Linguistic and oculomotor causes and consequences of word skipping: Insights from parafoveal N400 fixation-related potentials

In the process of understanding a text, readers make a sequence of eye movements from one word to the next in order to directly fixate the words that must be recognized in, more or less, the order in which they were written. Decades of eye tracking research have established that eye movement behavior (e.g., the duration of fixations on words) is tied to linguistic processing and that these behaviors can be used to make inferences about underlying cognitive language processing (see Rayner, 1998). However, some of the variance in oculomotor behavior during reading has also been attributed to lower-level visuospatial characteristics of the text (Brysbaert & Vitu, 1998). So, some questions remain about the nature of the brain-behavior connection when it comes to reading behavior.

In addition to well established linguistic influences on fixation durations, readers frequently *skip* words and the variance in word skipping can be partially attributed to the difficulty of parafoveal word processing. For example, readers are more likely to skip high frequency words (Angele et al., 2014) words that are expected based on supportive sentence context, (Drieghe et al., 2005), and more likely to skip function words (65% of the time) than content words (15% of the time; see Rayner, 1998). High frequency function words (e.g., *the*) are skipped even when they are contextually incompatible (Angele & Rayner, 2013), perhaps automatically as a consequence of oculomotor constraints, rather than deep parafoveal linguistic processing. So, questions remain about the extent to which skipped words are fully identified bottom-up and integrated into the sentence context or if they are only shallowly identified, but comprehension proceeds based on context clues and mentally "filling in the blank". In the current study we co-registered eye tracking and EEG recordings from 48 native English speaking undergraduates and measured fixation-related brain potentials with the aim of distinguishing between these two accounts.

We time-locked to fixations on pretarget words and used a gaze contingent display change to isolate brain responses (i.e., the N400 fixation-related brain potential) associated with parafoveal processing when a target word was either skipped or fixated. The N400 component has been established as being related to semantic expectancy and semantic retrieval. So, we used the N400 as an index of the depth of semantic processing of the parafoveally manipulated words. All sentences were high constraint (i.e., high cloze), that supported expectations of a particular three-letter word. The parafoveal preview was manipulated and was either (1) expected, (2) an anomalous orthographic neighbor of the expected word, or (3) an anomalous instance of the article *the*. We then separated trials post hoc based on whether the target was skipped or fixated (i.e., *behavior-contingent analysis of FRPs*).

We found a parafoveal N400 effect in response to the anomalous neighbor preview, which occurred only when the word was skipped, and a parafoveal N400 effect in response to the anomalous *the*, which was present regardless of skipping (Table 1; Figure 1). We interpret this pattern as evidence that content word skipping is related to more thorough parafoveal word identification. However, short function words may be skipped automatically because they are easy to identify. Skipping rates for the were quite high (~70%; see Figure 2), so we also propose cases in which *the* was fixated may be unintended and due to oculomotor error, since the N400 effect indicated that the word had been identified parafoveally.

However, we also found that regression rates were higher when words were skipped and when the preview was anomalous (Table 2; Figure 3). So, although skipped words appear to have been identified parafoveally, the recognition that they were contextually incompatible appears to occur downstream of the initial skipping decision. Therefore, we argue that eye movements are planned prior to complete comprehension and is based on partial linguistic processing and that integration processes continue after the eyes have moved on

Figure 1. Parafoveal N400 FRPs by preview condition split by skipping behavior

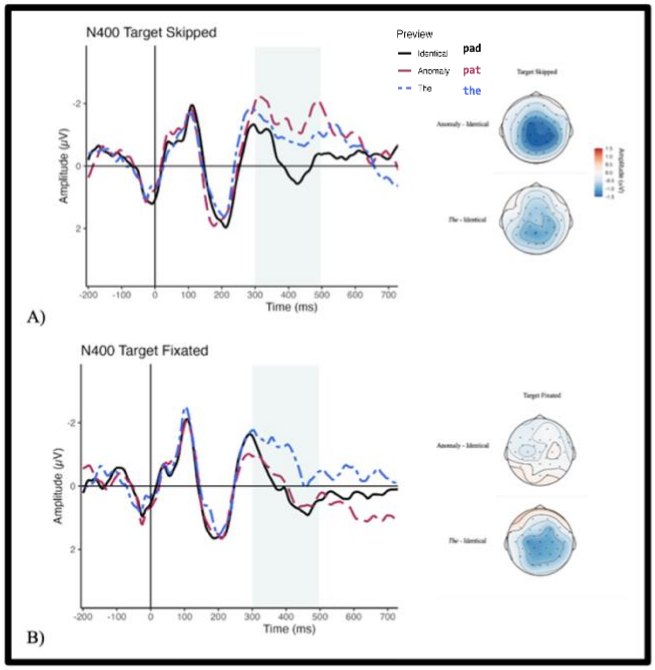

Table 1. Results of lmer predicting N400 effect by preview condition and trial-level skipping behavior

	N400 - Target Skipped				N400 - Target Fixated			
Predictors	*Est.*	*SE*	*t*	*p*	*Est.*	*SE*	*t*	*p*
(Intercept)	-1.01	0.20	-4.95	**<0.001**	-0.55	0.19	-2.84	**0.004**
Anomaly vs. Identical	1.38	0.45	3.04	**0.002**	0.28	0.36	0.79	0.428
Identical vs. *The*	-0.76	0.34	-2.20	**0.028**	-1.04	0.42	-2.50	**0.012**

Figure 2. Skipping rates by preview condition

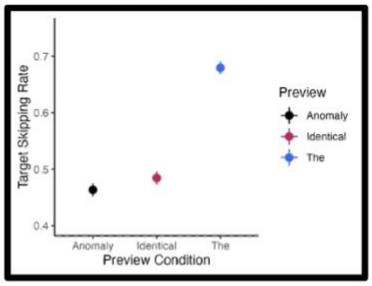

Figure 3. Regression rates by preview condition as a function of whether the target word was skipped

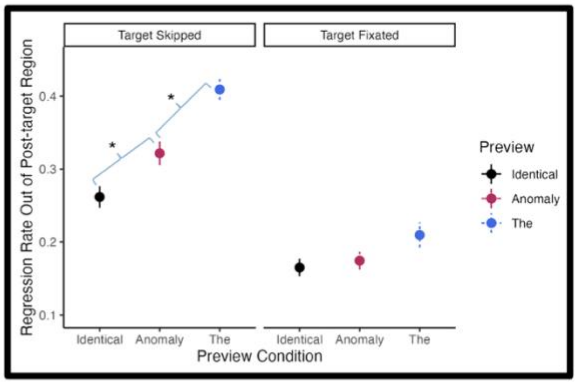

Table 2. Results of lmer predicting regression rate by preview condition and trial-level skipping behavior

	Target Skipped Baseline				Target Fixated Only			
Predictors	*Est.*	*SE*	*z*	*p*	*Est.*	*SE*	*z*	*p*
(Intercept)	0.44	0.06	-6.40	**<0.001**	0.18	0.03	-10.85	**<0.001**
Anomaly vs. Identical	0.71	0.09	-2.55	**0.011**	0.86	0.14	-0.89	0.372
Identical vs. *The*	2.18	0.29	5.79	**<0.001**	1.35	0.26	1.57	0.116
Target Skipping (Fixated vs. Skipped)	0.42	0.03	-11.29	**<0.001**				
Anomaly vs. Identical x Skipping	1.32	0.23	1.57	0.116				
Expected vs. *The* x Skipping	0.58	0.11	-2.96	**0.003**				

References

Rayner, K. (1998). Eye movements in reading and information processing: 20 years of research. *Psychological Bulletin, 124*(3), 372.

Angele, B., Laishley, A. E., Rayner, K., & Liversedge, S. P. (2014). The effect of high-and low-frequency previews and sentential fit on word skipping during reading. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 40*(4), 1181.

Angele, B., & Rayner, K. (2013). Processing the in the parafovea: Are articles skipped automatically?. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 39*(2), 649.

Brysbaert, M., & Vitu, F. (1998). Word skipping: Implications for theories of eye movement control in reading. In *Eye guidance in Reading and Scene Perception* (pp. 125-147). Elsevier Science Ltd.

Drieghe, D., Rayner, K., & Pollatsek, A. (2005). Eye movements and word skipping during reading revisited. *Journal of Experimental Psychology: Human Perception and Performance, 31*(5), 954.