Successor surprisal effect in reading: a brain electric potential study with and without parafoveal preview

Readers process words incrementally, where a multitude of constraints affect word processing. The development of theories and computational models of word recognition requires understanding of these constraints, which come from different sources, such as the information from the currently fixated word, the preceding text and also the following word. A large body of research has shown that readers extract *some* information related to the next word from parafoveal vision without fixating it directly and that this information influences the currently fixated word. There is an ongoing debate about whether word predictability of the next word (so-called successor word predictability effect) influences the currently fixated word and whether this effect is due to parafoveal processing or due to predictions made from the preceding context. The next word's probability (or predictability of a word) is often measured with the information-theoretic notion of *surprisal*. Recent behavioral studies that utilized self-paced reading and eye-tracking experiments with masked words in the parafovea showed that successor surprisal effects are still present when the word is not visible in the parafovea (Angele et al., 2015; van Schijndel & Schuler, 2017; van Schijndel & Linzen, 2018) calling into question that this effect is solely due to parafoveal processing.

Neurophysiological methods, such as event-related brain potentials (ERPs), provide a rich set of information related to brain dynamics during word processing at a millisecond precision, which reflect different stages of word processing. Importantly, neural correlates of the successor word surprisal effect have not been explored yet. Our study explores this effect in two English experiments: in an ERP study (n = 33) where sentences are presented one word at a time at the center of the screen, thus precluding parafoveal preview, and in a co-registered EEG & eye-tracking study (n = 30) where same sentences were shown, and readers moved their eyes freely over text with words in the parafovea being visible. *Surprisal* of each word in a sentence (n = 126) was calculated as a negative log probability of a word given its preceding context using Transformer language model as operationalized in Merkx & Frank (2020). In previous studies, N400, an ERP component peaking at ~400 ms from stimuli onset, was shown to be sensitive to word surprisal of the current word (Frank et al., 2013). Using linear mixed-effects modelling, we tested the successor word predictability effect by examining whether the N400 of the current word was affected by the word surprisal of the following word in both experiments.

Contrary to Angele et al. (2015) and other similar studies, we found no effect of successor word surprisal in the ERP study, where parafoveal word preview was not available (p = .70). However, the successor word surprisal effect was shown in the co-registered EEG data (p = 0.005), where readers have the next word's information visible to them. More interestingly, only words that received at least two fixations on the current word showed a next word's surprisal effect on N400. Additionally, eye movement data showed a spillover effect of preceding word surprisal on total reading time of the current word (p = 0.007), whereas in the ERP study, the spillover effect was absent.

Since readers read the same stimuli in both experiments, and the only crucial difference in experiments was the availability of the parafoveal vision, we suggest that the successor surprisal effect arises as a result of the word's visibility to readers in the parafovea. Importantly, our results establish the time during word processing when next word surprisal is shown to have an effect (during 300-500 ms after the first fixation of the current word). Since the currently fixated word's surprisal effect along with successor surprisal effect are both elicited at the same N400 window, this finding is consistent with the processing gradient models of reading, such as SWIFT (Engbert et al., 2002), which postulate that attention during reading is distributed across multiple words simultaneously.

References

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