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OBSERVATION

Preview Benefit and Parafoveal-on-Foveal Effects from Word N+2

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Running Head: Preprocessing word n+2

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Abstract

Using the gaze-contingent boundary paradigm with the boundary placed after word n, we manipulated preview of word n+2 for fixations on word n. There was no preview benefit for first-pass reading on word n+2, replicating the results of Rayner, Juhasz, and Brown (2007), but there was a preview benefit on the three-letter word n+1, that is, after the boundary, but before word n+2. Additionally, both word n+1 and word n+2 exhibited parafoveal-on-foveal effects on word n. Thus, during a fixation on word n and given a short word n+1, some information is extracted from word n+2, supporting the hypothesis of distributed processing in the perceptual span.

Key words: eye movements, reading, preview benefit, parafoveal-on-foveal effects

Two competing hypotheses organize much current research on eye-movement control during reading: (a) parallel lexical processing of words in the perceptual span with efficiency decreasing with eccentricity of words relative to the point of fixation and (b) strictly serial word-by-word processing with sequential shifts of attention. The differences between these positions are much more graded than this simple dichotomy suggests (for recent presentations see, e.g., Engbert, Nuthmann, Richter, & Kliegl, 2005; Inhoff, Eiter, & Radach, 2005; Kliegl, Nuthmann, & Engbert, 2006; Kliegl, 2007; McDonald, Carpenter & Shillcock, 2005; Pollatsek, Reichle, & Rayner, 2006; Pynte & Kennedy, 2006).

A critical empirical question for all theoretical proposals is the spatial extent of the influence of parafoveal words. The perceptual span, a region extending three to four letters to the left and up to fifteen letters to the right of fixation, sets the outer limits (McConkie & Rayner, 1975; Rayner & Bertera, 1979). Letter-specific information, however, is extracted only up to seven or eight letters to the right (e.g., Rayner, 1998, for a review). Granting preview of word n+1 during a fixation on word n facilitates later processing of word n+1. This preview benefit is measured with the boundary paradigm, where a critical word in the direction of reading is only revealed when the eyes cross the space before it (Rayner, 1975). There is also evidence that sublexical or lexical properties of word n+1 influence the fixation on word n. Comprehensive reviews of this controversial debate from different perspectives can be found in Inhoff, Radach, Starr, and Greenberg (2000), Kennedy (2000), Kennedy, Pynte, and Ducrot (2002), and Rayner, White, Kambe, Miller, and Liversedge (2003).

Rayner et al. (2007) went beyond earlier research and examined preview benefit on a target word with boundaries placed either after the preceding word (n+1 preview condition) or even the word preceding it (n+2 preview condition). There were preview benefits in the former but no preview benefits in the latter case and there were no parafoveal-on-foveal effects in two experiments.[1] These results were interpreted to favor models like E-Z Reader that expect preprocessing of word n+2 only under very specific circumstances, for example, after skipping a highly frequent word n+1 (Reichle, Pollatsek, Fisher, & Rayner, 1998; Pollatsek, Reichle, & Rayner, 2006).

Given the theoretical relevance of Rayner et al.'s (2007) experiments for the claim of distributed processing in the perceptual span (Engbert et al., 2005; Kliegl et al., 2006; Kliegl, 2007), we replicated a variant of Rayner et al.'s n+2 preview condition. We implemented the boundary paradigm with an invisible boundary located after the last letter of word n while word n+2 was presented either as a correct preview (i.e., identical preview condition) or as a random letter string (i.e., non-word preview condition). Aside from the language, Rayner et al.'s and our experiment mainly differed in three ways. First, we used three-letter words in position n+1 (i.e., after the boundary), rather than 3/4-letter or 5/6-letter words, to increase chances for letter-specific information of word n+2 to fall into the perceptual span. Second, our word n+1 was either a function word or a content word; Rayner et al. used only content words. Assuming serial attention shifts from word to word during fixation on word n, preview benefit for word n+2 is more likely to occur for function than content words in position n+1. Third, our word n averaged seven letters in length; Rayner et al. used short function words inviting a high skipping probability and reducing chances of preprocessing word n+2 during fixations on word n. In addition, we checked for effects of preview of word n+2 in fixations on each of the words n, n+1 and n+2; Rayner et al. reported fixation times combined for words n and n+1, although this implied that some fixations occurred before and some after the boundary. In summary, our experiment was designed to facilitate the detection of an n+2 effect.

Method

Participants

Thirty students, native speakers of German with normal or corrected-to-normal vision, participated in a one-hour session; they were paid 6 € or received course credit.

Apparatus

Participants were seated at a distance of 60 cm in front of an Iiyama Vision Master Pro 514 monitor (1024 x 768 resolution; 21 inch; refresh rate 150 Hz; font: regular Courier New 12; 2.2 characters per degree of visual angle). Both eyes were monitored with an EyeLink II system (SR Research, Osgoode, ON, Canada) with a sampling rate of 500 Hz and an instrument spatial resolution of 0.01°. Heads were positioned on a chin rest to minimize head movements.

Procedure

Participants were naive concerning the experimental manipulation, but instructed to read single sentences for comprehension (i.e., three-alternative multiple-choice questions followed, on average, every third sentence; 92% were answered correctly). They were calibrated with a standard nine-point grid for both eyes and recalibrated after every 15 sentences or if the eye was not detected at the initial fixation point at the left side of the center line within two seconds. If the eye was detected, a sentence was displayed with the first word's optimal viewing position replacing the original fixation point. Participants ended presentation of a sentence with a glance into the lower right corner of the screen.

Materials

Participants read 6 training and 160 test sentences. Test sentences were constructed around a three-word target region (i.e., word n, word n+1, word n+2). Length of word n ranged from 4 to 13 letters ($M = 7$) with mean frequency of 259 per million; word n+1 was a three-letter content word in half of the sentences (mean frequency: 29 per million) and a three-letter function word in the other (mean frequency: 3,812 per million); finally, length of word n+2 ranged from 4 to 7 letters ($M = 5$) with a mean frequency of 746 per million. Frequency-norms are based on the 125-million DWDS corpus (Geyken, in press).

An invisible boundary was set after the last letter of word n. For all fixations up to and including word n, word n+2 was either the correct word (i.e., identical preview condition) or a random string of letters (i.e., non-word preview condition) that was matched in both length and shape (in terms of upper- and lower-case letters) with the correct target word. When the eyes crossed the boundary, word n+2 was in both cases replaced with the correct word (in the identical preview condition it was replaced by itself). Post-hoc we identified the exact time of display change for each participant's trials. The delay of display change relative to crossing the boundary was 8.3 ms (ranging from 5 to 11.7 ms) due to system delays within the eyetracker (SR Research Ltd., 2006) and the monitor's refresh rate. Irrespective of delay time, we analyzed only such trials in which the display change was completed during a forward saccade. Across participants, sentences with a content word and with a function word at position n+1 were presented equally often with identical or non-word preview.

Analysis

Inferential statistics are based on a linear mixed-effects model (*lme*) specifying participants and items as crossed random effects. This analysis takes into account differences between participants and differences between items in a single sweep and has been shown to suffer substantially less loss of statistical power in unbalanced designs than traditional ANOVAs over participants (F1) and items (F2; see Baayen, in press, Pinheiro & Bates, 2000; Quené & van den Bergh, 2004, for simulations).

We used the *lmer* program (*lme4* package; Bates & Sarkar, 2006) in the *R* system for statistical computing (R Development Core Team, 2006) and report regression coefficients (b; absolute effect size in ms), standard errors (SE), and p-values for an upper-bound n of denominator degrees of freedom computed as n of observations minus n of fixed effects. As these p-values are potentially anti-conservative, we generated confidence intervals from the posterior distribution of parameter estimates with Markov Chain Monte Carlo methods, using the *mcmcsamp* program in the *lme4* package with default specifications (e.g., n=1000 samples; locally uniform priors for fixed effects; locally non-informative priors for random effects). Both procedures yielded the same results.

Finally, we also computed post-hoc power statistics for the preview and lexical status main effects and for the interaction effect on first fixation durations (with effect sizes similar to those reported earlier, e.g., Kliegl, 2007), and using *lme* estimates of between-participant, between-item, and residual variances (Gelman & Hill, in press). For the observed proportion of random loss of items, power estimates based on 1000 simulations each were around .85 for word n and n+2 and .59 for word n+1 (due to the higher skipping rate).

Results

The analyses are based on right-eye first-pass reading measures of trials with valid display change. Including track losses, 37% of the sentences were excluded from analyses. As we had started with 160 items, there still were sufficient data for the analyses in all design cells. Primary dependent variables were first-fixation durations (FFD; including single-fixation durations) and gaze durations (GD, defined as the sum of FFD and immediate refixations of the relevant word) on each of the three critical words. Table 1 provides a breakdown of these measures for each of the three words by preview condition of word n+2 and lexical status of word n+1. We also include information about skipping probability. We report separate analyses for words n+2, n+1, and n.

-- Insert Table 1 about here --

Effects on word n+2

None of the main effects or interactions was significant for FFD and GD (all p-values > .33). These analyses replicate the results of Rayner et al. (2007) who also did not find a preview benefit effect for fixations on word n+2.

Additional analyses for FFD and GD were carried out conditional on skipping of the three-letter function or content word n+1 (see Table 2). Again, none of the effects or interactions involving the theoretically interesting preview manipulation were significant, neither for FFD nor for GD on word n+2 [all p-values > .30]. We did observe a few known effects: First, FFD and GD were longer after skipped words n+1 [FFD: b = 12, SE = 2.8, p < .001; GD: b = 66, SE = 4.3, p < .001]. Second, there were two pieces of evidence for spillover: (a) the lexical status of word n+1 was only visible in FFD on word n+2 if word n+1 had been fixated [interaction of lexical status and skipping status of word n+1: b = 11, SE = 5.0, p < .05]. (b) GD was longer after a content word n+1 than after a function word n+1 [b = -13, SE = 5.9, p < .05].

-- Insert Table 2 about here --

Effects on word n+1

First-fixation duration. As shown in Table 1, if preview of word n+2 was denied while fixating word n (i.e., non-word preview), FFD—the first fixation after crossing the boundary when the correct word n+2 is visible for the first time—was 11 ms longer in comparison to the identical preview condition for a content word n+1 (190 vs. 201 ms) and 9 ms longer for a function word n+1 (203 vs. 212 ms). The overall effect of preview condition was significant [b = 9.2, SE = 2.6, p < .001]. FFD on function words was 12 ms longer than on content words [b = 9.4, SE = 3.4, p < .01]. The interaction was not significant [p = .28].

Gaze duration. For GD the preview benefit amounted to 11 ms for content words (196 vs. 207 ms) and 10 ms for function words (209 vs. 219 ms), respectively. The main effect of preview was highly significant [b = 11 ms, SE = 3 ms, p < .001]. The main effect of lexical status also reached significance [b = 9 ms, SE = 4 ms, p < .05]. The interaction was not significant [p = .52].

Skipping probability. As expected from previous research (e.g., O'Regan, 1979; Gautier et al., 2000), function words n+1 were skipped 15 % more frequently than content words n+1 [b = .13, SE = .03, p < .001]. Neither the main effect of preview nor the interaction between preview and lexical status were significant [all p-values > .10].

Summary. The duration results are new; they document extraction of information from word n+2 during fixation on word n that manifests itself during fixation on word n+1. Parallel processing is also suggested by the direction of the main effect of lexical status on fixations on word n+1, which may indicate that the subsequent word n+2 is parafoveally preprocessed during fixations on short, high-frequency function words.

Effects on word n

First-fixation duration. Participants fixated word n longer if the subsequent word n+1 was a content word than if it was a function word (203 ms vs. 196 ms) [b = -7.9, SE = 3.0, p < .01]. Neither the effect of preview of word n+2 [p = .22], nor its interaction with lexical status of word n+1 [p = .42] were significant for FFD.

Gaze duration. Content words in position n+1 led to significantly longer GD on word n than function words (245 ms vs. 219 ms) [b = -28.0, SE = 5.6, p < .001]. Moreover, GD was 8 ms shorter with identical preview (227 vs. 235 ms), that is, there was a significant parafoveal-on-foveal effect stemming from word n+2 [b = 6.7, SE = 3.2, p < .05]. This effect was due to a 15 ms difference for content words in position n+1 and a neglible 1 ms difference for function words, an interaction that reached significance [b = -13.1, SE = 6.4, p < .05].

Summary. We found a parafoveal-on-foveal effect of lexical status (or frequency) of word n+1 on first-fixation and gaze durations on word n. In addition, we found an 8 ms parafoveal-on-foveal preview benefit from word n+2 in gaze durations on word n. In line with the effects on word n+1, the results favor parallel over serial processing.

Discussion

The experimental results lead to a somewhat more differentiated picture than the one painted by Rayner et al. (2007) about the effects of word n+2 becoming available only after the eyes move from word n to word n+1. We will discuss preview benefit on word n+2, effects of preview of word n+2 on word n+1, and parafoveal-on-foveal effects on word n.

Preview benefit on word n+2. Like Rayner et al. (2007) and also Yang et al. (2006), we failed to find evidence for a preview benefit of word n+2 in fixations on word n+2. Recently, McDonald (2006) performed an experiment in which saccades triggered a display change of word n+1 while crossing the middle of word n. He reported a preview benefit effect on word n+1 only when the saccade landed on word n+1, but not when it led to a refixation on word n after the boundary. His conclusion was that preview benefit depends on word n+1 being selected as a saccade target. If the second half of word n is interpreted as word n+1, one could also consider his result as consistent with the absence of an n+2-preview benefit.

Effects on word n+1. We obtained small but reliable effects of preview of word n+2 for FFD and GD on word n+1, which were on average 10 ms and 11 ms longer when word n+2, now the word directly to the right, had not been available during the preceding fixation on word n. Note that, irrespective of preview condition, word n+2 was always visible as the correct preview when the eyes had crossed the boundary and landed on word n+1. This effect on word n+1 looks like a preview benefit effect, if benefits of n+2 preview may be expressed on intermediate fixations, prior to word n+2. The effect may also be viewed as a delayed parafoveal-on-foveal effect of word n+2 on word n+1. Further experiments are needed to test these alternatives. Yang et al. (2006) also reported such an effect on word n+1.

The result is not necessarily in disagreement with Rayner et al. (2007; Experiment 2) who reported a small but non-significant preview effect of 5 ms for first-fixation durations and one of 6 ms for gaze durations within their pre-target region – that is when word n and word n+1 in our experiment are treated as a single unit. As word n in Rayner et al.'s experiment was always a one to three-letter function word, most fixations in this region occurred on content word n+1 (i.e., after the display change). A minority of these fixations, however, occurred prior to the display change, which may have weakened the effect. Difference in statistical power between the experiments is another possible source for the difference.

Parafoveal-on-foveal effects. There are two genuine parafoveal-on-foveal effects. Preview of word n+2 and lexical status of word n+1 affected durations on word n. Both effects originate at words to the right of the currently fixated word n. Rayner et al. (2007), like previous boundary experiments (see Rayner et al., 2003, for a review), did not obtain reliable parafoveal-on-foveal effects, but Yang et al. (2006) at least found such an effect for manipulating preview of word n+1. Our effects were numerically quite small. Therefore, we suspect again that differences between studies relate to statistical power for items or participants. The parafoveal-on-foveal n+2-preview effect on gaze duration was observed only when word n+1 was a content word. This interaction was opposite to our expectation: We predicted an n+2-preview effect for function words n+1 because of less processing demand in this pattern. Rather than engaging in a speculative explanation of this counterintuitive, but potentially very important result, we propose to wait for independent experimental validation.

Boundary and corpus-analytic effects. As lexical status correlates strongly with lexical frequency, the parafoveal-on-foveal n+1-effect is compatible with reports from corpus analyses (Kennedy & Pynte, 2005; Kliegl et al., 2006; Pynte & Kenndey, in press). Rayner et al. (2007) discounted corpus analyses, because, for example, "the fact that there are so many short words in natural text may inflate certain effects" (p. 30). We basically agree with this assessment, except that, from our perspective, experiments manipulating only content words may yield *deflated* effects in comparison to reading of natural text. In general, manipulations of target word frequency or plausibility yield quite inconistent results, but there is some positive evidence for parafoveal-on-foveal effects (e.g., Hyönä & Bertram, 2004; Rayner, Warren, Juhasz, Liversedge, 2004). Also Kliegl (2007) reported for several experiments extended fixation durations on function words prior to subsequently skipped content words, suggesting that some adjectives or nouns are processed during fixations on a preceding determiner. This pattern is compatible with Radach's (1996) "word-group" hypothesis. We doubt that these highly specific parafoveal-on-foveal effects are solely due to mislocated fixations, as argued by Rayner et al. (2004).

Implications for E-Z Reader. A major theoretical motivation for the n+2 paradigm is its relevance for implemented models of saccade generation in reading. In E-Z Reader (Pollatsek et al., 2006; Reichle et al., 1998), properties of word n+2 are only processed if attention has shifted to this word. During a fixation on word n, attention can only be shifted to word n+2 after complete sequential lexical access of word n and word n+1. This double-shift implies (1) cancellation of a saccade program to word n+1 and (2) programming a new saccade to word n+2 and, consequently, skipping of word n+1. However, we observed preview benefit not on word n+2, but on word n+1. As word n+1 was skipped very often (48% on average), fixations on word n+1 might have been mislocated and initially targeted to land on word n+2 (Nuthmann et al., 2005, 2007). Thus, the effect of preview on word n+1 would be an effect of word n+2 in cases when word n+1 was completely processed and was intended to be skipped. Under this specific condition, E-Z Reader expects a preview benefit from word n+2. Unfortunately, in the analysis conditionalizing on skipping of word n+1, we did not find any preview benefit on word n+2 for sentences with skipped word n+1 (see McDonald, 2006; Rayner et al., 2007, footnote 3, for suggestive evidence of this kind).

Implications for SWIFT. The results also reveal a limitation of the SWIFT model in its current implementation (Engbert et al., 2005). In principle, in comparison to the no-preview condition, a head start of lexical processing of word n+2 in the preview condition might cause smaller lexical activation when the eyes finally hit this word and lead to less foveal inhibition with less delay of the saccade program (i.e., a shorter fixation duration on word n+2). Yet, preview benefit was observed on word n+1, not word n+2. There is no explicit mechanism that extends first or single fixation durations on word n conditional on properties of words to the right within the perceptual span. Foveal inhibition is modulated only by the lexical activation of the currently (and recently) fixated word(s). Therefore, with this mechanism, increases of fixation durations due to the difficulty of a subsequent word (i.e., the replaced preview of word n+2 while fixating word n+1) are difficult to explain. There are several options to re-specify the model. For example, from a parallel processing point of view, foveal inhibition might be influenced not only by processing difficulty of the currently fixated word, but also by those of other words in the perceptual span.

In summary, both the preview benefit of word n+2, expressed on word n+1, and the two parafoveal-on-foveal effects on word n are compatible with a distributed parallel processing view (Engbert et al., 2005; Kliegl et al., 2006; Kliegl, 2007). If all words residing within the perceptual span are processed at the same time—although to different degrees—and if word n+2 is at least partly in the perceptual span, preview manipulations of word n+2 should influence its preprocessing and, consequently, exhibit a preview benefit on some of the fixations after crossing the boundary. Understanding the details of parafoveal-on-foveal effects and subsequent preview benefits as well as the possible moderation of these effects by lexical status clearly represents a theoretically challenging construction site for models of eye guidance in reading.

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Footnote

1. At the time when this experiment was in progress, Yang, Wang, and Rayner (2006) reported a preview effect of word n+2 on word n+1 from an n+2-boundary experiment of reading Chinese with one-character words in position n+1.

Table 1. Means (standard deviations) of first-fixation duration (FFD), gaze duration (GD), and skipping probability (SP) for word n, word n+1 and word n+2 broken down by preview condition (word n+2) and lexical status of word n+1.

	word n		word n+1		word n+2	
Preview of n+2	identical	non-word	identical	non-word	identical	non-word
FFD						
CW	200 (59)	205 (61)	190 (56)	201 (55)	206 (68)	206 (72)
FW	195 (62)	196 (60)	203 (58)	212 (60)	204 (62)	202 (65)
GD						
CW	237 (101)	252 (116)	196 (70)	207 (65)	238 (107)	247 (119)
FW	218 (89)	219 (85)	209 (65)	219 (65)	240 (100)	240 (109)
SP						
CW	.03 (.18)	.03 (.16)	.42 (.49)	.40 (.49)	.11 (.31)	.12 (.32)
FW	.05 (.22)	.04 (.20)	.56 (.50)	.55 (.50)	.11 (.31)	.11 (.31)

Note. Lexical status of word n+1 was either content word (CW) or function word (FW); preview condition of word n+2 was either identical or a non-word..

Table 2. Means (standard deviations) of first-fixation duration (FFD) and gaze duration (GD) on word n+2 broken down by preview condition (word n+2), lexical status of word n+1, and skipping status of word n+1.

	word n+1 not skipped		word n+1 skipped	
Preview	identical	non-word	identical	non-word
FFD				
CW	204 (71)	202 (80)	208 (64)	211 (59)
FW	198 (71)	195 (71)	208 (55)	207 (60)
GD				
CW	215 (86)	221 (107)	267 (122)	280 (126)
FW	216 (93)	216 (108)	256 (102)	256 (106)

Note. CW: content word n+1; FW: function word n+1.