed in the type of parafoveal preview allotted to the target (see Table 1 for an example). In the two change conditions, the first three letters of the target word were kept intact, as it is known that the bulk of the orthographic preview effect is produced by 2–3 word-initial letters (Rayner, Well, Pollatsek & Bertera, 1982).

Table 1. *An example of the three parafoveal preview conditions (identical, emotional, neutral) for the target word* pentu *("cub")*

Identical preview:	Mielestäni minkä tahansa eläimen **pentu** on hurjan suloinen. ↑
Emotional preview:	Mielestäni minkä tahansa eläimen **penis** on hurjan suloinen. ↑
Neutral preview:	Mielestäni minkä tahansa eläimen **penni** on hurjan suloinen. ↑
Target word fixated:	Mielestäni minkä tahansa eläimen <u>pentu</u> on hurjan suloinen. ↑
	"In my opinion, any animal's cub/penis/penny is extremely cute."

Notes: The arrow depicts the approximate fixation location during the parafoveal preview and the target word fixation. The parafoveal previews are here shown in bold and the target word is underlined (not in the experiment proper). At the bottom of the table, an English translation is given for the three preview conditions.

Readers' eye movement measures yield an on-line record of the processing as it unfolds over time. The earliest possible point in time to find a parafoveal semantic preview effect is when the word preceding the parafoveal preview is foveated. As mentioned above, such an effect was observed by Inhoff *et al*. (2000a). This effect is known as the semantic parafoveal-on-foveal effect (Kennedy, 1998, 2000; Kennedy, Pynte & Ducrot, 2002). If an emotional word is perceived in the parafovea, it may attract the eyes to it (see Calvo & Lang, 2005, for such an effect observed with emotional scenes), which could result in a shorter fixation duration prior to fixating the target.

The second and perhaps more plausible point in time to find a parafoveal preview effect is when the target word is fixated. If the information obtained of the target word when in the parafovea does not match with what is perceived when it is directly fixated, a processing cost should occur. Thus, the two change conditions should produce longer fixation times on the target word than the no change condition. Most importantly, on the assumption that the semantic content of emotional words is readily obtained from the parafovea, the emotional word condition should produce the longest fixation durations.

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In addition to fixation times on the target, we also used pupil size as an index of parafoveal semantic processing. Emotional stimuli are likely to induce an arousal in the autonomous nervous system, which in turn is reflected as pupil dilation (see Janisse, 1977), but with some delay. It takes at least 300 ms before a response to a triggering event begins to show up as pupil dilation; the pupil reaches its maximum about 1 s after a single triggering event (Hoeks & Levelt, 1993). Thus, the earliest possible time to detect an effect in pupil size is in the latest stages of processing the target word itself, but the effect should be stronger during the next couple of fixations after leaving the target word. In fixation time measures, the semantic effect may also appear as a delayed effect. Therefore, we also analyzed the durations of fixations made after exiting the target word as well as the durations of regressive fixations back to the target word.

METHOD

Participants

Twenty-four university students took part in the experiment as part of a course requirement. Two participants were dropped from the analyses due to an excessive number of eye blinks.

Apparatus

Eye movements were collected by the EYELINK eyetracker manufactured by SR Research Ltd. (Canada). The eyetracker is an infrared video-based tracking system combined with hyperacuity image processing. There are two cameras mounted on a headband (one for each eye) including two infrared LEDs for illuminating each eye. The headband weighs 450 g in total. The cameras sample pupil location and pupil size at the rate of 250 Hz. Registration is monocular and is performed for the selected eye by placing the camera and the two infrared light sources 4–6 cm away from the eye. The spatial accuracy is better than 0.5 degrees. Head position with respect to the computer screen is tracked with the help of a head-tracking camera mounted on the center of the headband at the level of the forehead. Four LEDs are attached to the corners of the computer screen, which are viewed by the head-tracking camera, once the subject sits directly facing the screen. Possible head motion is detected as movements of the four LEDs and is compensated for on-line from the eye position records.

Materials

The experiment was conducted in Finnish. Target words were embedded in single sentences that extended a maximum of two lines. An eye-movement-contingent display change paradigm was employed (Rayner, 1975). An invisible boundary was set two character spaces to the left from the target word. When the eyes crossed this boundary, the target word was changed to its intended form. The display change was triggered when one single eye sample was identified that had crossed the boundary. It took an average of about 13 ms to implement the change once the eyes crossed the invisible boundary. Thus, when the target was foveally inspected, it always appeared in the same form. Three parafoveal preview conditions were created for each target: (a) an emotional word, (b) a neutral word, and (c) an identical word (i.e., the word was replaced by itself). The preview triplets shared the first three letters, and they were of the same length. To maximize the emotional intensity of the preview words in the emotional preview condition, we aimed to use high-arousal sex-related and curse words. Due to the initial-letter and length constraints mentioned above, and due to the fact that the number of these words is relatively restricted, we presented each emotional preview word twice. The preview words in the emotional condition comprised 45% sex-related words (e.g., *penis*, *whore*), 21% threat-related (e.g., *murder*, *cancer*), 10% curse words (e.g., *hell*, *damn*), 14% drug-related (e.g., *cocaine*), and 10% other negative words (e.g., *Hitler*, *Nazi*). The neutral preview condition consisted of words that were not assumed to induce an emotional response (e.g., *blanket*, *penny*, *bridge*). An example sentence triplet is given in Table 1 above.

Sixty sentence triplets like the one shown in Table 1 were created. Each participant saw only one version of each sentence triplet, so each participant was exposed to 20 sentences in each of the three experimental conditions. The three different versions of each sentence triplet were counterbalanced between participants. The experimental sentences were mixed with 20 filler sentences, where no display change was made.

The sentences were presented in 12 point Courier font. The target word appeared sentence-medially and never appeared as the first or last word in a text line. To attract an eye fixation reasonably close to the parafoveal preview, the word preceding the target word was chosen to be 5–10 letters long (words of this length typically attract one eye fixation on them). The average length of the target words was 6.4 characters, ranging from 5 to 9 characters. With a viewing distance of about 60 cm, one character space subtended approximately 0.3 degrees of visual angle. In the eye movement analyses, the target area extended two character spaces to the left of the first letter of the target word and two character spaces to the right of the final letter of the target word.

Procedure

Prior to the experiment, the eyetracker was calibrated using a nine-point calibration grid that extended over the entire computer screen. Prior to each sentence, the calibration was checked by presenting a fixation point in a center-left position of the screen; if needed, calibration was automatically corrected, after which a sentence was presented to the right of the fixation point.

Participants were instructed to read the sentences for comprehension at their own pace. They were further told that periodically they would be asked to paraphrase the last sentence they had read to make sure that they attended to what they read. It was emphasized that the task was to comprehend, not to memorize the sentences. A short practice session containing ten sentences preceded the experiment proper.

RESULTS

Repeated measures analyses of variance were performed on the dependent variables; the type of parafoveal preview (emotional, neutral, identical) was a within-participant (F_1) and within-item (F_2) variable. Several eye fixation measures were employed as dependent variables. We first examined the fixation duration prior to fixating the target to see whether parafoveal preview would exert a very early effect (i.e., the so-called parafoveal-on-foveal effect). The length of the saccade to the target word as well as the location of initial fixation on the target were also used to measure very early

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Table 2. *Means and standard deviations (SD) of eye measures for the three parafoveal preview conditions (identical, emotional vs. neutral word)*

	Preview type					
	Identical		Emotional		Neutral	
Eye measure	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*
Duration of fixation prior to the target[a]	221	32	215	32	224	44
Length of the incoming saccade[b]	8.17	0.89	8.16	1.14	8.17	1.11
Initial fixation location[b]	3.29	0.67	3.32	0.60	3.36	0.61
Duration of 1st fixation on the target[a]	226	39	243	49	245	51
Duration of 2nd fixation on the target[a]	186	30	197	34	191	29
Gaze duration on the target[a]	291	73	314	71	318	73
Pupil size of the 1st fixation on the target[c]	1395	467	1394	463	1394	447
Pupil size of the 2nd fixation on the target[c]	1322	421	1329	411	1321	400
Probability of making a regression from the target	0.09	0.12	0.11	0.11	0.12	0.11
Duration of 1st fixation after leaving the target[a]	221	37	224	31	228	35
Duration of 2nd fixation after leaving the target[a]	194	51	207	44	199	42
Pupil size of 1st fixation after leaving the target[c]	1373	453	1370	449	1376	445
Pupil size of 2nd fixation after leaving the target[c]	1378	456	1369	445	1378	431
Duration of 1st regressive fixation on the target[a]	25	20	44	46	35	28
Pupil size of 1st regressive fixation on the target[c]	1435	521	1430	522	1486	544
Duration of 2nd regressive fixation on the target[a]	7	13	6	15	4	7
Total fixation time[a]	325	78	360	82	357	81

Note: [a] = in ms; [b] = in character spaces; [c] = in pixels.

effects, as the saccade to the target word is programmed when the eyes are still fixating a previous word. As our primary measures, we analyzed durations of fixations on the target word. Recall that the target word was identical across the three parafoveal preview conditions. Possible lagged effects were examined by analyzing the fixation durations after leaving the target and the duration of regressive fixations made back to the target. Finally, pupil size was used to index an emotional response of the autonomic nervous system. The means and standard deviations of all measures are shown in Table 2.

Trials were excluded where the target word was skipped; only three such trials existed. In the display change condition, trials were excluded if the change took place after a fixation had already started on the target word,[1] or if a display change was triggered prematurely.[2] Thirteen percent of trials were excluded using these criteria. The number of excluded trials did not differ between the experimental conditions ($F < 1$). One sentence triplet where the target word mistakenly appeared in the second text line was removed from the analyses.[3]

Duration of fixation prior to the target

The duration of fixation immediately prior to fixating the target word was not reliably affected by preview type ($F_1(2, 42) = 1.75$, $p > 0.1$; $F_2 < 1$), although the trend was in the predicted direction (i.e., the emotional condition produced the shortest fixation time). Recall that we expected the emotional words to capture attention and pull the eyes toward them, which should lead to short fixations. However, this prediction was not supported by the data.

The length of the incoming saccade

It is possible to argue that the identification of an emotional word in the parafovea would attract the eyes to it, which in turn would lead to a longer saccade extent. However, this did not appear to be the case, as the length of the saccade entering the target word was not affected by preview type ($F_{1,2} < 1$; see Table 2).

The location of initial fixation

Analogously to the incoming saccade length, the initial fixation location on the target word was not influenced by preview type ($F_{1,2} < 1$; see Table 2).

First-pass reading of the target word

The duration of first fixation on the target was reliably affected by preview type ($F_1(2, 42) = 5.43$, $p < 0.01$; $F_2(2, 114) = 7.58$, $p = 0.001$). The identical preview produced a shorter first fixation (226 ms) than the two change condition, which produced a first fixation of almost equal duration (243 vs. 245 ms). For the gaze duration measure, durations of fixations falling on the target prior to exiting it are summed up. Gaze duration displayed an effect of preview type that was marginal in the item analysis ($F_1(2, 42) = 4.14$, $p < 0.05$; $F_2(2, 114) = 2.47$, $p < 0.1$). Similarly to the first fixation

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duration, the identical condition produced the shortest gaze duration and the two change conditions had highly similar gaze durations. The duration of second fixation was not affected by preview type (both *F*s < 1). In the final analyses of the target word reading, we examined the average pupil size during the first and second fixation. The main effect of preview type remained clearly non-significant for both fixations (all *F*s < 1).

Fixations after leaving the target

To examine possible lagged effects, we analyzed the durations and average pupil sizes of the first two fixations made after fixating away from the target, regardless of whether they were directed to the right or left of the target. However, we first analyzed the probability of making a regression from the target, which was not influenced by preview type ($F_1(2, 42) = 1.20$, $p > 0.1$; $F_2 < 1$). Neither were the fixation durations affected by preview type (both *F*s < 1 for the first fixation; for the second fixation: $F_1 < 1$; $F_2(2, 114) = 2.32$, $p > 0.1$). In the second fixation duration, there was a trend for the emotional preview condition displaying a slightly longer duration than the other two preview conditions. Finally, the average pupil size for these two fixations showed no significant effects (all *F*s < 1).

Duration of regressive fixations

We next analyzed the average duration of regressive fixations made back to the target word. For this analysis, we included regressions made to the target within the next three fixations after the target was exited for the first time. If no regression was made, the trial was coded as 0 (thus, this duration measure correlates highly with the probability of making a regressive fixation on the target). We wanted to exclude later regressions, as they may be less sensitive to local parafoveal preview effects (for instance, regressions made after reaching the end of sentence may reflect sentence wrap-up).

The duration of first regressive fixation was marginally affected by preview type $F_1(2, 42) = 2.68$, $p < 0.1$; $F_2(2, 114) = 2.71$, $p < 0.1$); regression time was shortest for the identical condition and longest for the emotional condition. Pairwise *t* tests indicated that the identical condition differed marginally from both the emotional ($t_1(21) = 1.90$, $p < 0.1$; $t_2(57) = 2.12$, $p < 0.05$) and the neutral condition ($t_1(21) = 1.72$, $p < 0.1$; $t_2(57) = 1.85$, $p < 0.1$), but the two change conditions did not differ from each other. The average pupil size for the first regressive fixation was affected by preview type, but only in the by-participant analysis ($F_1(2, 28) = 4.36$, $p < 0.05$; $F_2(2, 114) = 1.21$, $p > 0.1$).[4] However, the effect was of an unexpected nature; the neutral condition tended to produce the largest pupil size. The duration of second regressive fixation showed no reliable effect of preview type (both *F*s < 1).

The final analysis related to the second-pass reading concerned the total fixation time, which is the sum of all fixations landing on the target word (i.e., gaze duration + duration of regressive fixations made within the next three fixations after the target was exited). The main effect of preview type proved significant for this measure ($F_1(2, 42) = 6.47$, $p < 0.01$; $F_2(2, 114) = 4.53$, $p = 0.01$). The identical preview produced shorter total fixation times than the two changed conditions, but the emotional preview did not differ from the neutral preview (a difference of 3 ms).

Launch site analyses

The analyses reported above for the complete data set showed no evidence for parafoveal semantic processing. In the final set of analyses, we considered the possibility that the lack of significant differences between the emotional and neutral preview condition may be due to the variability in the launch sites obscuring the differences. In other words, if the target word is "parafoveally previewed" from a distant location, the possibility of finding evidence for parafoveal semantic processing may be reduced. Thus, we grouped the trials into two categories: (a) far launch site trials, and (b) near launch site trials. The launch site was considered to be far when it was at least four character spaces to the left from the end of the word preceding the target; the near launch site was less than four character spaces from the end of the preceding word (60% of the trials were near launch site trials). The probability of launching a saccade to the target from the near site was not affected by preview type (both *F*s < 1). In the following, we report launch site analyses for those eye fixation measures, for which the main effect of preview type proved significant or marginally significant. Launch site was entered in the ANOVAs as a within-participant and a within-item variable. Of particular interest are possible Preview Type × Launch Site interactions. The condition means for the analyzed measures are given in Table 3. The analyses were based on 21 subjects and 43 items.

For the duration of first fixation on the target word, the critical Preview Type × Launch Site interaction remained non-significant ($F_1(2, 40) = 1.32$, $p > 0.1$; $F_2(2, 84) = 1.74$, $p > 0.1$). In gaze duration, the interaction approached significance in the by-participant analysis ($F_1(2, 40) = 3.05$, $p < 0.1$; $F_2 < 1$). However, the nature of the interaction was not as predicted. As it appears from Table 3, in the near launch site the preview type had little influence, whereas in the far launch site the two change conditions displayed longer gazes than the identical preview. This pattern of results was also reflected as a main effect of launch site ($F_1(1, 20) = 40.69$, $p < 0.001$; $F_2(1, 42) = 21.15$, $p < 0.001$); the near launch site was associated with shorter gazes (282 ms) than the far launch site (338 ms). The main effect suggests that a greater parafoveal preview benefit is obtained from a near than a far distance. The Preview Type × Launch Site interaction remained non-significant in the duration of first regressive fixation to the target (both *F*s < 1) and in the total fixation time on the target ($F_1(2, 40) = 1.50$, $p > 0.1$; $F_2 < 1$). For the

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Table 3. *Durations of fixations (in ms) on the target word for the three parafoveal preview conditions (identical, emotional vs. neutral word), as a function of the launch site (near vs. far)*

	Preview type					
	Identical		Emotional		Neutral	
Eye measure	Near	Far	Near	Far	Near	Far
Duration of 1st fixation on the target	228	226	241	243	239	254
Gaze duration on the target	276	302	282	354	286	359
Duration of 1st regressive fixation on the target	23	21	51	37	35	33
Total fixation time	306	331	332	387	327	392

total fixation time, the main effect of launch site proved significant ($F_1(1, 20) = 25.91$, $p < 0.001$; $F_2(1, 42) = 11.19$, $p < 0.01$); the nature of the effect was analogous to the one observed for gaze duration.

To sum up, the launch site analyses demonstrated that the lack of differences between the emotional and neutral previews was not compromised by the launch site. More specifically, supportive evidence for parafoveal semantic processing could not be obtained even for trials, where the preceding fixation prior to foveating the target word was close to the parafoveal preview.

Other follow-up analyses

One may argue that the failure to observe a parafoveal semantic effect is due to our manipulation not being strong enough. Admittedly, there was some variation in the emotional preview items. Yet, 45% of the items were sex-related (many of them obscene words), whose parafoveal recognition should leave a trace in the eye records (either as inflated fixation duration, a greater number of regressions back to the target, and/or larger pupil size). To test the possibility that the semantic manipulation was not strong enough, we recomputed all item analyses separately for the sex-related items. However, the results turned out very similar to the overall analyses, so there is no need to report them in detail here.

On the basis of the recent studies conducted by Calvo and colleagues (Calvo & Castillo, 2005; Calvo & Lang, 2005), it may be argued that threat-related words may be particularly susceptible to be perceived parafoveally. This would serve an adaptive function in that quick and easy recognition of threat-related contents would be advantageous in preparing the system to encounter harmful stimuli. Thus, we conducted item analyses separately for the threat-related words (21%). Gaze duration and total fixation time demonstrated a tendency in the predicted direction (i.e., the emotional condition produced the longest fixation times), but the crucial difference between the emotional and the neutral parafoveal previews was not significant in pairwise *t* tests (*p*s > 0.32). The gaze durations (in ms) were 312, 373, and 342, and the total fixation times 343, 414, and 381, for the identical, emotional, and neutral preview conditions, respectively.

Finally, we considered the possibility that the lack of parafoveal semantic effect could have been caused by some of the target words being too long to be perceived parafoveally (the average length was 6.4 characters, but the length ranged from 5 to 9 characters). A new set of item analyses were conducted on the shortest (5–6 character spaces) targets (60% of all targets). The results turned out highly similar to those done for the complete data set. Thus, the above reported results were not compromised by target word length.

DISCUSSION

The present study was designed to find evidence for the existence of parafoveal semantic processing during reading. The majority of previous studies have failed to find support for parafoveal semantic processing (see Rayner *et al.*, 2003, for a recent review). We argued that the semantic manipulations may not have been strong enough to exert an effect. In the present study, we aimed to remedy this by presenting in the parafovea negatively valenced, emotional words with a high arousal level, particularly sex-related and curse words, to increase the chances of finding evidence for the view that meaningful information may be obtained from the parafovea during reading. A recent repetition priming study of Calvo and Castillo (2005) demonstrated that in a non-reading task threat-related contents are more readily obtained from the parafovea than neutral contents.

Parafoveal semantic processing was studied using an eye-movement-contingent display change paradigm. The target words were embedded in sentences, and the participants read the sentences at their own pace for comprehension. In the display change conditions, the target word was initially replaced by an emotional or a neutral word; in the control condition, the target word was preserved throughout the trial. During the saccade made to the target, the parafoveal word was changed to the target word. Thus, the emotional and neutral words were only seen parafoveally. We predicted that if contents related to emotional words would be readily obtained parafoveally, we should see significant differences

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in the eye movement records between the emotional and neutral preview conditions. However, analyses of the durations of fixations around the target showed no such effects. Nor did the pupil size yield any signs that could be interpreted to suggest that the emotional content of the parafoveal preview would have been activated.

We did find evidence that an identical preview speeded up subsequent foveal processing in comparison to the previews where a display change was introduced (first three letters were kept intact, but the remaining letters were changed). This effect is orthographic and/or visual in nature; there was a penalty in processing when the word-final letters were replaced with visually dissimilar letters. In gaze duration, this effect amounted to a 25 ms preview benefit for the identical condition over the changed conditions (averaged over the two conditions). The effect size is somewhat larger than the average effect size observed in previous studies using an analogous (i.e., the first 2–3 letters of the parafoveal word preserved and the rest replaced by visually dissimilar letters) manipulation (Henderson & Ferreira, 1990; Pollatsek, Lesch, Morris & Rayner, 1992; but see Lima, 1987; Rayner *et al.*, 1982). The average effect size is 14 ms and the range is 5–30 ms (see Hyönä, Bertram & Pollatsek, 2004, for a summary). Yet, generally speaking, our 25-ms display change effect is relatively modest. The largest effect (101 ms) is reported by Hyönä *et al.* (2004) for a change made to the second constituent of long compound words (the last letters were replaced with visually similar letters). An effect of similar magnitude (91 ms) was reported by Inhoff, Starr and Schindler (2000b) for two-noun English compounds, where the constituents were separated by a space. All in all, our modest effect size is in line with the conclusion that no semantic information was obtained from the parafovea. One would assume that a semantic mismatch between the parafoveal and foveal stimuli would produce a sizeable effect.

Several follow-up analyses were performed to examine whether the lack of parafoveal semantic effect was compromised by launch site, target word length, or the type of emotional preview. The post-hoc analyses done as a function of the launch site demonstrated that the absence of an effect cannot be ascribed to natural variation in launch sites. The parafoveal semantic effect remained absent also for trials where the eye fixation was positioned close to the parafoveal preview prior to fixating the target word. Second, short target words (5–6 letters) displayed a highly similar pattern of results to those obtained for the complete target set. Third, the pattern of results did not change markedly when the analyses were restricted either to sex-related or threat-related words only. Numerically, the threat-related parafoveal previews produced the longest gaze durations and total fixation times, but they did not differ statistically from the neutral previews. This tendency is consistent with the priming study of Calvo and Castillo (2005), who reported evidence in favor of the view that quick and automatic parafoveal recognition of potentially harmful stimuli (e.g., threat-related words) serves an adaptive purpose. Even if this were the case also in reading and not only in identity priming, the fact remains that parafoveal semantic processing does not routinely occur in reading, otherwise we should also have observed a similar tendency for highly arousing sex-related words, which we did not.

Our failure to find evidence for a parafoveal semantic effect in reading is consistent with what Rayner and colleagues (Altarriba *et al.*, 2001; Balota *et al.*, 1985; Rayner *et al.*, 1986, 2004) have previously reported. Taken together, these studies suggest that in reading access to the word identities is achieved serially by separately foveating each word. As Rayner *et al.* (2003) argue, an exception to this rule may be made for words that are short and predictable from the previous sentence context. These words may be recognized while fixating on the previous word, which then leads to skipping over that word. In the present study, the target words were not so short (an average of 6.4 letters) that they could be regularly skipped. In fact, there were only three instances when this occurred.

From a functional and adaptive point of view, the lack of a parafoveal semantic effect does not sound at all implausible. As visual acuity is significantly reduced in the parafovea, efforts to achieve full recognition of a word via parafoveally available information do not necessarily pay off, as the parafoveal word can easily be brought to the foveal vision by making an eye movement to it. Written words separated by spaces make easy targets for saccades, and thus using words as recognition units seems functionally plausible. Serially attending to one word at a time naturally follows from what is said above. Although this may be the general rule, there are exceptions to it. First, when a word is sufficiently long so that a part of it falls outside foveal vision when fixated, such a long word cannot be used as a recognition unit, but its recognition is achieved piecemeally (for the identification of long compound words, see Bertram & Hyönä, 2003; Hyönä & Pollatsek, 1998; Pollatsek, Hyönä & Bertram, 2000). Second, when two adjacent words form a spaced compound (i.e., the two constituents are separated by a space), attention may also spread to the second constituent when fixating the first constituent (see above for the discussion of Inhoff *et al.*, 2000b).

The results of the present study appear to stand in contrast to those of Calvo and Castillo (2005), who found that briefly (150 ms) presented parafoveal prime words speeded up lexical decision times for simultaneously presented foveal words when both the prime and the target were threat-related. This was taken to suggest that threat-related contents may be obtained from the parafovea. We think the discrepancy in the results may be accounted for by differences in the task requirements and the ensuing processing load. Reading involves a higher processing load than lexical decision, as it also involves integrative comprehension processes, in addition to word recognition. We point to two pieces of evidence that are consistent with our claim. First,

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as discussed in the Introduction, a parafoveal semantic effect obtained by Murray (1998) using a physical comparison task (i.e., the participants were asked to judge whether two sentences were physically identical or not) was not replicated using a normal reading task (see Rayner *et al.*, 2003). Second, Calvo and Lang (2005) found evidence for parafoveal semantic processing of emotional pictures when no foveal task was introduced, while with a foveal task (letter naming) the semantic effect disappeared (see also Lavie & Fox, 2000).[5]

In conclusion, the results of the present study converge on the view that orthographic and visual information is obtained of the parafoveal word in reading, but meaning-related information is not.

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NOTES

[1] These were trials where the eyes crossed the invisible boundary toward the end of the saccade triggering the display change. The same procedure was applied to the identical condition, where a display change triggered by the boundary crossing saccade was in fact also made. Naturally, when letters are replaced by the same letters, no change can be detected.

[2] These were trials where the fixation to the left of the boundary was positioned so close to the boundary that at least one sample within the fixation had an X coordinate marking boundary crossing (one eye sample was sufficient to trigger the change).

[3] For this sentence the return sweep from the end of the first line to the beginning of the second line prematurely triggered the display change.

[4] Fifteen participants contributed to the by-participant analysis and 13 sentences to the by-item analysis.

[5] A third possible explanation for the discrepancy in the results of the present study and that of Calvo and Castillo (2005) may be proposed by making recourse to the different nature of effects investigated in the two studies. We sought for interference effects (i.e., emotional preview interfering with the processing of a neutral target when foveated), whereas Calvo and Castillo provided evidence for facilitatory priming effects (i.e., a threat-related word presented parafoveally speeded its subsequent foveal processing, when presented in a different letter-case). They failed to find inhibition effects (i.e., a threat-related parafoveal prime did not inhibit the recognition of a neutral word; see Exp. 4). However, it should be noted that their experiments differed in two important ways from the present one. First, the facilitatory effects were obtained using identity primes, while the lack of inhibition effects was obtained when the prime and the target did not share any letters with each other. In the present study, the parafoveal preview and the target shared the three initial letters. Second, in the priming task it is not required to integrate the prime with the target, whereas in reading the parafoveal preview word needs to be integrated with the form encountered when it is foveated. In normal reading, but not in the boundary paradigm, the parafoveal preview and the foveated form appear always in one and the same form.

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