The effect of contextual constraint on parafoveal processing in reading

Elizabeth R. Schotter, **Michelle Lee**, **Michael Reiderman**, and **Keith Rayner**
University of California, San Diego

Abstract

Semantic preview benefit in reading is an elusive and controversial effect because empirical studies do not always (but sometimes) find evidence for it. Its presence seems to depend on (at least) the language being read, visual properties of the text (e.g., initial letter capitalization), the type of relationship between preview and target, and as shown here, semantic constraint generated by the prior sentence context. Schotter (2013) reported semantic preview benefit for synonyms, but not semantic associates when the preview/target was embedded in a neutral sentence context. In Experiment 1, we embedded those same previews/targets into constrained sentence contexts and in Experiment 2 we replicated the effects reported by Schotter (2013; in neutral sentence contexts) and Experiment 1 (in constrained contexts) in a within-subjects design. In both experiments, we found an early (i.e., first-pass) apparent preview benefit for semantically associated previews in constrained contexts that went away in late measures (e.g., total time). These data suggest that sentence constraint (at least as manipulated in the current study) does not operate by making a *single word form* expected, but rather generates expectations about what *kinds of words* are likely to appear. Furthermore, these data are compatible with the assumption of the E-Z Reader model that early oculomotor decisions reflect "hedged bets" that a word will be identifiable and, when wrong, lead the system to identify the wrong word, triggering regressions.

Recently, researchers have debated whether, and to what extent, readers obtain *semantic preview benefit* from the upcoming word during reading (Hohenstein & Kliegl, 2013; Hohenstein, Laubrock, & Kliegl, 2010; Rayner, 2009; Rayner & Schotter, 2014; Rayner, Schotter, & Drieghe, 2014; Schotter, 2013; Schotter, Angele, & Rayner, 2012; Yan, Richter, Shu, & Kliegl, 2009; Yang, Wang, Tong, & Rayner, 2010). Semantic preview benefit refers to the phenomenon in the *boundary paradigm* (Rayner, 1975) in which reading times on a

Correspondence to: Elizabeth R. Schotter, eschotter@ucsd.edu, (858) 822-7813, Department of Psychology University of California, San Diego La Jolla, CA 92093.

[1]Across different studies, some researchers have manipulated the context using a single word (e.g., Zola, 1984), a sentence fragment (Balota, Pollatsek & Rayner, 1985; Drieghe, Rayner, & Polltasek, 2005), a prior sentence (e.g., Rayner, Slattery, Drieghe, & Liversedge, 2011), or an entire paragraph (e.g., Ehrlich & Rayner, 1981). Additionally, other researchers have investigated predictability in a corpus analysis, using the original cloze task (Taylor, 1953) where subjects provide a guess for the next word at every point in the sentence. The results are largely similar across these methodological details so we will focus our discussion on *sentence* context, but acknowledge that we are using this term loosely, and in some instances the word "sentence" could be replaced with "prior word" or, "prior sentence," or "paragraph."

fixated *target* word are faster when a *preview* word previously in its location (i.e., before it was fixated) is semantically related to the target, compared to unrelated. Semantic preview benefit is controversial because its presence varies depending on which language is tested; originally, semantic preview benefit was not observed in English (Rayner, Balota, & Pollatsek, 1986; Rayner, Schotter, & Drieghe, 2014) but was observed in German (Hohenstein & Kliegl, 2014; Hohenstein, Laubrock, & Kliegl, 2010) and Chinese (Yan, Richter, Shu, & Kliegl, 2009; Yan, Zhou, Shu, & Kliegl, 2012; Yang, 2013; Yang, Wang, Tong, & Rayner, 2010). The inconsistency with which semantic preview benefit is observed raises the issue of, not whether it is real, but rather what conditions are necessary and sufficient for it to be observed, which will potentially lead us to a better understanding of the reading process as a whole.

Recently, Schotter (2013) did find evidence for semantic preview benefit in English, but only when the preview and target were synonyms (e.g., *start begin*), not if they only shared an associative semantic relationship (e.g., *ready begin*). Furthermore, Rayner and Schotter (2014) tested whether an orthographic property that differs between English and German (i.e., capitalization of the first letter of nouns) might partially explain these cross-language differences. They found that, in English, initial letter capitalization increased the magnitude of preview benefit generally, and led to semantic preview benefit (for similar effects in German, see Hohenstein & Kliegl, 2014).

One of the reasons semantic preview benefit is controversial is because many researchers presume that firm evidence for its presence would either be incompatible with the E-Z Reader model (a serial attention shift model of oculomotor control in reading) or would only be possible under very specific and rare circumstances (Hohenstein & Kliegl, 2014). However, Schotter, Reichle, and Rayner (2014) used E-Z Reader to simulate the data from Schotter (2013) and demonstrated that semantic preview benefit is not incompatible with its architecture. The components of the model can be grouped into five broad categories: (1) pre-attentive visual processing, which occurs for multiple words so long as they are within the limits of the perceptual span; (2) two serial stages of lexical processing (L_1 is an early, cursory stage and L_2 is a late, full identification stage); (3) attention allocation; (4) post-lexical integration of word meanings; and (5) two stages of saccade programming (M_1, which is labile (cancellable) followed by M_2, which is non-labile). The completion of the first lexical processing stage (L_1) initiates both the second stage (L_2) and the beginning of saccade programming (M_1). Thus, because saccade programming is triggered by the completion of only cursory lexical processing, these saccade decisions are considered "dumb" in that they are not initiated based on complete lexical identification of the word. The model accounts for preview benefit by means of the relative timing of the completion of lexical processing on the current word and the saccade away from it. For example, saccade programming requires about 125 ms from the start of planning until execution; if the completion of lexical identification (i.e., L_2, which is initiated at the same time as saccade programming) occurs before this time, attention shifts to the upcoming word and begins cursory lexical processing (i.e., L_1) on the upcoming word before the eyes move to it.

Schotter et al. took a new perspective on modeling the boundary paradigm, with the E-Z Reader model and thus a new consideration of how parafoveal processing influences the

reading process. Specifically, they used the model to estimate how far into lexical processing of the parafoveal word the model had progressed. In the simulations of Schotter's (2013) data, the model estimated that preprocessing of the preview had reached the L_2 stage of the model (i.e., semantic processing) a modest but non-trivial 8% of the time. Importantly, although not discussed by Schotter et al., (2014), a corollary of this finding is that in these cases the model had also reached the stage of saccade programming *away* from the parafoveal word because the end of the L_1 stage initiates both the start of L_2 and the start of M_1 (i.e., saccade programming). We will return to this idea in the General Discussion.

Given that the other languages that demonstrate semantic preview benefit did not exclusively use synonym previews, the type of semantic relationship cannot be the only explanation of cross-language differences. Schotter (2013; see also Laubrock & Hohenstein, 2012) suggested that these cross-language differences in the presence of semantic preview benefit might be explained by differences in orthography; languages with an orthography that is shallow (e.g., German) or non-alphabetic (e.g., Chinese) might be more likely to show the effect because semantics may be accessed sooner during preview, due to less time spent decoding phonology (compared to in English). As a consequence, the earlier access to semantic information from the preview in German and Chinese might allow more time for spreading activation among semantic representations in the linguistic system, allowing for something akin to semantic priming (Schotter, 2013). A direct test of this hypothesis is difficult because it is not possible to rigorously control all the differences across these languages while manipulating the theoretically relevant variables. Instead, in the present study we turn to a different contributing factor to the reading process (and semantic pre-activation) that has received little attention in relation to semantic preview benefit thus far, but may be an important consideration: contextual constraint or expectations of upcoming words (see below).

The influence of sentence context on reading

While it is well-demonstrated that the meaning generated from the prior sentence context exerts an influence on language processing, the exact nature of this effect is poorly understood. Part of the lack of clarity surrounding the effect of sentence context is that, across studies, researchers have manipulated it in different ways, measured it with different methods, and used different theoretical constructs to discuss it.

DeLong, Troyer, and Kutas (2014) provide an overview of the distinction between different theoretical constructs, highlighting the following terms, which we will group further as they pertain to reading. 1. *Prediction* suggests an active, conscious, effortful process in which a single item is predicted and there are benefits for success (i.e., if the predicted word is encountered) and costs for failure (i.e., if any other word is encountered). This construct is more likely to operate in more strategic tasks that require an overt judgment, for which the response time is slower than the typical eye movement in reading (e.g., 250 ms). 2. *Pre-activation/Anticipation* suggests a less specific process, for which 'landscapes' of pre-activated items (i.e., multiple possible words) are dynamically shifted by all available information sources. This construct is a more apt description of what may be happening during reading in that parafoveal (and subsequently foveal) visual information may be what

reshapes the "landscapes" of pre-activated semantic concepts that were generated by the context. 3. Lastly, De Long et al. (2014) note that *predictability* "can be divorced from prediction, in that an item can be predictable even if it is not predicted" (p. 633), which leads us to the issue of how one can measure expectations generated by the sentence context and the degree to which such measures relate to processes involved in reading.

Word form cloze predictability

The most common way to determine the effect of the sentence context on word recognition in reading is to create sentences in which a particular word is highly expected in a particular location (e.g., "The children went outside to…"). To confirm the manipulation, researchers use a modified cloze task (see Taylor, 1953 for the original cloze task) in which the prior sentence context is provided (as above) and subjects supply the word that they think comes next. Typically, the way these data are analyzed is by coding the response as correct (e.g., 1) if the subject supplied the word that the experimenter intended (e.g., "play" in the example, above) and incorrect (e.g., 0) if the subject supplies any other word; the predictability of a word is determined as the proportion of "1" responses for that word. There are some modifications to this coding scheme (e.g., accepting the intended word's plural/singular counterpart or other small morphological variations), but for the most part this procedure is used to determine how expected a particular *word form* is, given the context. In order to create a comparison of predictability, reading times on these highly expected words are contrasted with reading times on a word that was never or rarely supplied by the subjects in the norming procedure, but is nonetheless a plausible word that makes sense in the exact same sentence (e.g., "swim" in the example above; generally, this is confirmed with another norming task in which subjects rate how acceptable/sensible the sentence is).

Using this manipulation, several reading studies have found that both the likelihood of fixating a word and the duration of the fixation are modulated by cloze predictability (Balota, Pollatsek, & Rayner, 1985; Drieghe, Rayner, & Pollatsek, 2005; Ehrlich & Rayner, 1981; Kliegl, Grabner, Rolfs, & Engbert, 2004; Rayner, Slattery, Drieghe, & Liversedge, 2011; Rayner & Well, 1996; Zola, 1984). Initially, researchers hypothesized that the effect of predictability was the manifestation of the reading system "guessing" the upcoming word (e.g., McClelland & Oregan, 1981a,b; cf. Rayner & Slowiaczek, 1981), similar to the "prediction" account described by De Long et al. (2014). On this view, the system uses parafoveal preview to confirm this guess (i.e., that there is a linear relationship between predictability and reading time; see Smith & Levy, 2013 for a discussion). This is the underlying assumption in both the E-Z Reader (Reichle, Pollatsek, Fisher, & Rayner, 1998) and SWIFT (Engbert, Nuthmann, Richter, & Kliegl, 2005) models of oculomotor control in reading.

Recently, however, there have been several findings that question the interpretation that individual words are guessed or predicted. First, the relationship between cloze predictability and reading time is *not* linear, but rather varies across the predictability spectrum: in reading studies, words that have a high or moderate cloze predictability are fixated for less time than words that have a low cloze predictability, but there does not seem to be much distinction between words with high or moderate cloze predictability (Rayner &

Well, 1996; see also, Ehrlich & Rayner, 1981; Hyönä, 1993). This inconsistency could be due to limitations of the cloze task in measuring small differences in absolute predictability, or due to a logarithmic relationship between predictability and reading time. Indeed, a logarithmic relationship was reported by Smith and Levy (2013), who concluded that this relationship suggests "the comprehension system must be able to simultaneously pre-activate large portions of its lexicon in a quantitatively graded fashion" (p. 311). Perhaps then, despite the fact that cloze predictability demonstrates a very strong quantitative relationship with reading times, measuring the effect of context on word processing in this way may not fully capture how readers use context to make reading more efficient. Therefore, we must consider other ways in which the effect of context can be measured.

Contextual constraint

As an alternative to cloze predictability, which focuses primarily on differing degrees of expectations for different words given the same context, some researchers have employed manipulations of the context itself. One of the limitations of using the cloze task to measure these manipulations is that the primary way it is coded and used to generate stimuli for experiments obscures information about the *distribution* of responses, which may be of theoretical importance when considering the reading process. For example, a moderately constraining sentence generally leads to cloze probabilities of around .3 to .6, meaning that a particular word form is supplied by one third to two thirds of the subjects tested. But given that very same outcome, there could be many different underlying distributions. Figure 1 demonstrates the cleanest mathematical relationship one could imagine (i.e., constraint works by decreasing the standard deviation of the distribution of responses, honing on words surrounding a particular meaning or event). It is most straightforward to compare a very high constraint sentence in which one word form is highly favored (e.g., a cloze probability of .8 or higher) and almost no other word forms are provided (e.g., cloze scores of < .1) with a low constraint sentence in which there is almost no consistency in the responses, with all word forms having low cloze scores. The interpretation of such a comparison would lend support to the "prediction" hypothesis, described above, because the constraint serves to change the expectations for a single word. However, it is not clear that extremely high cloze sentences are that common, given that they are relatively uninformative (i.e., do not add any new information since the comprehender can infer the completion). One could argue that very high constraint sentences (e.g., "The opposite of black is...") constitute a qualitatively different type of sentence, rather than an extreme on the constraint continuum (however, adjudicating between these possibilities is beyond the scope of this paper). Thus, it may be more informative to consider sentences with a moderate degree of constraint. That is, such sentences raise the expectations for a particular word form with some consistency, but do not make that word obligatory.

More important for the present study, however, is the question of what the nature of the *other* responses in moderate cloze sentences looks like. For example, if provided with the sentence, "At the dog show, Spot had the most points and won the coveted…" the experimenter's intended target word could be "prize," and in our norming task (see below) this word form was provided 40% of the time aligning with the conclusion that the sentence provides a moderate degree of cloze. However, inspection of the other responses suggests

that crucial information is missing from this coding scheme: "award", "medal", and "ribbon" were provided 20%, 10% and 10% of the time, respectively. If one assumes that theses are acceptable synonyms of the target, then we might conclude that the constraint of the sentence is actually quite high (i.e., including all of these responses because the *meaning* was predicted leads to a cloze score of 80%). Additionally, one could argue that the remaining responses "bone" and "blue" satisfy this coding principle, as well, assuming that a bone would be a nice prize for a dog and that blue was provided because the subject imagined a "blue ribbon" as the prize. Thus, this sentence actually generates a high degree of expectation surrounding the writer's intended idea (i.e., a reward for a good job), but that this idea can manifest itself as a variety different word forms.

An interesting potential consequence of sentence constraint acting in this way is that we would expect, in contrast to the "prediction" hypothesis, that increasing constraint to a moderate level (i.e., not to the point where one word is obligatory) would make it easier to read, not only the highest cloze word, but also words that are related to the meaning that the reader expects. Indeed, this is what Kutas and Hillyard (1984) found when they measured *event related brain potentials* (*ERPs*) to the final words in sentences that were constrained to varying degrees. In this study, Kutas and Hillyard manipulated both the sentence constraint and the target word orthogonally, allowing them to investigate the effect of both variables. However, they note that, because these variables are intrinsically tied, it is impossible to fully dissociate them; cloze probabilities of the best completion in the high constraint sentences were much higher (.92) than in the moderate (.63) and low constraint sentences (.29). When they compared the ERPs across conditions, they found that the most expected word in the most constrained context did not elicit a significant N400 (considered an index of the difficulty of semantic processing; DeLong et al., 2014), but low-cloze words in all sentence constraint conditions elicited N400s of approximately similar amplitudes. In contrast, when comparing ERPs to the best completions across degrees of sentence constraint they found graded effects related to the amplitude of the N400 component, which lends support for the idea of landscapes of pre-activation.

Additionally, Kutas & Hillyard (1984) found the largest N400 to words that were unrelated to the best completion (e.g., "Don't touch the wet dog" when the word with the highest cloze was "paint") and a relatively reduced N400 for words that were semantically related to the best completion (e.g., "coffee" in the sentence "He liked lemon and sugar in his____" where the best completion was "tea"), even though both words had extremely low cloze probabilities and were perfectly acceptable completions. From these data it is unclear whether the reduction in the N400 to these semantically related words stems from distributed pre-activation (i.e., that "coffee" was, to some degree, pre-activated) or to semantic spreading activation from the most highly provided response. However, one could argue that these two interpretations are part and parcel of the same process of distributed expectations.

Further evidence that multiple meanings are being pre-activated comes from a study investigating (self-paced) reading times; Roland, Yun, Koenig, and Mauner (2012) created moderately constraining contexts (e.g., "The aboriginal man jabbed the angry lion with a/an ____") that yielded a distribution of responses in the modified cloze task, generally

surrounding a particular semantic feature (e.g., pointed objects). They compared reading times on words in these sentences with words in sentences that were less semantically constraining (e.g., replacing the word "jabbed" with "attacked" creates less of a preference for a pointed instrument completion). Roland et al. (2012) found that the degree of semantic similarity (measured via *latent semantic analyses LSA*) between the most expected word ($M_{cloze(p)}$ = .24) and the word provided (in the reading task) significantly predicted processing time; reading times were shorter when the provided word was semantically similar to the expected word than when it was semantically dissimilar, even though both words were in the low-cloze probability range ($M_{cloze(p)}$ = .02).

Prediction beyond single words: predicting events—There is one further issue when considering the use of cloze probability to measure the effect of the sentence context, which relates to the distinction between predictability and prediction. Mainly, when subjects provide responses in the cloze task, they (almost always) provide a single word that satisfies the semantic and syntactic constraints imposed on that sentence position (cf. Roland et al., 2012). That is, the sentence "The children went outside to…" must be completed with a verb to be grammatical. However, in the scenario that the subject imagines in order to complete this task, she may imagine not only the action she will provide, but also auxiliary event-related information. For example, if the subject completing the cloze task were in a northern location in winter, she might imaging that "play" in this scenario entails building a snowman, having a snowball fight, sledding, etc. Therefore, even though almost all the subjects would respond with "play" (perhaps because of its high lexical frequency, or because the idea is fairly cliché) does not mean that they are not also imagining these other entities that are not grammatically licensed, which may be part of elaborative inference or other discourse comprehension processes.

There is empirical data to support this suggestion. Metusalem, Kutas, Urbach, Hare, McRae, and Elman (2012) conducted an ERP experiment in which subjects read short, two-sentence scenarios that set up a particular event (e.g., "A huge blizzard ripped through town last night. My kids ended up getting the day off from school.") They then read a third sentence with one of three possible target words (e.g., They spent the whole day outside building a big _____ in the front yard.") and compared the ERP waveforms across those words. The three words were (1) a highly expected word (*snowman*; M_{clozep} = .81), (2) a contextually anomalous word that was related to the event (*jacket*; M_{clozep} = .00), or (3) a contextually anomalous word that was unrelated to the event (*towel*; M_{clozep} = .00). Metusalem et al. (2012) found a reduced N400 for the event-related word compared to the event-unrelated word, even though neither word was ever produced in the cloze norming task. Thus, these data support the idea that sentence (or in this case, discourse) contexts can generate expectations for event-related words beyond just the next, grammatically- and semantically-licensed word.

The interaction between context and parafoveal preview

Taken together, these findings (Kutas & Hillyard, 1984; Metusalem et al., 2012; Roland et al., 2012) suggest that the sentence context pre-activates (and consequently facilitates processing of) a non-singular set of ideas and words. Given that both contextual constraint

and parafoveal preview exert robust effects on reading behavior, the question remains how their influences interact to affect online processing. Crucially, the use of the boundary paradigm (Rayner, 1975) allows us to dissociate the information the reader has about the preview word (in parafoveal vision) from the target word (once it is fixated). An advantage of this experimental design is that it allows us to provide the reading system with previews of words that may not make sense grammatically in the sentence, which change to sensible target words once the display change occurs. Therefore, any potential disruption to comprehension that is created by the hedged bet based on a preview of a semantically associated but grammatically inappropriate word can be repaired if the reader makes a regression to view the perfectly sensible target word. It is likely, then, that the identity of the preview would have more of an influence on early reading measures (e.g., single fixation duration and gaze duration) than on later reading measures (e.g., total reading time) when the system has had more time to encounter the target.

The present study uses the boundary paradigm and the preview manipulation employed by Schotter (2013; identical, synonym, semantically associated, and unrelated) and introduces a manipulation of contextual constraint. That is, Schotter exclusively used neutral sentences with very low cloze probabilities for any of the preview or target words in order to investigate the influence of parafoveal preview *alone*. But a crucial part of much of the theorizing about the reading process (described above) suggests that contextual constraint may change how preview benefit effects are manifested (i.e., by changing expectations about what words should or could appear). Therefore, it is important to empirically test whether and how expectations about and parafoveal preview of words change the way they are read.

Experiment 1

Method

Subjects—Forty undergraduates at the University of California San Diego participated in the experiment for course credit. All subjects were native English speakers with normal or corrected-to-normal vision and were naïve to the purpose of the experiment.

Apparatus—Eye movements were recorded with an SR Research Ltd. Eyelink 1000 eye tracker (with a sampling rate of 1000 Hz) in a tower setup that restrains head movements with forehead and chin rests. Viewing was binocular, but only the movements of the right eye were recorded. Subjects were seated approximately 60 cm away from a 20" HP p1230 CRT monitor with a screen resolution of 1024 x 768 pixels and a refresh rate of 150 Hz. The sentences were presented in the center of the screen with black Courier New 14-point font on a white background and were always presented in one line of text with 3.8 characters subtending 1 degree of visual angle. Following calibration, eye position errors were (maximally) less than 0.3°. The display change was completed, on average, within 4 ms (range = 0–7 ms) of the tracker detecting a saccade crossing the boundary.

Materials and Design—Stimuli were created using the targets and previews from Schotter (2013; Table 1): identical (*begin begin*), synonym (*start begin*), semantically related (*ready begin*) and unrelated (*check begin*). The semantically related condition

consists of semantic associates of the target word. In contrast to Schotter (2013), each target item was presented in a biased sentence context that constrained toward the meaning of the target/synonym (see Appendix and normative data section, below). The target word was always preceded and followed by a minimum of three words.

Normative Data—Fifteen UCSD students, who did not participate in the reading experiment, participated in a cloze norming task to evaluate the predictability of the target and preview words. This norming task revealed that the sentences were moderately constraining toward the meaning of the target/synonym, with (on average) the target only being produced on average 21% of the time, the synonym being produced 25% of the time, the semantically related and unrelated words being produced 0% of the time. However, as discussed in the Introduction, this traditional way of coding cloze data does not capture the extent to which the sentence constrains to the meaning that is shared by the target and synonym (e.g., when both the target and synonym are accepted the joint cloze probability is 46%). Therefore, to create a measure that more readily captures subjects' expectations we also coded the responses for whether any word representing that general idea was reported (see Introduction) and found cloze probabilities of, on average, 75%. These responses were coded independently by two of the experimenters and the inter-rater reliability was quite high (Pearson's r = .9).

Procedure—Subjects were instructed to read the sentences for comprehension and to respond to occasional comprehension questions, pressing the left or right trigger on the response controller to answer yes or no, respectively. At the start of the experiment (and during the experiment if calibration error was greater than .3 degrees of visual angle), the eye-tracker was calibrated with a 3-point calibration scheme. At the beginning of the experiment, subjects received five practice trials, each with a comprehension question, to allow them to become comfortable with the experimental procedure.

Each trial began with a fixation point in the center of the screen, which the subject was required to fixate until the experimenter started the trial. Then a fixation box appeared on the left side of the screen, located at the start of the sentence. Once a fixation was detected in this box, it disappeared and the sentence appeared. The sentence was presented on the screen until the subject pressed a button signaling they had completed reading the sentence. The target replaced the preview once the subject's gaze crossed an invisible boundary located before the space before the target and took between 0 and 7 ms to complete. Subjects were instructed to look at a target sticker on the right side of the monitor beside the screen when they finished reading to prevent them from looking back to a word (in particular, the target, which was often located in the center of the sentence, near the location of the fixation point that started the next trial) as they pressed the button. Comprehension questions followed 30 (41%) of the sentences, requiring a "yes" or "no" response. Comprehension accuracy was very high (on average 93%). The experimental session lasted approximately thirty minutes.

Results and Discussion

The same data processing procedure used in Schotter (2013) was used in this experiment: Fixations shorter than 80 ms within one character of a previous or subsequent fixation were

combined. All remaining fixations shorter than 80 ms or longer than 800 ms were eliminated. Trials in which there was a blink or track loss on the target word or on an immediately adjacent word during first pass reading were excluded, as were trials in which the display change was triggered by a saccade that landed to the left of the boundary or trials in which the display change was completed late. Additionally, gaze durations longer than 2,000 ms and total times longer than 4,000 ms were excluded, as well as any fixation duration measures that were more than 3 standard deviations from the mean for that measure for that subject. These data exclusions left 4920 trials (85% of the original data) available for analysis.

We report standard reading time measures (Rayner, 1998) used to investigate the time-course of word processing in reading. This includes measures of fixation time when the word was fixated, which can be divided into early measures (i.e., those that terminate at the end of first-pass reading: once the reader's eyes move away from it for the first time) and late measures (i.e., those that include time spent re-reading the target word or words prior to it). Early reading time measures include *first fixation duration* (the duration of the first fixation on the word, regardless of how many fixations are made), *single fixation duration* (the duration of a fixation on a word when it is the only fixation on that word in first pass reading), and *gaze duration* (the sum of all fixations on a word prior to leaving it, in any direction). Late reading time measures include *go-past time* (the sum of all fixations on a word and any words to the left of it before going past it to the right), and *total time* (the sum of all fixations on a word, including time spent re-reading the word after a regression back to it). Because go-past time incorporates re-reading previous words after a regression out of the target and total time includes rereading the target after a regression from subsequent words, go-past time can be considered an earlier late measure than total time.

Data were analyzed using inferential statistics based on generalized linear mixed-effects models (LMMs) with preview entered as a fixed effect with planned contrasts (see below) and subjects and items as crossed random effects (see Baayen, Davidson, & Bates, 2008), using the maximal random effects structure (Barr, Levy, Scheepers & Tily, 2013)[2]. There were three planned contrasts built into the model: one tested the difference between the identical condition and the unrelated condition (i.e., an identical preview benefit), another tested for a difference between the synonym and the unrelated condition (i.e., a synonym preview benefit), and the third tested for a difference between the semantically related condition and the unrelated condition (i.e., a semantically related preview benefit). Contrasts were achieved by setting the unrelated condition to the baseline (intercept) in the model and using dummy coded variables to test for the individual contrasts for the comparisons of each of the other conditions to the unrelated condition.

In order to fit the LMMs, we used the lmer function from newest lme4 package (version 1.1–7; Bates, Maechler, Bolker, & Walker, 2014) within the updated R Environment for Statistical Computing (R Development Core Team, 2014). For fixation duration measures,

---

[2]Some of the models failed to converge with the maximal random effects structure so we simplified those models iteratively and report the model with the fullest random effects structure. These were the changes in Experiment 1: we removed the correlation between the item intercept and item slopes for first fixation duration, single fixation duration; we removed the correlation between item intercepts and item slopes as well as the correlation between subject intercepts and subject slopes for go-past time and total time.

we report linear mixed-effects regressions on the raw data: regression coefficients (b), which estimate the effect size (in milliseconds) of the reported comparison, and the (absolute) t-value of the effect coefficient are reported. Log-transforming the dependent variable had almost no effect on the patterns of significance, so for transparency we report the results from the untransformed models. For binary dependent variables (fixation probability data), logistic mixed-effects regression models were used, and regression coefficients (b), which represent effect size in log-odds space, and the (absolute) z value and p value of the effect coefficient are reported. Absolute values of the *t* and *z* statistics greater than or equal to 1.96 indicate an effect that is significant at approximately the .05 alpha level.

Fixation duration measures—Because it is of theoretical interest to the oculomotor models of reading, we first analyzed whether the different previews had an effect on gaze duration on the pretarget word (i.e., whether we observed a parafoveal-on foveal effect; see Drieghe, 2011 for a review). If we were to find such an effect, it would suggest that readers had processed the upcoming word extensively, prior to making a saccade toward it. However, there were no differences across conditions for gaze duration on the pretarget word (247 ms, 248 ms, 249 ms, and 244 ms in the identical, synonym, semantically associated, and unrelated conditions, respectively; all ts < 1.26), indicating no parafoveal-on-foveal effects.

Reading measures on the target word are shown in Table 2 and results of the LMMs on fixation duration measures are reported in Table 3 with the size of the effect (in ms) being represented by the b values. Across all measures there was a significant identical preview benefit such that reading times were significantly shorter on the target when the preview was identical than when it was unrelated (all ts > 3.92). There was a significant preview benefit in the synonym condition; reading times were significantly shorter on the target when the preview was a synonym of the target than when it was unrelated in all measures (all ts > 3.81). Importantly, similar to the N400 findings of Metusalem et al. (2012), there was a significant apparent preview benefit in the semantically associated condition in early reading time measures (first fixation duration, single fixation duration, and gaze duration; all ts > 2.68), but this effect went away in later measures (go-past time: t = 1.33; total time: t < 1). These data suggest that the initial, apparent facilitation provided by the semantically related preview in first pass reading measures went away as the reader had more time to process the precise meaning of the word (Figure 2); we return to this finding in the discussion section.

Fixation probability measures—Results of the LMMs on fixation probability measures are reported in Table 4. It is important to note that any effects across condition observed on fixation probability must be due to processing of the preview (rather than the relationship between preview and target) because the identity of the target has not yet been encountered by the time the fixation/skipping decision is made. Both the identical and synonym preview conditions produced significantly lower probabilities of fixating the target than the unrelated condition (both ps .05), which did not differ from the semantically related condition (p = .29). This effect is likely due to the higher word form cloze probability for the identical and synonym previews (.21 and .25, respectively) than for the other two (both .00). For regressions out of the target, none of the preview contrasts were significant, indicating that

subjects were equally likely to make a regression from the target to prior words across conditions (all ps > .07). Readers were less likely to make a regression into the target in the identical condition than in the unrelated condition (p < .05) but neither the semantically related nor the synonym conditions were significantly different from the unrelated condition (both ps > .08), suggesting that any display change led to an increased likelihood of making a regression back to the target, relative to when the word did not change.

Overall, these data suggest that first-pass saccade decisions away from an individual word can be affected by expectations about that word based on prior context. Most notably, while in neutral contexts semantic associates did not demonstrate preview benefit (Schotter, 2013), when those same words were embedded in constraining contexts target words were initially read faster (i.e., during first-pass reading) when preceded by a preview of a semantically associated word compared to an unrelated word. Importantly, however, in later reading time measures when full identification of the target word completed, the apparent preview benefit for semantic associates disappeared (Figure 2).

Experiment 2

In order to directly test how contextual constraint influences preview benefit effects in reading, we conducted a second experiment in which both the constraint and preview manipulations were implemented in a within-subjects design.

Method

The method was the same as in Experiment 1 with the following exceptions.

Subjects—Seventy-two undergraduates at the University of California San Diego participated in the experiment. None of them participated in any of the other experiments and were chosen using the same inclusion criteria as Experiment 1.

Materials and Design—Each subject saw stimuli in each of the 8 conditions in a 2 (constraint: high vs. low) x 4 (preview: identical vs. synonym vs. related vs. unrelated) design. Stimuli were identical to those used in Schotter (2013) for the neutral condition and identical to those used in Experiment 1 for the constrained condition.

Results and Discussion

Comprehension accuracy was very high (on average 96%). The same data processing procedure used in Experiment 1 was used in Experiment 2. These data exclusions left 7557 trials (85% of the original data) available for analysis. There were no differences across conditions for gaze duration on the pretarget word (all ts < 1.11), indicating no parafoveal-on-foveal effects (pretarget gaze durations in constrained sentences were 251 ms, 248 ms, 244 ms, and 249 ms and in neutral sentences were 242 ms, 246 ms, 247 ms, and 246 ms in the identical, synonym, semantically related, and unrelated conditions, respectively). Reading time measures on the target word are shown in Table 5. For clarity of exposition (so direct comparisons to the prior experiments are easier) we first report analyses of subset models fit to the four preview conditions fit separately for the different sentence constraint

conditions. We address the issue of interactions between the two factors in a separate section, afterward.

Neutral sentence conditions (replication of Schotter, 2013)

Fixation duration measures: Results of the LMMs on fixation duration measures are reported in Table 6. As reported by Schotter, 2013, across all measures there was a significant identical preview benefit such that reading times were significantly shorter on the target when the preview was identical than when it was unrelated (all ts > 2.33). There was an apparent early preview benefit in the synonym condition; reading times were significantly shorter on the target when the preview was a synonym of the target than when it was unrelated in early measures (all ts > 2.64), the effect was marginally significant in go-past time (b = 12.36, t = 1.84), and was not significant in total time (b = 2.89, t = 0.42). The difference between reading time measures in semantically related and unrelated conditions did not significantly differ in any reading time measure (all ts < 1.27). Therefore, these data confirm the preview benefit effects for identical and synonym previews and non-significant preview benefit for semantically related previews reported by Schotter (2013) for words in neutral sentences. Furthermore, these data demonstrate that the pattern of effects is robust even when those sentences are read intermixed with sentences that are highly constraining.

Fixation probability measures: Results of the LMMs on fixation probability measures are reported in Table 7. Only the synonym preview condition produced significantly lower probabilities of fixating the target than the unrelated condition (p < .05), which did not differ from either the identical or the semantically related condition (both ps > .57). For regressions out of the target, none of the preview contrasts were significant, indicating that subjects were equally likely to make a regression from the target to prior words across conditions (all ps > .38). Readers were less likely to make a regression into the target in the identical condition than in the unrelated condition (p < .005) and were more likely to make a regression into the target in the synonym condition than the unrelated condition (p < .05), but the semantically related condition was not significantly different from the unrelated condition (p = .10).

Constrained sentence conditions (replication of Experiment 1)

Fixation duration measures: As in Experiment 1, across all measures there was a significant identical preview benefit such that reading times were significantly shorter on the target when the preview was identical than when it was unrelated (all ts > 4.60). There was a significant preview benefit in the synonym condition; reading times were significantly shorter on the target when the preview was a synonym of the target than when it was unrelated in all measures (all ts > 4.02) except for total time, where the effect was marginally significant (TVT: b = 12.09, t = 1.85). There was an apparent early preview benefit in the semantically related condition that was significant in all reading time measures (all ts > 2.17) except for total time where the effect completely disappeared (t = 0.79).

Fixation probability measures: There were no significant differences in the probabilities of fixating the target (all ps > .07). Readers were more likely to make regressions out of the target in the unrelated condition than in all other preview conditions (all ps < .05). Readers

were less likely to make a regression into the target in the identical condition than in the unrelated condition (p < .001) but there was no difference in regressions into the target between either the synonym condition or the semantically related condition than the unrelated condition (both ps > .29).

Additional analyses: Tests for interactions between constraint and preview—
To better understand the interaction between sentence constraint and parafoveal preview we conducted analyses on the four most theoretically interesting measures. These measures represent the earliest, initial identification stages of processing the word (i.e., single fixation duration and gaze duration) through later, integration and re-analysis stages (i.e., go-past time, and total time). We ran two separate sets of analyses: one using only the data from Experiment 2 since each subject experienced items in every condition and this provides the most straightforward test for an interaction. However, Experiment 2 contained only 72 subjects and 123 items across 8 conditions so we ran additional analyses on the combined the data from three experiments (Schotter (2013) Experiment 2, current Experiment 1, and current Experiment 2) in order to maximize power by taking advantage of all 152 subjects. For both sets of models, we entered the preview contrasts as dummy-coded treatment contrasts with the unrelated condition as the baseline (as in the previous analyses) and entered sentence constraint as a centered predictor. Because only some subjects experienced both levels of sentence constraint (i.e., subjects in current Experiment 2), the random effects structure for subjects contained random intercepts and slopes for preview contrasts only and the random effects structure for items contained intercepts and slopes for both preview contrasts and sentence constraint, entered separately (i.e., without the correlations between them). These interactions are presented in Figure 3 and results of the statistical analyses are presented in Table 8, showing the results of the model with only the Experiment 2 data and the results of the model with the combined data. As seen in Figure 3, the pattern of effects does not change depending on whether only the Experiment 2 data are considered compared to when the data from the combined experiments are used. However, due to the decreased power in the analyses with Experiment 2 data only many of the interactions from those models are not significant while they are significant in the model with the combined data; we note the differences, below.

The data from single fixation duration and gaze duration are quite similar: the sentence context has no effect on reading times in the unrelated preview condition in either the model with Experiment 2 data or the model with the combined data (all ts < 0.82). For the other three preview conditions (identical, synonym, and semantically related), there were significant interactions with sentence constraint in the model with all data (all ts > 1.99)— the magnitude of these preview benefits were increased in constrained relative to neutral sentences (by approximately 10 ms and 13 ms, for single fixation duration and gaze duration respectively). While the effects were in the same direction and of similar magnitude in the model with only Experiment 2 data, they were not statistically significant (all ts < 1.94).

The pattern of data for go-past time was qualitatively similar to the early measures and was consistent between the model with Experiment 2 data and the model with the combined data; there was no effect of constraint on the unrelated condition (both ts < 0.82) and the preview benefits for the three related preview conditions increased in magnitude by

approximately 20 ms in constrained relative to neutral sentence contexts. However, while the interaction was significant for the synonym and semantic preview conditions (all ts > 2.26), it was not significant for the identical preview benefit condition (both ts < 1.88).

Lastly, total time (the latest of these measures because it includes re-reading of the target *after* first-pass time has ended) shows a different pattern of effects. First, there was a significant effect of sentence context in the unrelated condition in both models (both ts = 3.56)—reading times were about 22 ms shorter in constrained contexts. Second, the significant identical preview benefit in neutral contexts did not significantly increase in magnitude in constrained contexts in either model (t < 0.72), but sentence constraint did interact with the moderately sized synonym preview benefit in neutral contexts so that it doubled in magnitude in constrained contexts; this effect was not significant in the model with only Experiment 2 data (t = 1.23), but was significant in the model with the combined data (t = 2.95). The semantic preview benefit was not significant in neutral contexts and there was no interaction with constraint in either model (both ts < 1.28).

General Discussion

In the present study, we recorded reading times on preview/target words from Schotter (2013) that were embedded in sentences that were moderately constrained so that, rather than a particular word form, the idea shared by the target/synonym was highly predicted (75% of the time). We found that, in contrast to the data reported by Schotter (2013), semantically associated previews yielded faster reading times compared to an unrelated preview during early (first-pass) reading time measures and this apparent preview benefit subsided in late reading time measures. In a second experiment, we replicated both the results from Schotter (2013) and Experiment 1 in a fully within-subjects design, and thus we are quite confident in the data.

These data reveal yet another circumstance under which semantic preview benefit can be observed in English—a formerly elusive finding to report—when the preview/target is embedded in a constraining context. But why might a context that constrains toward a particular idea (e.g., Janet lives on fifth *avenue/street*…) also lead to faster processing of the target when the preview is only associatively related to the predicted meaning (e.g., *suburb*) and may not make sense? To explain this, we return to the ideas we raised in the introduction. These data (as well as those reported by Kutas & Hillyard, 1984; Metusalem et al., 2012; and Roland et al., 2012) suggest that sentence constraint leads readers to generate expectations about upcoming *words*, rather than make a specific, unitary prediction the upcoming word. This interpretation aligns with the idea of pre-activation/anticipation, discussed by De Long et al. (2014) and the suggestion by Smith and Levy (2013) that this pre-activation happens in a qualitatively graded fashion. Thus, even though the previews in the semantically associated condition do not necessarily fit grammatically into the sentence context, they could nonetheless be activated by the comprehension system in anticipation of their role in the general event being described (Elman, 2009). Importantly though, once the system has enough time to identify, process, and attempt to integrate the meaning of these preview words we may observe comprehension difficulty (e.g., increased total time due to

more re-reading) if the word does not sensibly fit into the context. How might a process like this occur?

A mechanistic account of the present findings

Recall that one of the assumptions built into the E-Z Reader model is that early oculomotor decisions are "dumb." Therefore early on in the reading process, the system should not assess whether the word makes sense in great detail. Rather, the system may opportunistically take advantage of any source of information available to hedge a bet that the word will be identifiable in order to time eye movements efficiently. Therefore, decisions about when to move the eyes forward (i.e., at the completion of L_1) indicate "hedged bets" that the word in question *will be* identifiable by the time the eyes move away from it, rather than indicating full recognition of the word. Schotter, Reichle, and Rayner (2014) suggested that the system uses three sources of information to make these oculomotor decisions: prior context, parafoveal preview, and foveal target information. With respect to our data, a constraining prior sentence context contributes one indication that the word should be easy to identify and we observed a different pattern of preview benefit when the sentence was constraining (Experiment 1 and the constrained conditions in Experiment 2) than when the sentence was not constraining (Schotter, 2013 and the neutral conditions in Experiment 2). With respect to the semantic preview benefit observed in the constrained sentences, this may be due to the interaction of semantic expectations generated from the context combined with a lack of assessment or integration to ensure that the interpretation is sensible.

Generally, accounts in which eye movement decisions are based solely on the preview are used to explain skipping decisions (because the target had not yet been displayed/ encountered when the decision was made), but seemingly pose a greater challenge when explaining preview benefit effects (i.e., eye movement decisions once the eyes land on the target—after the display has changed)[3]. To explain this, we return to a discussion of the boundary paradigm. In the introduction, we mentioned that Schotter et al. (2014) proposed a new way of modeling the boundary paradigm—by estimating the proportion of trials on which processing of the upcoming *preview* word had progressed to the L_2 stage in the model. Recall that a corollary of advancing to the L_2 stage is that the model also advances to the M_1 stage (beginning of saccade programming away from that word). Thus, in those cases, the model estimates that the system can begin programming a saccade away from a word, even before fixating it. Because the model allows for multiple saccade programs to be planned in parallel (E. Reichle, personal communications, December 3, 2014), there should be cases in which the eyes land on the target word, but the saccade program away from that word has already begun and is based on information what was obtained from the preview, rather than the new information from the target.

Importantly, these "dumb" oculomotor decisions are only hypothesized to occur early in the reading process (i.e., in E-Z Reader, this refers to the completion of L_1). On this view, once the word is fully recognized, then integration with the sentence occurs and the system should

---

[3]We thank Denis Drieghe for pointing this out.

realize that there is a problem. Thus, we observed that the apparent preview benefit for semantically associated words in constrained sentences disappeared in later measures (i.e., those that include regressions; see Figure 2). Moreover, because this realization that the word does not make sense should happen *after* full word recognition (i.e., after first-pass reading), we would expect that the cost of hedging a bet on the semantically associated word should show up in total time (which includes regressions back to the target after it was left) more strongly than in go-past time (which includes regressions back to words before the target from the target itself). In fact, this is the exact pattern of data we observed: the difference between the semantically associated and unrelated conditions in constrained sentences was larger in go-past time (8 ms in Experiment 1 and 24 ms in Experiment 2) than in total time (4 ms in Experiment 1 and 6 ms in Experiment 2; see Figure 3).

The proposition that early oculomotor decisions are "dumb" and later decisions (i.e., regressions) should be more sensitive to meaning and integration processes suggests that we should observe a dissociation between the pattern of effects in these measures. That is, we would observe an apparent early preview benefit (faster processing of a target with a semantically related compared to unrelated preview), which then leads to a preview cost (or equivalent time to an unrelated preview condition) during later measures that include regressions, if the preview word is nonsensical in the sentence context. Importantly, this should be more likely to happen when the context is moderately constraining, rather than in contexts that are highly constraining (i.e., that make one word obligatory).

Other influences that have demonstrated an "apparent/inappropriate preview benefit," at least with respect to the measure of skipping, are word length and frequency. For example, an extremely high frequency word like *the* is skipped very frequently (approximately 50% of the time), even when it is syntactically or semantically inappropriate within the sentence context (Angele & Rayner, 2013; Angele, Laishley, Rayner, & Liversedge, 2014). While neither the semantic spreading activation nor the feature overlap accounts would predict this finding (e.g., it is unclear what are the semantic features of "the" that would overlap with the three-letter verbs used as targets in these studies), an account by which frequency is used (at least for very short three-letter words) as a heuristic to make skipping decisions may be viable. However, the stimuli from these studies are so specific to short words that it is unclear whether these effects generalize.

It may seem counterintuitive that readers should skip (or fixate only briefly) words that are unexpected or do not make sense in the sentence context. Nonetheless, these data suggest that a highly constraining context most likely facilitates reading of, not only the expected word, but also other words that seem as though they should be easy to recognize. This recognizability may be based on several factors, including both length and frequency (Angele & Rayner, 2013; Angele, et al., 2014), and also expectations generated by the context, combined with semantic similarity to the expected meaning (Kutas & Hillyard, 1984; Metusalem et al., 2012; Roland et al., 2012). Thus, in the present study we found that previews that are associatively related to the context being developed led to faster early reading time than previews that were completely unrelated to the context in moderately constrained contexts (current Experiment 1 & current Experiment 2, constrained contexts)

even though no such facilitation was observed for semantically associated words in neutral sentence contexts (Schotter (2013) & current Experiment 2, neutral contexts).

Conclusion

The results of the experiments reported here contribute evidence that the presence of an observable semantic preview benefit depends on certain conditions being met but, importantly, we are now beginning to be able to predict when it will and will not be observed. Mainly, semantic preview benefit is unlikely to be observed when reading in a deep orthography, such as English, and there are no cues from the text to support it. This is important to contextualize cross-language differences with respect to semantic preview benefit because languages in which it is observed (e.g., Chinese and German) are more likely to have such cues (see Schotter, 2013; Schotter, Reichle, & Rayner, 2014). However, even when reading in a language with a deep orthography, properties of the text may provide cues that facilitate semantic preview benefit (e.g., visual salience from the preview/ target instantiated by capitalizing the initial letter; Rayner & Schotter, 2014; see also Hohenstein & Kliegl, 2014). The studies reported here demonstrate another property of the text that may encourage semantic preview benefit: constraint from the prior sentence. Furthermore, these data add evidence to a growing literature showing that sentence context facilitates (at least initially) processing of a group of event-related words, rather than only the most expected word form. Together, these studies suggest that the reading system takes advantage of any source of information available to facilitate reading. For the most part, when experimenters do not manipulate the text during reading, this is advantageous. Importantly, we were able to see the negative consequence of this risky reading strategy in that, when readers had assumed that the preview/target word would be easily recognizable and were incorrect (i.e., in the semantically associated preview condition) later reading measures showed a reading time cost.

Acknowledgments

References

Angele B, Laishley AE, Rayner K, Liversedge SP. The effect of high-and low-frequency previews and sentential fit on word skipping during reading. Journal of Experimental Psychology: Learning, Memory, and Cognition. 2014; 40:1181–1203.

Angele B, Rayner K. Processing< em> the in the parafovea: Are articles skipped automatically? Journal of Experimental Psychology: Learning, Memory, and Cognition. 2013; 39:649–662.

Baayen RH, Davidson DH, Bates DM. Mixed-effects modeling with crossed random effects for subjects and items. Journal of Memory and Language. 2008:390–412.

Balota DA, Pollatsek A, Rayner K. The interaction of contextual constraints and parafoveal visual information in reading. Cognitive Psychology. 1985; 17:364–390. [PubMed: 4053565]

Barr DJ, Levy R, Scheepers C, Tily HJ. Random effects structure for confirmatory hypothesis testing: Keep it maximal. Journal of Memory and Language. 2013; 68:255–278.

Bates, DM.; Maechler, M.; Bolker, B. Lme4: Linear mixed-effects models using S4classes. R package version 0.999375–42. 2011. <http://CRAN.R-project.org/package.lme4>

Bates, D.; Maechler, M.; Bolker, BM.; Walker, S. lme4: Linear mixed-effect models using S4 classes (R package Ver. 1.1–7). Vienna, Austria: R Foundation for Statistical Computing; 2014.

Bicknell, K.; Levy, R. A rational model of eye movement control in reading. In: Haji , J.; Carberry, S.; Clark, S.; Nivre, J., editors. Proceedings of the 48th annual meeting of the Association for Computational Linguistics (ACL). Uppsala, Sweden: Association for Computational Linguistics; 2010. p. 1168-1178.

Blanchard HE, Pollatsek A, Rayner K. The acquisition of parafoveal word information in reading. Perception & Psychophysics. 1989; 46:85–94. [PubMed: 2755766]

DeLong KA, Troyer M, Kutas M. Pre-Processing in Sentence Comprehension: Sensitivity to Likely Upcoming Meaning and Structure. Language and Linguistics Compass. 2014; 8:631–645.

Drieghe, D. Parafoveal-on-foveal effects on eye movements during reading. In: Liversedge, S.; Gilchrist, I.; Everling, S., editors. Oxford Handbook on Eye Movements. Oxford, UK: Oxford University Press; 2011. p. 839-855.

Drieghe D, Rayner K, Pollatsek A. Eye movements and word skipping during reading revisited. Journal of Experimental Psychology: Human Perception and Performance. 2005; 31:954–969. [PubMed: 16262491]

Ehrlich SF, Rayner K. Contextual effects on word perception and eye movements during reading. Journal of Verbal Learning and Verbal Behavior. 1981; 20:641–655.

Elman JL. On the meaning of words and dinosaur bones: Lexical knowledge without a lexicon. Cognitive Science. 2009; 33:547–582. [PubMed: 19662108]

Engbert R, Nuthmann A, Richter EM, Kliegl R. SWIFT: a dynamical model of saccade generation during reading. Psychological Review. 2005; 112:777–813. [PubMed: 16262468]

Hohenstein S, Kliegl R. Semantic preview benefit during reading. Journal of Experimental Psychology: Learning, Memory, and Cognition. 2014; 40:166–190.

Hohenstein S, Laubrock J, Kliegl R. Semantic preview benefit in eye movements during reading: A parafoveal fast-priming study. Journal of Experimental Psychology: Learning, Memory, and Cognition. 2010; 36:1150–1170.

Hyönä J. Effects of thematic and lexical priming on readers' eye movements. Scandinavian Journal of Psychology. 1993; 34:293–304. [PubMed: 8303233]

Kliegl R, Grabner E, Rolfs M, Engbert R. Length, frequency, and predictability effects of words on eye movements in reading. European Journal of Cognitive Psychology. 2004; 16:262–284.

Kutas M, Hillyard SA. Brain potentials during reading reflect word expectancy and semantic association. Nature. 1984; 307:161–163. [PubMed: 6690995]

Laubrock J, Hohenstein S. Orthographic consistency and parafoveal preview benefit: A resource-sharing account of language differences in processing of phonological and semantic codes. Behavioral and Brain Sciences. 2012; 35:292–293. [PubMed: 22929177]

Levy R. Expectation-based syntactic comprehension. Cognition. 2008; 106:1126–1177. [PubMed: 17662975]

McClelland JL, O'Regan JK. Expectations increase the benefit derived from parafoveal visual information in reading words aloud. Journal of Experimental Psychology: Human Perception and Performance. 1981a; 7:634–644.

McClelland JL, O'Regan JK. On visual and contextual factors in reading: A reply to Rayner and Slowiaczek. Journal of Experimental Psychology: Human Perception and Performance. 1981b; 7:652–657.

Metusalem R, Kutas M, Urbach TP, Hare M, McRae K, Elman JL. Generalized event knowledge activation during online sentence comprehension. Journal of memory and language. 2012; 66:545–567. [PubMed: 22711976]

R Core Team. R: A language and environment for statistical computing. R foundation for statistical computing; Vienna, Austria: 2014. http://www.R-project.org/

Rayner K. The perceptual span and peripheral cues in reading. Cognitive Psychology. 1975; 7:65–81.

Rayner K. The Thirty Fifth Sir Frederick Bartlett Lecture: Eye movements and attention during reading, scene perception, and visual search. Quarterly Journal of Experimental Psychology. 2009; 62:1457–1506.

Rayner K, Balota DA, Pollatsek A. Against parafoveal semantic processing during eye fixations in reading. Canadian Journal of Psychology. 1986; 40:473–483. [PubMed: 3502884]

Rayner K, Schotter ER. Semantic preview benefit in reading English: The effect of initial letter capitalization. Journal of Experimental Psychology: Human Perception & Performance. 2014; 40:1617–1628. [PubMed: 24820439]

Rayner K, Schotter ER, Drieghe D. Lack of semantic parafoveal preview benefit in reading revisited. Psychonomic Bulletin & Review. 2014; 21:1067–1072. [PubMed: 24496738]

Rayner K, Slattery TJ, Drieghe D, Liversedge SP. Eye movements and word skipping during reading: Effects of word length and predictability. Journal of Experimental Psychology: Human Perception and Performance. 2011; 37:514–528. [PubMed: 21463086]

Rayner K, Slowiaczek ML. Expectations and parafoveal information in reading: Comments on McClelland and O'Regan. Journal of Experimental Psychology: Human Perception and Performance. 1981; 7:645–651.

Rayner K, Well AD. Effects of contextual constraint on eye movements in reading: A further examination. Psychonomic Bulletin and Review. 1996; 3:504–509. [PubMed: 24213985]

Rayner K, Well AD, Pollatsek A, Bertera JH. The availability of useful information to the right of fixation in reading. Perception and Psychophysics. 1982; 31:537–550. [PubMed: 7122189]

Reichle ED, Pollatsek A, Fisher DL, Rayner K. Toward a model of eye movement control in reading. Psychological Review. 1998; 105:125–157. [PubMed: 9450374]

Roland D, Yun H, Koenig JP, Mauner G. Semantic similarity, predictability, and models of sentence processing. Cognition. 2012; 122:267–279. [PubMed: 22197059]

Rumelhart, DE. Some problems with the notion that words have literal meanings. In: Ortony, A., editor. Metaphor and Thought. Cambridge University Press; 1979. p. 71-82.

Schotter ER. Synonyms provide semantic preview benefit in English. Journal of Memory and Language. 2013; 69:619–633.

Schotter ER, Angele B, Rayner K. Parafoveal processing in reading. Attention, Perception, & Psychophysics. 2012; 74:5–35.

Schotter ER, Reichle ED, Rayner K. Rethinking Parafoveal Processing in Reading: Serial Attention Models can Account for Semantic Preview Benefit and n+2 Preview Effects. Visual Cognition. 2014; 22:309–333.

Smith NJ, Levy R. The effect of word predictability on reading time is logarithmic. Cognition. 2013; 128:302–319. [PubMed: 23747651]

Taylor WL. "Cloze procedure": a new tool for measuring readability. Journalism Quarterly. 1953; 30:415–433.

Yan M, Richter EM, Shu H, Kliegl R. Readers of Chinese extract semantic information from parafoveal words. Psychonomic Bulletin and Review. 2009; 16:561–566. [PubMed: 19451385]

Yan M, Zhou W, Shu H, Kliegl R. Lexical and sublexical semantic preview benefits in Chinese reading. Journal of Experimental Psychology: Learning, Memory, and Cognition. 2012; 38:1069–1075.

Yang J. Preview effects of plausibility and character order in reading Chinese transposed words: Evidence from eye movements. Journal of Research in Reading. 2013; 36:S18–S34.

Yang J, Wang S, Tong X, Rayner K. Semantic and plausibility effects on preview benefit during eye fixations in Chinese reading. Reading and Writing. 2010; 25:1031–1052. [PubMed: 22593624]

Zola D. Redundancy and word perception during reading. Perception and Psychophysics. 1984; 36:277–284. [PubMed: 6522220]

Appendix

Stimuli used in the experiments. Target words (identical previews) are presented in boldface (not in boldface in the experiments). Columns to the right represent the synonym, semantically related and unrelated previews. Neutral sentences were taken from Schotter (2013) and were used in Experiment 2, constrained sentences were used in Experiments 1 and 2.

	Type	Sentence	Synonym	Semantic	Unrelated
1	Neutral	The dishes are stored **below** the sink in the kitchen.	under	handy	order
1	Constrained	It is common knowledge that 90% of an iceberg's mass lies **below** the water's surface.	under	handy	order
2	Neutral	The sons were quite **lousy** at doing their chores before dinner.	awful	great	rated
2	Constrained	I won't see that movie because everyone said it was really **lousy** and a waste of money.	awful	great	rated
3	Neutral	Tim wanted to be more than **buddies** with Stacey, but she had a boyfriend.	friends	hugging	towards
3	Constrained	Jen gave Mary a matching bracelet because they're best **buddies** and love each other.	friends	hugging	towards
4	Neutral	At the zoo I saw the giant **adult** panda eating bamboo leaves.	older	aging	album
4	Constrained	Tadpoles become frogs as they change from an adolescent stage to an **adult** stage of life.	older	aging	album
5	Neutral	Ian auctioned an antique **clock** to raise money for a charity.	watch	timer	match
5	Constrained	Jessica was constantly checking time on her large **clock** so she wouldn't be late.	watch	timer	match
6	Neutral	Max had to have the teacher **clarify** when the homework assignment was due.	explain	discuss	captain
6	Constrained	The confused students always ask the tutor to please **clarify** questions on the tests.	explain	discuss	captain
7	Neutral	Everyone was pleased that the talented **chef** prepared such a wonderful meal.	cook	food	acid
7	Constrained	The restaurant recruited a famous **chef** and it was a great success.	cook	food	acid
8	Neutral	Sarah tried using **curlers** on her stubborn straight hair before prom.	rollers	styling	suffice
8	Constrained	Peg hates straight hair, so instead of a flatiron she uses **curlers** to style her hair.	rollers	styling	suffice
9	Neutral	After working out, Shelley felt a sudden **acute** pain in her calves.	sharp	quick	strip
9	Constrained	Dogs can locate missing people because their sense of smell is very **acute** and precise.	sharp	quick	strip
10	Neutral	The Johnson family fell in love with the beautiful **vast** backyard at their new home.	huge	open	dogs
10	Constrained	The sea is relatively unexplored because it's extremely **vast** and contains danger.	huge	open	dogs
11	Neutral	The little girl complained about her upset **tummy** and asked to skip soccer practice.	belly	torso	daddy
11	Constrained	Lisa's new dog loves rolling over for people to rub her fuzzy **tummy** and fluffy tail.	belly	torso	daddy
12	Neutral	Tammy noticed many items were left **blank** when grading the exam.	empty	clear	imply

	Type	Sentence	Synonym	Semantic	Unrelated
12	Constrained	The student didn't know any answers and left her exam completely **blank** and failed it.	empty	clear	imply
13	Neutral	Cops need to be aware of a possible **ambush** while on the job.	attack	battle	effort
13	Constrained	While paintballing, Bob's strategy is to sneak up and secretly **ambush** the other team.	attack	battle	effort
14	Neutral	My friends have the same favorite **movie** that they watch every week.	video	audio	water
14	Constrained	On Friday, the kids went to Blockbuster to rent a scary **movie** for their sleepover.	video	audio	water
15	Neutral	The children must **mow** the lawn every Friday.	cut	dig	net
15	Constrained	Matt's lawn restoration job means there are several lawns he must **mow** in a short time.	cut	dig	net
16	Neutral	We had to read many **surveys** in our psychology class.	reviews	breadth	measure
16	Constrained	The restaurant had positive responses on their **surveys** which made it popular.	reviews	breadth	measure
17	Neutral	Betty enjoys going to the nearby **town** to go shopping on the weekends.	city	area	only
17	Constrained	Jo saw a missing person report for a boy in the neighboring **town** that went missing.	city	area	only
18	Neutral	Frank always sits in the exact **middle** of the classroom.	center	corner	member
18	Constrained	When playing darts, you should always aim for the exact **middle** of the target.	center	corner	member
19	Neutral	Despite living at the beach, George **seldom** goes surfing.	rarely	cannot	nicely
19	Constrained	Lou's boss initially worried he would be late, but that is actually **seldom** the case.	rarely	cannot	nicely
20	Neutral	Jenna loved how her necklace would **sparkle** on sunny days.	glitter	flicker	platter
20	Constrained	The girl loved to twirl in her dress and watch the sequins **sparkle** in the sunshine.	glitter	flicker	platter
21	Neutral	My dog can always **select** the correct bowl with the treat inside.	choose	reject	chance
21	Constrained	To change the font, go to the tools menu and then **select** the font you would like.	choose	reject	chance
22	Neutral	My roommate will continuously **scrub** the dishes until they are clean.	clean	bathe	alone
22	Constrained	For hygienic purposes, doctors must **scrub** their hands thoroughly.	clean	bathe	alone
23	Neutral	Steven made a mean **quip** about his sister's hair.	joke	jest	gate
23	Constrained	The comedian made the crowd laugh with a funny **quip** about his ex wife.	joke	jest	gate
24	Neutral	After a week the messy family started to create a heaping **rubbish** pile in their yard.	garbage	rummage	postage
24	Constrained	The house reeked of rotten food after he didn't empty the smelly **rubbish** for 4 days.	garbage	rummage	postage
25	Neutral	The horse race will **begin** in a couple minutes.	start	ready	check
25	Constrained	At the race, the horses will line up and then the race will **begin** shortly after that.	start	ready	check
26	Neutral	Erin fell asleep for a mere **moment** while driving on the highway.	second	period	around
26	Constrained	Tech support told Al to hold for a short **moment** but it had been hours.	second	period	around

	Type	Sentence	Synonym	Semantic	Unrelated
27	Neutral	The man was a notorious **murderer** responsible for the many deaths.	assassin	killings	enormous
27	Constrained	When a homicide aired on the news, the search for the cruel **murderer** became bigger.	assassin	killings	enormous
28	Neutral	The ring had a beautiful **jewel** in the center.	stone	pearl	clean
28	Constrained	The princess' tiara was full of diamonds and one big pink **jewel** in the middle.	stone	pearl	clean
29	Neutral	Shelia would never **utter** a word about what happened.	speak	vocal	equal
29	Constrained	When the teacher told the class to quiet down, no one would dare **utter** a word at all.	speak	vocal	equal
30	Neutral	The weatherman predicted that a dangerous **tornado** might hit the town this week.	twister	cyclone	booster
30	Constrained	In the Wizard of Oz, Dorothy and Toto were swept up by a huge **tornado** and flew away.	twister	cyclone	booster
31	Neutral	After a while Kim noticed a weird **scent** coming from the trash can.	smell	noses	vault
31	Constrained	Dogs are known for their excellent noses, able to detect a faint **scent** from far away.	smell	noses	vault
32	Neutral	After dinner Wendy always **rinsed** the dishes before putting them in the dishwasher.	washed	soaked	socket
32	Constrained	When she washed her hands, she scrubbed and then **rinsed** them before drying them.	washed	soaked	socket
33	Neutral	After the party the couch felt **grimy** from all the guests sitting on it.	dirty	filth	lucky
33	Constrained	After rolling around in the yard, the dog was very **grimy** and needed a bath.	dirty	filth	lucky
34	Neutral	After witnessing the theft, many **guards** chased the thief.	police	cadets	palace
34	Constrained	Famous people need security and hire **guards** to protect them at events.	police	cadets	palace
35	Neutral	Although having a car may seem **essential** there are many other ways to commute.	necessary	requisite	remaining
35	Constrained	To go to the Olympics, my trainer says it is absolutely **essential** to run each day.	necessary	requisite	remaining
36	Neutral	Although the apartments decor was very **drab** the owners felt it suited their needs.	dull	grey	hulk
36	Constrained	Lois likes bright colors and thinks her grandma's sofa is too **drab** for her new home.	dull	grey	hulk
37	Neutral	Andrew enjoyed the interesting **tome** he borrowed from the library.	book	read	fact
37	Constrained	In the old library, the shelves were full except for one missing **tome** that was lost.	book	read	fact
38	Neutral	Boris needed a loyal **sponsor** to begin his campaign trail.	support	advisor	suggest
38	Constrained	If an athlete is popular, companies will want to financially **sponsor** or promote them.	support	advisor	suggest
39	Neutral	Brad thought his project idea was incredibly **ingenious** and wanted to tell everyone.	brilliant	inventive	fortified
39	Constrained	Dan doubted Ian's smarts, but his idea was quite **ingenious** and solved many problems.	brilliant	inventive	fortified
40	Neutral	Callie and her coworker must **evade** the office because their boss is mad at them.	avoid	greet	round
40	Constrained	The police never caught the wanted murderer because he could **evade** them very well.	avoid	greet	round

	Type	Sentence	Synonym	Semantic	Unrelated
41	Neutral	Carla had a pleasant **chat** with her friend at the salon.	talk	rant	half
41	Constrained	When Jim is homesick he goes on Skype to personally **chat** with his parents.	talk	rant	half
42	Neutral	Carter is always **bothering** Lisa in class when she tries to take notes.	harassing	involving	burrowing
42	Constrained	Many kids were scared of the bully who was constantly **bothering** them for lunch money.	harassing	involving	burrowing
43	Neutral	Children are often very **obdurate** when it comes to cleaning up.	stubborn	outburst	stitches
43	Constrained	Most men refuse to ask for help because they are really **obdurate** and too proud.	stubborn	outburst	stitches
44	Neutral	Chris is always told that he should **relax** after playing a soccer game.	sleep	chill	cheap
44	Constrained	After a long week, most people are exhausted and should **relax** all weekend long.	sleep	chill	cheap
45	Neutral	Dan needed to have his **molar** replaced after many years of eating candy.	tooth	crown	tenth
45	Constrained	The dentist recommended that I have the cavity in my back **molar** removed very soon.	tooth	crown	tenth
46	Neutral	Dave admired his well kept **turf** while driving home.	lawn	yard	lava
46	Constrained	The gardeners were known to maintain a trimmed grass **turf** for a low monthly price.	lawn	yard	lava
47	Neutral	Dave wore his favorite **hat** to the baseball game.	cap	bag	cry
47	Constrained	Frank always wore his lucky baseball **hat** to the game.	cap	bag	cry
48	Neutral	Elizabeth goes to the store **nearly** every weekend to buy groceries.	almost	always	street
48	Constrained	Kate was relieved her car wasn't hit, but yelled because Tom **nearly** scraped it.	almost	always	street
49	Neutral	Every year the children **wish** for new toys.	hope	pray	days
49	Constrained	Blowing on her birthday candles, Gail didn't tell anyone her **wish** so it will come true.	hope	pray	days
50	Neutral	Felix likes to wear clean **boots** to his line dancing party.	shoes	socks	chess
50	Constrained	Jill had a big closet to store her many pairs of high heeled **boots** and matching bags.	shoes	socks	chess
51	Neutral	Fred and Will ordered nine **super** burritos after the little league game.	great	ample	point
51	Constrained	Teachers encourage students, saying their work is really **super** and giving them stars.	great	ample	point
52	Neutral	Gary thought if he put on a costume he could **excite** the children in the class.	thrill	arouse	thrift
52	Constrained	Jan's life is dull so she went on a rollercoaster hoping it would **excite** her a bit.	thrill	arouse	thrift
53	Neutral	George was afraid of a possibly **lethal** bite while handling the snake at the zoo.	deadly	mortal	kindly
53	Constrained	Snake bite victims should go to the ER because venom can be very **lethal** if not treated.	deadly	mortal	kindly
54	Neutral	Her perfume was very **aromatic** and caught the attention of many men.	fragrant	distinct	linguist
54	Constrained	The perfume salesman described the scent as very **aromatic** and great for any occasion.	fragrant	distinct	linguist
55	Neutral	His father is a proud **physics** teacher in my school district.	science	biology	various

	Type	Sentence	Synonym	Semantic	Unrelated
55	Constrained	Isaac Newton contributed much to the study of general **physics** in his lifetime.	science	biology	various
56	Neutral	Howard was extremely **envious** of my new game boy.	jealous	zealous	gardens
56	Constrained	After seeing his brother's new toy, Scott became very **envious** and tried to steal it.	jealous	zealous	gardens
57	Neutral	I always stay at the same **cabin** in Tahoe for vacation.	house	shack	known
57	Constrained	Because Henry loves the woods, he built a rustic **cabin** there so he could go often.	house	shack	known
58	Neutral	I got a really cool **gadget** for my seventeenth birthday.	device	iphone	drives
58	Constrained	Trevor reads technology magazines to learn about the newest **gadget** of the year.	device	iphone	drives
59	Neutral	I have always wanted to attend **academy** meetings down the hall.	society	seminar	variety
59	Constrained	To attend the conference, you must be a member of the elite **academy** for social science.	society	seminar	variety
60	Neutral	I noticed that there was a small stone **spire** on top of the tower.	tower	point	horse
60	Constrained	At the church, there is a bell hanging in the tallest **spire** that rings on Sundays.	tower	point	horse
61	Neutral	I received a very important **prize** for my hard work at the company.	award	stars	weird
61	Constrained	At the dog show, Spot had the most points and won the coveted **prize** for best in show.	award	stars	weird
62	Neutral	I wrote down the incorrect **avenue** and got lost on my way to the restaurant.	street	suburb	client
62	Constrained	Janet lives on fifth **avenue** by the fire department.	street	suburb	client
63	Neutral	In ancient times, the pharaoh needed **warriors** to defend his kingdom.	soldiers	strength	millions
63	Constrained	To keep the city safe, the pharaoh had many **warriors** that he paid very little.	soldiers	strength	millions
64	Neutral	In kindergarten the kids would loudly **notify** the teacher when someone cut in line.	inform	update	actors
64	Constrained	As soon as the employees identify a problem they must **notify** the manager immediately.	inform	update	actors
65	Neutral	In the morning Jessica **tallied** up all of the sales from last weekend.	counted	rounded	existed
65	Constrained	To ensure the money was right, the cashier always **tallied** the money before going home.	counted	rounded	existed
66	Neutral	In the pond a frog **leaped** across a lily pad and landed on a log.	jumped	hopped	gospel
66	Constrained	Jimmy tried to catch the evasive frog that **leaped** from the pond at the park.	jumped	hopped	gospel
67	Neutral	It appeared that the symphony **lacked** the true emotion the guests were expecting.	missed	showed	animal
67	Constrained	At the interview, Lisa used her charm to make up for what she **lacked** in experience.	missed	showed	animal
68	Neutral	Jack saw more **unusual** sightings in the woods last week.	strange	startle	storage
68	Constrained	On patrol, security watched for behavior that was extremely **unusual** but didn't see any.	strange	startle	storage
69	Neutral	James agreed to meet in the front **foyer** of the hotel before dinner.	lobby	doors	fifty

|	Type	Sentence	Synonym	Semantic	Unrelated
69	Constrained	The group suggested meeting in the hotel **foyer** before the tour began.	lobby	doors	fifty
70	Neutral	Jen thought it was a terrible **omen** that she had a nightmare before the exam.	sign	mark	nope
70	Constrained	Most people think a black cat crossing the street is a bad **omen** and try to avoid it.	sign	mark	nope
71	Neutral	Jill goes for a long **jog** in the morning.	run	leg	own
71	Constrained	To train for the marathon, Rachel must **jog** a few miles every day.	run	leg	own
72	Neutral	Joel made a rapid **halt** when the light turned red.	stop	skid	ship
72	Constrained	To avoid accidents at crosswalks, drivers must **halt** and wait for pedestrians.	stop	skid	ship
73	Neutral	Julie watched the birds **flock** together in the sky.	group	bunch	going
73	Constrained	When migrating, birds fly together in an organized **flock** to stay together.	group	bunch	going
74	Neutral	Kenny told his longtime **rival** to meet him outside for a fight after school.	enemy	fists	array
74	Constrained	In superhero movies, the heroes always defeat their **rival** and save the world.	enemy	fists	array
75	Neutral	Last night my dreams were very **lucid** so I wrote about them in my journal.	clear	stark	class
75	Constrained	James could see the lake bottom because the water was very **lucid** and calm that day.	clear	stark	class
76	Neutral	Last week, Alexander **totaled** his car on his way to school.	wrecked	skidded	awaited
76	Constrained	Because Tom is a careless driver, his car was completely **totaled** in an accident.	wrecked	skidded	awaited
77	Neutral	Laura had strong **ache** in her tooth after eating too much candy.	pain	ouch	join
77	Constrained	The dentist told Jim that cavities are causing his tooth **ache** and he should floss.	pain	ouch	join
78	Neutral	Many people are extremely **committed** to recycling their waste.	dedicated	betrothed	liberated
78	Constrained	For a marriage to last, the couple must be extremely **committed** to each other.	dedicated	betrothed	liberated
79	Neutral	The committee said the plan should be approved **contrary** to the president's advice.	opposite	rejected	appendix
79	Constrained	Columbus' time thought the world was flat but actually the complete **contrary** is true.	opposite	rejected	appendix
80	Neutral	My neighbor made a majestic **portrait** of my family as a Christmas present.	painting	panorama	pounding
80	Constrained	The vain woman hired an artist to draw her and hung the large **portrait** in her room.	painting	panorama	pounding
81	Neutral	My neighbor took out his vintage **Satan** costume for Halloween.	devil	demon	trend
81	Constrained	Christians believe in the goodness of God and evil of the wicked **Satan** as a fact.	devil	demon	trend
82	Neutral	My old nanny made me a bracelet with **string** for my fifth birthday.	thread	strand	threat
82	Constrained	When she saw it hanging from her sweater, she pulled the loose **string** off right away.	thread	strand	threat

	Type	Sentence	Synonym	Semantic	Unrelated
83	Neutral	Nadine goes to the gym because she wants to look **lean** in a swimsuit at the beach.	thin	slim	kiss
83	Constrained	The fitness model must go to the gym and eat well to keep her body **lean** for her job.	thin	slim	kiss
84	Neutral	Next week, we must **propose** a new financial plan to the executive board.	suggest	present	support
84	Constrained	The scientist needs approval for a study but is scared to publicly **propose** it to others.	suggest	present	support
85	Neutral	Peter was asked to point out on the large **globe** where Antarctica was.	world	earth	small
85	Constrained	Joey wants to travel around the whole **globe** and see many beautiful places.	world	earth	small
86	Neutral	Rain makes it difficult to properly **steer** the vehicle safely.	drive	wheel	times
86	Constrained	For my license test, I had to prove that I could properly **steer** a car and remain safe.	drive	wheel	times
87	Neutral	Rita had a very strong **feeling** about the political candidates.	opinion	thought	species
87	Constrained	To avoid offending others please do not share your **feeling** about the new president.	opinion	thought	species
88	Neutral	Sally forgot the specific **tune** she would always sing in the shower.	song	note	warp
88	Constrained	When I get bored I like to hum my favorite **tune** to pass the time.	song	note	warp
89	Neutral	Samantha was very **prudent** about not making a mistake in her drawing.	careful	precise	invited
89	Constrained	To avoid making mistakes, students must be very **prudent** and double check their tests.	careful	precise	invited
90	Neutral	Sheldon could not hear their **answers** over the loud music.	replies	opinion	replace
90	Constrained	In class, Sally raises her hand before she immediately **answers** so others can try first.	replies	opinion	replace
91	Neutral	Some animals eat from very **tall** trees in the zoo.	high	long	kept
91	Constrained	Skyscrapers are known to be very **tall** buildings in the city.	high	long	kept
92	Neutral	Some people think a heavy **brick** could break a window.	stone	block	clean
92	Constrained	Ivy League campuses are famous for pretty buildings made of solid **brick** and large quads.	stone	block	clean
93	Neutral	Some people thought the parrot was **mute** but it just did not want to talk.	dumb	talk	loud
93	Constrained	The child didn't speak so his mom thought he was born **mute** and took him to a doctor.	dumb	talk	loud
94	Neutral	Some students cannot **comprehend** the topics covered in lecture.	understand	assimilate	individual
94	Constrained	Diplomats at the UN use interpreters to help them **comprehend** what others are saying.	understand	assimilate	individual
95	Neutral	Steph noticed a torn **bill** in her wallet and looked for the other half.	note	card	side
95	Constrained	Kelly's mother gave her a twenty dollar **bill** to buy lunch at school.	note	card	side
96	Neutral	The chemist did not realize the reaction could **arise** without a spark.	occur	start	seven
96	Constrained	Being prepared helps people deal with any situation that could **arise** without notice.	occur	start	seven

|	Type	Sentence	Synonym	Semantic	Unrelated
97	Neutral	The church received a beautiful **piano** from an anonymous donor.	organ	flute	argue
97	Constrained	At the recital, the black and white keys of the large **piano** were jammed and sounded bad.	organ	flute	argue
98	Neutral	The class complained about the long **exam** to the professor.	test	quiz	kind
98	Constrained	After studying all night, Erin felt ready for her math **exam** and very confident.	test	quiz	kind
99	Neutral	The community thought of Amy with the highest **esteem** after her work at the shelter.	regard	praise	expand
99	Constrained	The professor got an award because everyone held him in high **esteem** and respected him.	regard	praise	expand
100	Neutral	The company did not realize the harsh **impact** their products had on the environment.	effect	result	attack
100	Constrained	The tragic event left a lasting **impact** on the entire community.	effect	result	attack
101	Neutral	The crowd could only see the very **rear** of the stage from the discounted seats.	back	side	find
101	Constrained	Jack tailgated the car in front of him and accidently bumped the very **rear** of the car.	back	side	find
102	Neutral	The decorator loved the detailed **lip** of the new vase.	rim	top	zoo
102	Constrained	To make music with a wine glass, run a wet finger along the glass' **lip** in a circle.	rim	top	zoo
103	Neutral	The dog would always **sniff** the grass in front of the house.	smell	whiff	vault
103	Constrained	Liz is a picky eater and uses her nose to cautiously **sniff** the food before eating.	smell	whiff	vault
104	Neutral	The losing team's **rebuttal** was so legendary that it went viral on YouTube.	response	reaction	congress
104	Constrained	To defend the case, the opposing counsel gave a convincing **rebuttal** to the argument.	response	reaction	congress
105	Neutral	The loving couple looked at the peaceful **shore** while on vacation.	beach	ocean	trust
105	Constrained	People go to Hawaii to walk along the sandy **shore** and enjoy the view.	beach	ocean	trust
106	Neutral	The noise caused Tim to suddenly **fall** to his knees and cover his ears.	drop	down	king
106	Constrained	On New Year's Eve in New York, waiting for the ball to slowly **fall** is very popular.	drop	down	king
107	Neutral	The notorious gang **defaced** the statue in front of city hall.	damaged	wrecked	foreign
107	Constrained	After graffitiing town hall, kids got in trouble because they **defaced** public property.	damaged	wrecked	foreign
108	Neutral	The police were **alert** on patrol when they got a call from dispatch.	ready	vigil	early
108	Constrained	On a stakeout, the policeman drank coffee to stay **alert** for any suspicious acts.	ready	vigil	early
109	Neutral	The response Tom received was not a very **fair** representation of his effort.	just	good	post
109	Constrained	Judges must give out punishments that are undoubtably **fair** for the crime committed.	just	good	post
110	Neutral	The road signs inform drivers when **hazardous** terrain is approaching.	dangerous	turbulent	diagnosis

	Type	Sentence	Synonym	Semantic	Unrelated
110	Constrained	Driving in the rain is known to be very **hazardous** and people should be more careful.	dangerous	turbulent	diagnosis
111	Neutral	The salesman said the car would hold its original **worth** for many years.	value	price	sites
111	Constrained	When pawning goods you must estimate the correct **worth** of many items.	value	price	sites
112	Neutral	The sisters could not **name** all their favorite movies because there were too many.	list	cite	best
112	Constrained	After studying state capitals, the teacher had the students quickly **name** all of them.	list	cite	best
113	Neutral	The soccer ball hit the shelf and made the vase **smash** into many pieces.	break	clean	heart
113	Constrained	If the glass vase fell off the shelf it would likely **smash** into many pieces.	break	clean	heart
114	Neutral	The student was very **astute** because she answered the tricky question.	clever	brains	cheese
114	Constrained	The mouse escaped the trap many times and is clearly very **astute** and quick.	clever	brains	cheese
115	Neutral	The students must **save** all their homework until the quarter is over.	keep	mass	long
115	Constrained	Lea collects cards and has a box where she will carefully **save** them away from harm.	keep	mass	long
116	Neutral	The surgeon promised an extremely **rapid** to start bubbling.	quick	brisk	giant
116	Constrained	Make an appointment at the DMV to make your visit more **rapid** than it would have been.	quick	brisk	giant
117	Neutral	The teacher always posted a relevant **topic** to start a discussion.	issue	theme	music
117	Constrained	The research paper's main **topic** was on the evolution of humans.	issue	theme	music
118	Neutral	The teacher thought most of the reports were too **brief** and needed more content	short	empty	stand
118	Constrained	To save time, the meeting was very **brief** and started on time.	short	empty	stand
119	Neutral	The teacher tried to plan **artful** activities for the children.	crafty	pretty	verily
119	Constrained	The beginner scrapbook class is for people who are not very **artful** and need help.	crafty	pretty	verily
120	Neutral	The team captain tried to establish **concord** between the rivals.	harmony	rapport	forming
120	Constrained	To end the war, the general proposed a new plan to promote **concord** among many groups.	harmony	rapport	forming
121	Neutral	The well trained **scout** led the group along the cliff.	guide	guard	quote
121	Constrained	When hiking in a new area, you should ask a knowledgeable **scout** for the best trail.	guide	guard	quote
122	Neutral	Tommy decided he would **fling** the stone into the pond later that day.	throw	chuck	floor
122	Constrained	To play fetch with dogs, just take the ball and then **fling** it far away.	throw	chuck	floor
123	Neutral	Will keeps a large **knife** in his backpack to protect himself.	blade	rifle	flute
123	Constrained	To cut the loaf of bread, the chef used a serrated **knife** with great expertise.	blade	rifle	flute

Highlights

- The boundary paradigm was used to assess preview benefit with stimuli from Schotter (2013).

- Previews/targets were embedded into constrained sentences (Schotter, 2013 used neutral).

- Semantic associates showed early preview benefit and late cost in constrained sentences.

- Within-subject experiment replicated effects for both neutral and constrained sentences.

- Results compatible with E-Z Reader assumption of early oculomotor "hedged bet".
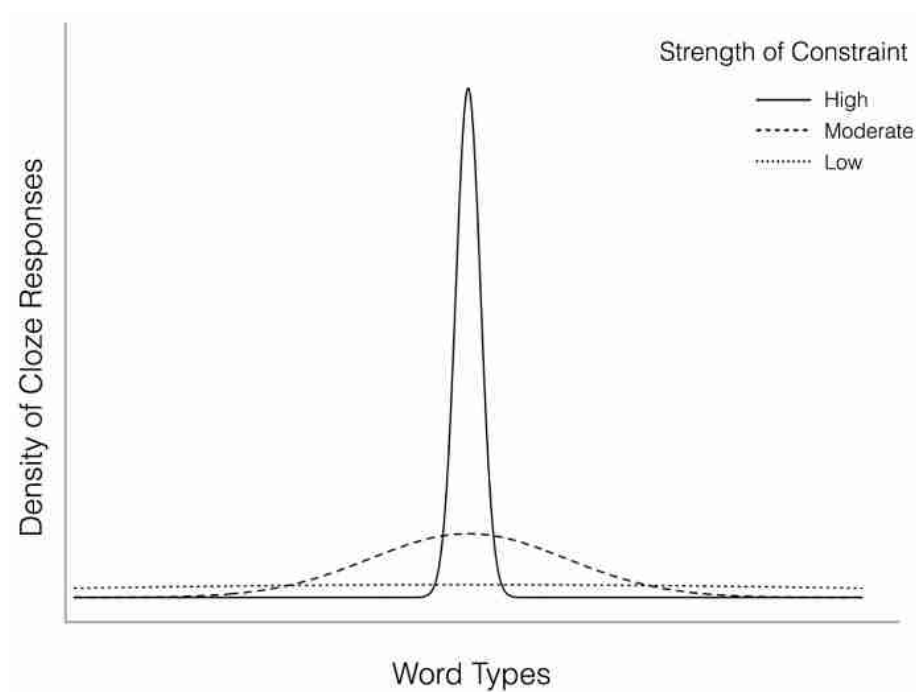
Figure 1.
Hypothetical density distributions of words provided in the cloze task as a function of sentence constraint.
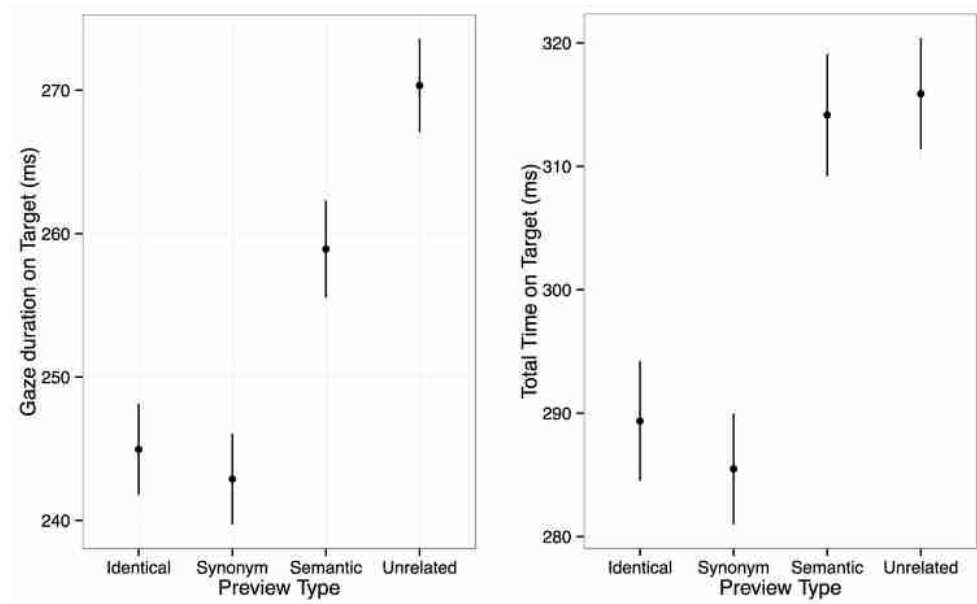
Figure 2.
Means and standard errors for gaze duration (left panel) and total time (right panel) on the target across the four preview conditions in Experiment 1. Note that the scale of the y-axis is different for the two measures.
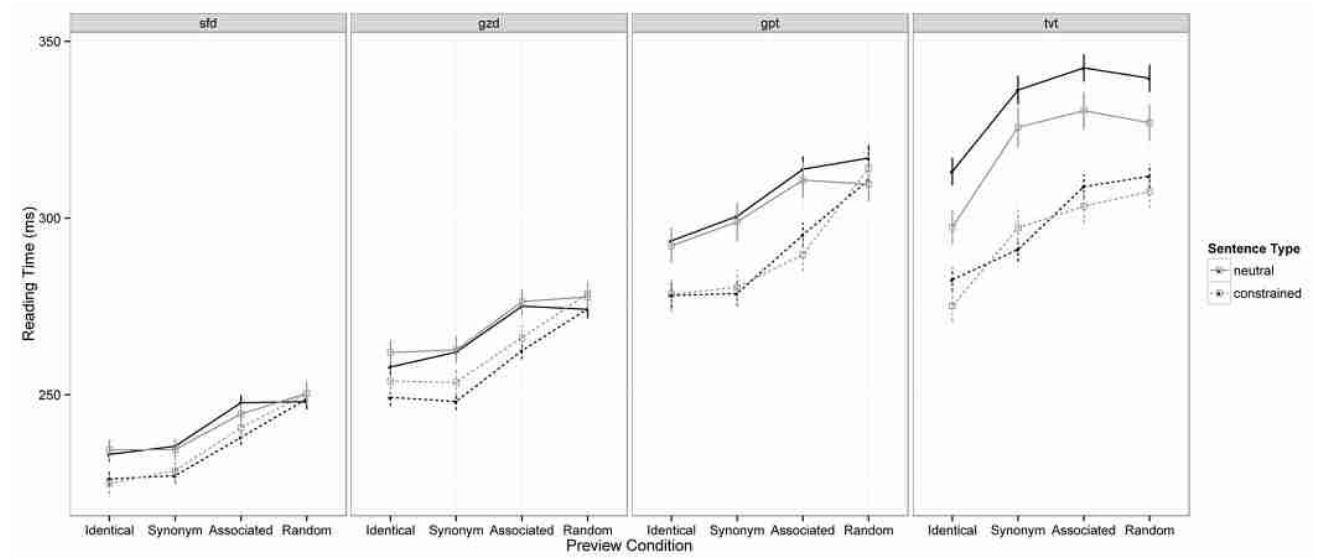
Figure 3.
Reading time on the target word as a function of preview condition and sentence type, across 4 reading time measures (sfd = single fixation duration, gzd = gaze duration, gpt = go-past time, tvt = total time). Solid lines represent the neutral sentence condition and dashed lines represent the constrained sentence condition. Grey lines with open squares represent the data from Experiment 2 only, black lines with closed circles represent that data combined across three experiments (Schotter (2013) Experiment 2; current study: Experiments 1 & 2).

Table 1

Lexical characteristics of and normative data for target and preview words used in the experiments. Standard errors are in parentheses.

Variable	Target Identical	Preview Condition		
		Synonym	Semantic	Unrelated
Length	5.61 (1.46)	5.61 (1.46)	5.61 (1.46)	5.61 (1.46)
Log Frequency (HAL)	8.31 (1.86)	10.26 (1.46)	8.99 (2.11)	10.04 (1.53)
Total Letters Shared with Target	--	.72 (.09)	.81 (.10)	.55 (.07)
Initial Letters Shared with Target	--	.09 (.03)	.15 (.05)	.09 (.03)
Cloze p in Neutral Contexts	.02 (.05)	.05 (.12)	.00 (.02)	.00 (.01)
Cloze p in Constrained Contexts	.21 (.02)	.25 (.03)	.00 (.00)	.00 (.00)
Preview-Target Relatedness (1–9 scale)	--	7.5 (.97)	5.6 (1.5)	2.4 (.97)

Table 2

Means and standard errors (aggregated by subjects) for reading measures on the target across condition.

Measure	Preview			
	Identical	**Synonym**	**Semantic**	**Unrelated**
Fixation Duration Measures				
First Fixation Duration	223 (4.7)	222 (4.5)	228 (4.9)	239 (4.9)
Single Fixation Duration	229 (5.9)	226 (4.7)	235 (6.1)	248 (5.7)
Gaze Duration	244 (6.5)	242 (5.5)	257 (6.3)	271 (6.3)
Go Past Time	277 (9.0)	277 (8.7)	300 (7.7)	308 (8.3)
Total Viewing Time	289 (9.1)	285 (8.9)	313 (9.6)	317 (7.5)
Fixation Probability Measures				
Fixation Probability	.77 (.02)	.75 (.02)	.77 (.03)	.82 (.02)
Regressions out of the Target	.08 (.01)	.09 (.01)	.11 (.01)	.11 (.02)
Regressions into the Target	.17 (.02)	.22 (.02)	.23 (.02)	.20 (.02)

Table 3

Results of the linear mixed effects models for reading time measures on the target across condition. Preview benefit refers to the difference in processing between the unrelated condition and either the identical, synonym, or semantically related, separately. Significant effects are indicated by boldface.

Measure	Preview Benefit Comparison	b	SE	|t|
First Fixation Duration				
	Intercept	**239.17**	**5.06**	**47.27**
	Identical	**−16.98**	**3.83**	**4.44**
	Synonym	**−17.55**	**4.59**	**3.82**
	Semantic	**−10.95**	**3.92**	**2.79**
Single Fixation Duration				
	Intercept	**248.71**	**5.84**	**42.57**
	Identical	**−20.87**	**4.22**	**4.94**
	Synonym	**−22.64**	**5.25**	**4.31**
	Semantic	**−13.27**	**4.15**	**3.20**
Gaze Duration				
	Intercept	**270.67**	**6.38**	**42.42**
	Identical	**−27.85**	**5.52**	**5.05**
	Synonym	**−29.73**	**5.34**	**5.57**
	Semantic	**−13.80**	**5.14**	**2.69**
Go-Past Time				
	Intercept	**309.11**	**8.56**	**36.13**
	Identical	**−32.31**	**7.08**	**4.57**
	Synonym	**−34.14**	**6.78**	**5.04**
	Semantic	−8.92	6.70	1.33
Total Time				
	Intercept	**317.84**	**8.58**	**37.05**
	Identical	**−31.04**	**7.90**	**3.93**
	Synonym	**−33.67**	**6.94**	**4.85**
	Semantic	−5.12	7.21	0.71

Table 4

Results of the logistic regression model for fixation probability measures on the target across condition. Preview benefit refers to the difference in processing between the unrelated condition and either the identical, synonym or semantically related, separately. Significant effects are indicated by boldface.

Measure	Comparison	b	|z|	p
Fixation Probability				
	Intercept	**1.80**	**10.11**	**< .001**
	Identical	**−0.29**	**1.96**	**.05**
	Synonym	**−0.49**	**3.50**	**< .001**
	Semantic	−0.17	1.06	.29
Regressions out of the Target				
	Intercept	**−2.41**	**13.23**	**< .001**
	Identical	−.31	1.58	.11
	Synonym	−.38	1.73	.08
	Semantic	.16	0.93	.35
Regressions into the Target				
	Intercept	**−1.61**	**11.56**	**< .001**
	Identical	**−.38**	**2.44**	**< .05**
	Synonym	.16	1.27	.20
	Semantic	.22	1.69	.09

Table 5

Means and standard errors (aggregated by subjects) for reading measures on the target across condition in Experiment 2.

Measure	Neutral				Constrained			
	Identical	Synonym	Semantic	Unrelated	Identical	Synonym	Semantic	Unrelated
Fixation Duration Measures								
First Fixation Duration	228 (4.1)	230 (4.3)	238 (4.2)	242 (4.7)	223 (3.5)	222 (3.9)	232 (4.4)	241 (4.5)
Single Fixation Duration	235 (4.5)	235 (4.5)	247 (5.1)	251 (5.9)	225 (4.0)	226 (4.4)	239 (5.2)	252 (5.5)
Gaze Duration	262 (5.5)	260 (6.1)	276 (6.6)	276 (6.3)	252 (5.0)	249 (5.6)	263 (5.6)	276 (5.9)
Go Past Time	293 (7.3)	295 (8.2)	310 (9.3)	309 (8.1)	276 (6.9)	277 (7.6)	287 (7.0)	311 (8.2)
Total Viewing Time	296 (7.2)	323 (9.7)	331 (11)	326 (8.8)	272 (6.2)	293 (7.4)	300 (7.4)	306 (7.3)
Fixation Probability Measures								
Fixation Probability	.89 (.01)	.86 (.02)	.89 (.01)	.89 (.01)	.79 (.02)	.80 (.02)	.81 (.02)	.83 (.02)
Regressions out of the Target	.09 (.01)	.09 (.01)	.09 (.01)	.11 (.01)	.07 (.01)	.08 (.01)	.08 (.01)	.11 (.01)
Regressions into the Target	.11 (.01)	.20 (.02)	.19 (.02)	.17 (.01)	.12 (.01)	.16 (.02)	.17 (.02)	.16 (.01)

Table 6

Results of the linear mixed effects models for reading time measures on the target for neutral and constrained sentences in Experiment 2. Preview benefit refers to the difference in processing between the unrelated condition and either the identical, synonym, or semantically related, separately. Significant effects are indicated by boldface.

Measure	Comparison	Neutral			Constrained		
		b	**SE**	**|t|**	**b**	**SE**	**|t|**
First Fixation Duration							
	Intercept	**242.46**	**4.79**	**50.58**	**240.96**	**4.58**	**52.63**
	Identical	**−15.15**	**3.56**	**−4.26**	**−18.77**	**4.07**	**−4.61**
	Synonym	**−13.15**	**3.96**	**−3.32**	**−17.73**	**4.40**	**−4.03**
	Semantic	−4.16	3.41	−1.22	**−8.29**	**3.80**	**−2.18**
Single Fixation Duration							
	Intercept	**251.63**	**5.84**	**43.08**	**251.19**	**5.50**	**45.66**
	Identical	**−16.96**	**4.23**	**−4.01**	**−25.34**	**4.67**	**−5.42**
	Synonym	**−17.04**	**4.36**	**−3.91**	**−22.74**	**5.45**	**−4.17**
	Semantic	−5.32	4.21	−1.26	**−11.67**	**4.63**	**−2.52**
Gaze Duration							
	Intercept	**276.30**	**6.98**	**39.61**	**275.87**	**5.92**	**46.63**
	Identical	**−15.36**	**6.56**	**−2.34**	**−26.15**	**5.66**	**−4.62**
	Synonym	**−15.97**	**6.03**	**−2.65**	**−26.17**	**5.21**	**−5.02**
	Semantic	−1.07	5.81	−.18	**−13.23**	**4.70**	**−2.81**
Go-Past Time							
	Intercept	**309.05**	**8.65**	**35.74**	**310.63**	**8.74**	**35.54**
	Identical	**−18.63**	**6.91**	**−2.70**	**−35.13**	**7.18**	**−4.90**
	Synonym	−12.36	6.72	−1.84	**−34.02**	**7.23**	**−4.70**
	Semantic	.43	6.63	.06	**−23.83**	**7.08**	**−3.37**
Total Time							
	Intercept	**328.18**	**9.79**	**33.51**	**305.10**	**8.10**	**37.65**
	Identical	**−31.84**	**6.34**	**−5.03**	**−32.48**	**6.79**	**−4.78**
	Synonym	−2.69	6.34	−.42	−12.09	6.53	−1.85
	Semantic	2.64	6.24	.42	−4.76	6.05	−0.79

Table 7

Results of the logistic regression model for fixation probability measures on the target across condition in Experiment 2. Preview benefit refers to the difference in processing between the unrelated condition and either the identical, synonym or semantically related, separately. Significant effects are indicated by boldface.

Measure	Comparison	Neutral			Constrained		
		b	|z|	p	b	|z|	p
Fixation Probability							
	Intercept	**2.85**	**13.33**	**<.001**	**2.15**	**10.30**	**<.001**
	Identical	−.08	−.39	0.70	−.32	−1.74	.08
	Synonym	**−.47**	**−2.29**	**<.05**	−.26	−1.38	.17
	Semantic	−.11	−.56	.58	−.13	−.67	.50
Regressions out of the Target							
	Intercept	**−2.55**	**13.06**	**<.001**	**−2.47**	**14.24**	**<.001**
	Identical	−.10	−.42	.67	**−.52**	**−2.17**	**<.05**
	Synonym	−.11	−.45	.65	**−.46**	**−2.15**	**<.05**
	Semantic	−.21	−.86	.39	**−.42**	**−1.98**	**<.05**
Regressions into the Target							
	Intercept	**−1.92**	**12.87**	**<.001**	**−1.75**	**15.78**	**<.001**
	Identical	**−.58**	**−2.98**	**<.005**	**−.81**	**−3.62**	**<.001**
	Synonym	**.33**	**2.14**	**<.05**	−.17	−1.04	.30
	Semantic	.27	1.62	.10	−.07	−.47	.64

Table 8

Results of the linear mixed effects models for reading time measures on the target across conditions in Experiment 2 (left columns) and three combined experiments (right columns). The first four rows in each section represent the intercept (unrelated condition) and preview benefit comparisons averaged across sentence condition. The last four rows represent tests for the effect of sentence constraint on the unrelated condition and the interaction between the preview manipulations and sentence constraint. Significant effects are indicated by boldface.

Measure	Comparison	Experiment 2 data only			Combined Experiments		
		b	SE	|t|	b	SE	|t|
Single Fixation Duration							
	Intercept	**251.19**	**5.09**	**49.35**	**249.46**	**3.40**	**73.48**
	Identical	**−20.66**	**3.48**	**5.93**	**−19.19**	**2.42**	**7.94**
	Synonym	**−20.33**	**3.54**	**5.74**	**−18.25**	**2.44**	**7.46**
	Semantic	**−8.20**	**3.27**	**2.51**	**−6.32**	**2.18**	**2.90**
	Constraint * Unrelated	−0.20	4.24	0.05	1.49	3.49	0.43
	Constraint * Identical PB	−9.24	5.42	1.70	**−7.74**	**3.87**	**2.00**
	Constraint * Synonym PB	−6.67	5.44	1.23	**−9.96**	**3.98**	**2.50**
	Constraint * Semantic PB	−6.59	5.44	1.21	**−11.76**	**3.90**	**3.02**
Gaze Duration							
	Intercept	**275.37**	**5.77**	**47.73**	**272.31**	**4.00**	**68.16**
	Identical	**−19.96**	**4.41**	**4.53**	**−21.37**	**3.11**	**6.87**
	Synonym	**−20.94**	**4.13**	**5.07**	**−20.40**	**2.74**	**7.45**
	Semantic	−7.24	3.90	1.86	**−6.19**	**2.64**	**2.35**
	Constraint * Unrelated	−1.10	4.67	0.24	0.57	3.88	0.15
	Constraint * Identical PB	−9.18	6.46	1.42	**−9.99**	**4.75**	**2.10**
	Constraint * Synonym PB	−11.05	6.49	1.70	**−15.29**	**4.66**	**3.28**
	Constraint * Semantic PB	−12.44	6.43	1.93	**−14.27**	**4.55**	**3.14**
Go-Past Time							
	Intercept	**309.30**	**7.48**	**41.37**	**312.87**	**5.43**	**57.58**
	Identical	**−26.44**	**5.33**	**4.97**	**−28.80**	**3.75**	**7.68**
	Synonym	**−23.23**	**4.75**	**4.89**	**−26.11**	**3.61**	**7.23**
	Semantic	**−12.46**	**5.14**	**2.42**	**−10.10**	**3.81**	**2.65**
	Constraint * Unrelated	1.14	6.91	0.16	−4.72	5.84	0.81

Measure	Comparison	Experiment 2 data only			Combined Experiments		
		b	SE	|t|	b	SE	|t|
	Constraint * Identical PB	−16.73	8.96	1.87	−10.47	6.65	1.57
	Constraint * Synonym PB	**−22.36**	**9.01**	**2.48**	**−17.48**	**6.46**	**2.71**
	Constraint * Semantic PB	**−25.76**	**8.94**	**2.88**	**−15.08**	**6.64**	**2.27**
Total Time							
	Intercept	**316.36**	**8.30**	**38.14**	**325.65**	**6.34**	**51.37**
	Identical	**−31.47**	**5.00**	**6.29**	**−30.29**	**4.09**	**7.40**
	Synonym	−7.53	5.21	1.45	**−14.29**	**3.62**	**3.95**
	Semantic	−1.77	4.72	0.37	−1.27	3.51	0.36
	Constraint * Unrelated	**−23.47**	**6.58**	**3.57**	**−21.45**	**5.94**	**3.61**
	Constraint * Identical PB	−0.27	8.76	0.03	−4.85	6.85	0.71
	Constraint * Synonym PB	−10.81	8.78	1.23	**−19.25**	**6.53**	**2.95**
	Constraint * Semantic PB	−8.75	6.65	1.01	−8.22	6.47	1.27