PREVIEW AND PRIMING: BRIDGING THE GAP BETWEEN BEAVIORAL AND NEURAL MEASURES OF READING

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ABSTRACT

Giulia Christine Pancani: Preview and Priming: Bridging the Gap between Behavioral and
Neural Measures of Reading
(Under the direction of Peter C. Gordon)

Behavioral and neural measures of reading offer divergent estimates of the time-course of

word recognition. The current work aims to reconcile Eye-Movement (EM) and Event-Related

Potential (ERP) measures with a series of experiments in which methodological differences are

reduced or eliminated.

Experiment 1 shows that Masked Repetition priming affects an early ERP component

(N250) which overlaps with the timeframe of EM effects, and a later component (N400). These

effects occur in both isolated word recognition and sentence reading tasks. Experiments 2-4

show that processing is delayed when semantically unrelated or physically deviant information is

present in the parafovea. The time-course of the effect of physically deviant previews shows

overlap between EMs and Fixation Related Potentials (FRPs), where it impacts the P300. In

contrast, Unrelated stimuli impact EMs incrementally as fixations grow longer, but they do not

impact the FRP until later, on the N400 component.

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Introduction

Over the past forty years, eye-movement (EM) research has shaped theories of reading by providing on-line measures of the processes that lead to comprehension. More recently, Event-Related Potentials (ERPs) have been used extensively to measure neural correlates of these same comprehension mechanisms and to gain a deeper understanding of how they unfold over time. However, findings from these two literatures do not always converge, and establishing a common ground has proven challenging due to differences in methodology. While participants in EM experiments typically read connected text and are free to move their eyes at their own reading rate, participants in ERP experiments are usually presented with one word at a time at a fixed presentation rate and asked not to move their eyes from a central fixation location. A consequence of these differences is that parafoveal preview, the ability to process words that are not currently being fixated, is available in EM studies but not in most ERP studies.

To this day, theories of reading and sentence processing fail to account for the discrepancies between these two sets of measures. The current work aims to provide some of the common ground necessary to reconcile EM and ERP. In doing so, it relates established EM and ERP measures obtained through canonical experimental paradigms to measures obtained by simultaneously recording EMs and ERPs in the same set of participants

The Time-course of Lexical Processing in Behavioral and Neural Measures

The divergence between EM and ERP findings is best documented for the time course of lexical access and processing. The EM literature has estimated that lexical access occurs within 100 and 150 ms after the onset of a fixation on a word (Rayner, 1998; Sereno, Rayner, & Posner, 1998). This estimation is based on the fact that fixations last on average 250 ms and that at least 60 ms are needed for the visual signal to travel from the retina to the higher cortices when the eyes first land on a word. In addition, before the eyes leave the word, approximately 150 ms are needed to program and launch a saccade. Lexical access is therefore bound to occur early even if one allows for the possibility that saccade programming begins while word recognition is still ongoing (Rayner, 1998; Sereno et al., 1998). In contrast, the ERP literature does not provide consistent evidence for lexical processing within this early timeframe and places lexical processing around 400 ms (Bornkessel & Schlesewsky, 2006; Kutas & Federmeier, 2000). While some ERP studies point to earlier effects, there is no consensus on their latency or their interpretation (Hauk, Davis, Ford, Pulvermüller, & Marslen-Wilson, 2006; Pulvermüller, Assadollahi, & Elbert, 2001; Rugg, 1983). Such discrepancies are particularly evident when both EMs and ERPs are recorded in separate experiments using the same language stimuli. In one such study (Ledoux, Gordon, Camblin, & Swaab, 2007a), supraliminally presented words were repeated within the context of a sentence (i.e. *At the office **Daniel** and Amanda moved the cabinet because **Daniel** needed room for the desk*) and EMs and ERPs were recorded in separate blocks. While EMs showed a repetition-priming facilitation on both early and later measures of processing, ERPs only showed facilitation on a later measure. More specifically, repetition attenuated the N400, a component that is associated with lexical integration and does not peak until 400 ms after the stimulus is presented. To some extent, the timing difference between the

two measures can be attributed to the mode of stimulus presentation; for the eye-tracking experiment sentences were presented normally with parafoveal preview available while in the ERP experiment sentences were presented one word at a time with a fixed presentation rate using RSVP. This is a standard method that is adopted to reduce electrical noise due to ocular artifacts in the EEG, but one that eliminates parafoveal preview.

Masked Priming studies can show early neural facilitation in the absence of parafoveal preview: here the repetition prime is masked and immediately precedes the target (Dufau, Grainger, & Holcomb, 2008; Grainger & Holcomb, 2009; Holcomb & Grainger, 2006; Kiyonaga, Grainger, Midgley, & Holcomb, 2007). The earliest effects of masked repetition priming in such experiments have been found to begin around 90 ms after stimulus presentation and to affect the N/P150, a component which is thought to reflect the prelexical mapping of visual features onto orthographic representations (Grainger & Holcomb, 2009). Shortly thereafter these foveal previews can attenuate the N250, a widely distributed component with a peak that occurs between 175 and 300 ms in frontal electrodes (Grainger, Kiyonaga, & Holcomb, 2006). The N250 is sensitive to both absolute and partial orthographic previews and has been interpreted as an index of processing at the interface between sublexical and lexical units, specifically reflecting a mismatch between the representations activated by the prime and those activated by the target. When the prime is a transposed-letter version of the target, the partial orthographic overlap results in greater N250 facilitation than when it is a letter substitution (i.e. 'barin–brain' vs 'bosin–brain') (Duñabeitia, Molinaro, Laka, Estévez, & Carreiras, 2009). However, if the transposed-letter preview is itself a word (i.e. 'causal–casual'), processing facilitation is no longer evident on the N250, suggesting that this component may reflect lexicosemantic as well as form level processes. While repetition effects on the early N/P150

depend on overlap on the retina between target and prime, effects on the N250 as well as the later N400 are resistant to small horizontal location shifts (Davis & Forster, 1994; Dufau et al., 2008) a finding that implies the integration of higher level previewed information in a way that is similar to parafoveal processing.

As mentioned above, this early facilitation surfaces in the isolated word recognition task where participants' attention is focused on the specific characteristics of the target word. It is unknown whether the N250 is affected by repetition during sentence reading, a task which requires attention to the semantic content of words and their relations to the sentential context. The presence of such early effects of repetition in sentence reading would narrow the temporal gap between neural and behavioral measures. It would further show that readers who are not in control of their reading rate can still extract and integrate preview information that is masked and presented foveally.

Preview and Priming

Proficient readers are able to move quickly through text and extract information efficiently by coordinating attentional, oculomotor and lexicosemantic processes. In order to begin lexical processing of a word within a sentence, a reader must first attend to it and begin processing its visual features. Most visual information is obtained from the fovea, the area of the retina with highest visual acuity which covers approximately 2° of the visual field, but some additional information is obtained from the parafovea, the surrounding area which has reduced retinal acuity (Rayner, 1998). In most cases, information that is extracted parafoveally from words to the right of fixation is integrated with foveal information once the words are fixated directly, thus accelerating processing (Balota, Pollatsek & Rayner, 1985). The benefit of this

parafoveal preview is shown by the increase in reading times when parafoveal information is masked, invalid or partial (Henderson & Ferreira, 1993; Inhoff, 1989; Schroyens, Vitu, Brysbaert, & d'Ydewalle, 1999). *Foveal previews* as those discussed above in *masked repetition priming* experiments offer analogous benefits. In this case, processing of a word is facilitated by a masked prime which is presented so briefly that it is not detected by the participant. The subsequent target word is facilitated when it is identical to the prime, suggesting that previewed information can be extracted within tens of milliseconds and used to "jump-start" processing of the next word (Forster & Davis, 1984; Grainger et al., 2006). While the first type of preview occurs during natural reading, the second is the principle method for studying neural processes, particularly ERPs (Grainger & Holcomb, 2009; Rugg & Nagy, 1989) but also functional Magnetic Resonance Imaging (fMRI) (Dehaene et al., 2001; Kouider & Dehaene, 2007; Naccache & Dehaene, 2001).

Parafoveal preview and masked repetition priming are functionally similar processes in that they rely on some type of briefly available preview to provide information about the upcoming text. Regardless of whether they tap into the same cognitive mechanisms, understanding how they relate is crucial to the interpretation of divergent findings in the EM and ERP literature.

Both types of preview can facilitate word recognition and lexical processing through the activation of representations of varying complexity, from orthographic to semantic. This information is then quickly processed despite sub-optimal circumstances of presentation: decreased retinal acuity in the parafovea results in perceptually impoverished parafoveal previews and short presentation duration followed by rapid masking make foveally previewed masked primes unavailable to conscious report (Eimer & Schlaghecken, 2002; McDonald, 2005)**.**

For both types of preview, facilitation does not depend fully on physical similarity between preview and target: previews facilitate targets that differ in size, case or font (Chauncey, Holcomb, & Grainger, 2008; Holcomb & Grainger, 2006; Rayner, McConkie, & Zola, 1980) and different levels of processing can be facilitated depending on the characteristics of the previewed information.

Though parafoveal processing occurs naturally during normal sentence reading, isolating its effects requires the use of *the boundary technique* (Rayner, 1975). This is a contingent-display paradigm in which sentences are presented on a screen and an invisible boundary is defined between a word (n) and the following (n+1). When the participants' eyes cross the invisible boundary they cause a display change that typically goes unnoticed due to a phenomenon known as saccadic suppression which prevents visual information from being recoded while the eyes are moving (A. Inhoff, Eiter, Radach, & Juhasz, 2003; Matin, 1974). $Word_{n+1}$ is masked or replaced by a different word until it is revealed by the display change, eliminating the possibility of true parafoveal processing. Reading times are shorter when full parafoveal preview is present compared to situations in which it is partial, invalid, degraded or absent (Gagl, Hawelka, Richlan, Schuster, & Hutzler, 2014; Henderson & Ferreira, 1993; A. W. Inhoff, 1989; Schroyens, Vitu, Brysbaert, & d'Ydewalle, 1999).

Masked repetition priming, on the other hand, occurs only in experimental tasks where stimuli are presented one at a time at the center of the screen and the prime is presented as a brief foveal preview preceding the target and is then immediately masked. The typical masked repetition priming task, isolated word recognition, requires participants to read words in isolation and to attend to their characteristics to perform a metalinguistic judgement, such as a lexical decision or a semantic categorization, after each target is presented. The priming benefit takes

the form of faster reaction times (RTs) in lexical-decision (Forster & Davis, 1984) and word-naming tasks (Ferrand, Grainger, & Segui, 1994) as well as reduced ERP components associated with the difficulty of recognizing a target in isolated word recognition (Dehaene et al., 2001; Grainger & Holcomb, 2009; Holcomb & Grainger, 2006) and shorter gaze durations on target words during sentence reading (Nakayama, Sears, & Lupker, 2010; Sereno & Rayner, 1992). These effects tend to be smaller and shorter-lived than their supraliminal counterparts (Forster & Davis, 1984; Holcomb, Reder, Misra, 2005) which have been found to occur even days after the initial presentation of a word (Scarborough, Cortese, & Scarborough, 1977; Jacoby, 1983).

The lack of preview awareness in both parafoveal processing and masked repetition priming does not imply that these processes occur without attention. On the contrary, findings that the foveal load mediates the parafoveal preview benefit (Henderson & Ferreira, 1990; White, Rayner, & Liversedge, 2005a) and that the size of the perceptual span is variable (Henderson, Pollatsek, & Rayner, 1989; A. W. Inhoff, 1989; Miellet, O'Donnell, & Sereno, 2009) indicate that parafoveal processing depends on covert attention being allocated to the right of fixation, though the mechanisms by which this occurs are the subject of debate (Engbert, Nuthmann, Richter, & Kliegl, 2005; Morrison, 1984; Reichle, Pollatsek, Fisher, & Rayner, 1998). In supraliminal priming, attention operates in two distinct ways depending on the stimulus onset asynchrony (SOA) between prime and target: with longer SOAs subjects can use information from the prime to actively predict the nature of the target whereas with shorter SOAs such top-down strategies are not employed (Posner & Snyder, 2004). Attention appears to play a similar role during masked priming though the topic has not been explored as extensively. When temporal attention is manipulated by varying the stimulus onset asynchrony (SOA) of the experimental trials so that participants cannot reliably predict the occurrence of target items,

priming is reduced or eliminated in number comparison and lexical decision tasks. This suggests that masked stimuli require some amplification by attention in order to be processed (Naccache, Blandin, & Dehaene, 2002; Smith, Besner, & Miyoshi, 1994). Accordingly, endogenous attention is a driver of parafoveal preview benefit and it is at least a component of the masked priming benefit. Because these two mechanisms operate in different domains of reading, further comparisons between them pose a challenge that demands a closer study of their effects under similar conditions. A deeper understanding of the similarities between parafoveal preview and masked priming can aid in the interpretation of discordant findings on the time-course of lexical processing from the behavioral and neural literature. The main goal of the current study is to reduce the differences between the methods used in the two literatures to obtain effects that can be related more easily. Four experiments are presented. In Experiment 1 we assess whether the neural effects of masked repetition priming extend from isolated word-recognition tasks to sentence reading during RSVP by comparing the two tasks with the same set of participants and stimuli. Experiment 2 replicates the parafoveal preview benefit effect in EMs using the contingent display paradigm and the same stimuli as Experiment 1. Experiment 3 explores the neural correlates of the parafoveal preview benefit employing a novel technique in which EMs and EEGs are synchronously recorded as participants read sentences with the contingent display paradigm. Finally, Experiment 4 identifies the neural equivalent of the parafoveal preview benefit by manipulating whether the preview was lexically or physically deviant from the target.

Experiment 1: Masked Repetition Priming in Words and Sentences

The first step in assessing whether previewed information is extracted and integrated similarly during parafoveal preview and masked repetition priming is to determine whether the effects of priming found in isolated word-recognition tasks can be replicated in a task that typically relies on parafoveal preview processing. This task is sentence reading. In Experiment 1 we do so by extending the masked priming technique used in isolated word recognition tasks to the RSVP mode that is traditionally used in ERP studies of sentence reading. We then compare its effects on targets embedded in word lists and in sentences. Previous studies have shown both early (N250) and later (N400) neural effects of masked repetition priming on isolated words presented in lists but only later (N400) effects when repetition occurred supraliminally within the context of a sentence despite early behavioral evidence that foveal previews were impacting processing at the earliest stages (Huang, Hopfinger, & Gordon, 2014; Ledoux et al., 2007a). The facilitation of featural word properties reflected by the N250 might be too short-lived or not survive the processing of intervening words, while lexical and semantic facilitation reflected in the N400 persists across the longer lags between words in sentences (Misra & Holcomb, 2003; Nagy & Rugg, 1989; Rugg & Nagy, 1989). Alternatively, participants may establish different perceptual sets to meet diverse task demands: this may result in reduced analysis of lower-level features during sentence reading, where the task focus is on a higher-level understanding of the sentence, compared to isolated word recognition for lexical decision, where the focus is on each word's lexicality.

Method

Participants. Twenty right-handed native English speakers (11 female, mean age 22.35 years) from the University of North Carolina at Chapel Hill and the surrounding community

participated in both the sentence-reading and isolated word-recognition phases of this experiment. All participants reported having normal or corrected to normal vision and no history of neurological impairment. They were compensated $25 for their participation and signed informed consent before beginning the experiment.

Stimuli.

Sentence Reading (RSVP) Task. The critical stimuli were five-to-eight letter words which were preceded by either the same word (Identity Preview, e.g., ARTICLE-article) or a different word (Unrelated Preview, e.g., MOSQUITO-magician) and were embedded in sentences (Appendix A). Each sentence contained two target words, one per preview type, for a total of 80 target words in 40 sentences. Two lists were created in which the preview type was counterbalanced and participants were randomly assigned one version of each sentence with the first target appearing as the third, fourth or fifth word in the sentence and the second target as the seventh, eighth or ninth word. Non-target words in each sentence served as fillers and were preceded by preview stimuli consisting of random letter strings which matched them in length. Each trial ended with a true/false comprehension question.

Isolated Word Lexical Decision Task. The critical stimuli were 80 words matched in length, mean frequency and frequency range[1] to the stimuli from the sentence reading task. They were preceded by identity or unrelated previews as in the previous task. Twenty non-word fillers were preceded by different previews and randomly distributed in each experimental list. The preview-target /filler pairs were presented in isolation and followed by a lexical decision task. A list of all experimental stimuli can be found in Appendix B.

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[1] 15.47 wpm in the Sentence reading task (range 1 to 67.37) and 15.28 wpm in the Isolated word lexical decision task (range 1 to 68.61) as established by the CELEX corpus (Baayen, Piepenbrock, & Gulikers, 1995).

Procedure. Participants sat in a dimly lit sound-attenuated booth, looking at a display that was placed at approximately 55 cm from their eyes. Half of the participants performed the Sentence Reading Task first and half performed the Isolated Word Lexical Decision Task first. A gamepad was used for manual responses for comprehension questions and lexical decisions. At the beginning of each task participants completed a 10 trial practice block to become familiar with the task and were given feedback on their performance by the experimenter.

All stimuli were displayed on a 17 inch CTR monitor with a refresh rate of 100 Hz in white Arial font over a black background. Previews were presented in lower-case and targets and fillers in uppercase.

For the Sentence Reading Task each trial (Figure 1) began with a 300 ms fixation cross followed by a 200 ms blank screen. The sentence was presented one word at a time in RSVP with an SOA of 500 ms between words that made up the sentence. Words were presented for 300 ms and were followed by a 150 ms blank screen. Each word was preceded by a 30 ms preview (random letter strings for filler words and related or unrelated previews for target words) and followed by a 20 ms blank screen.
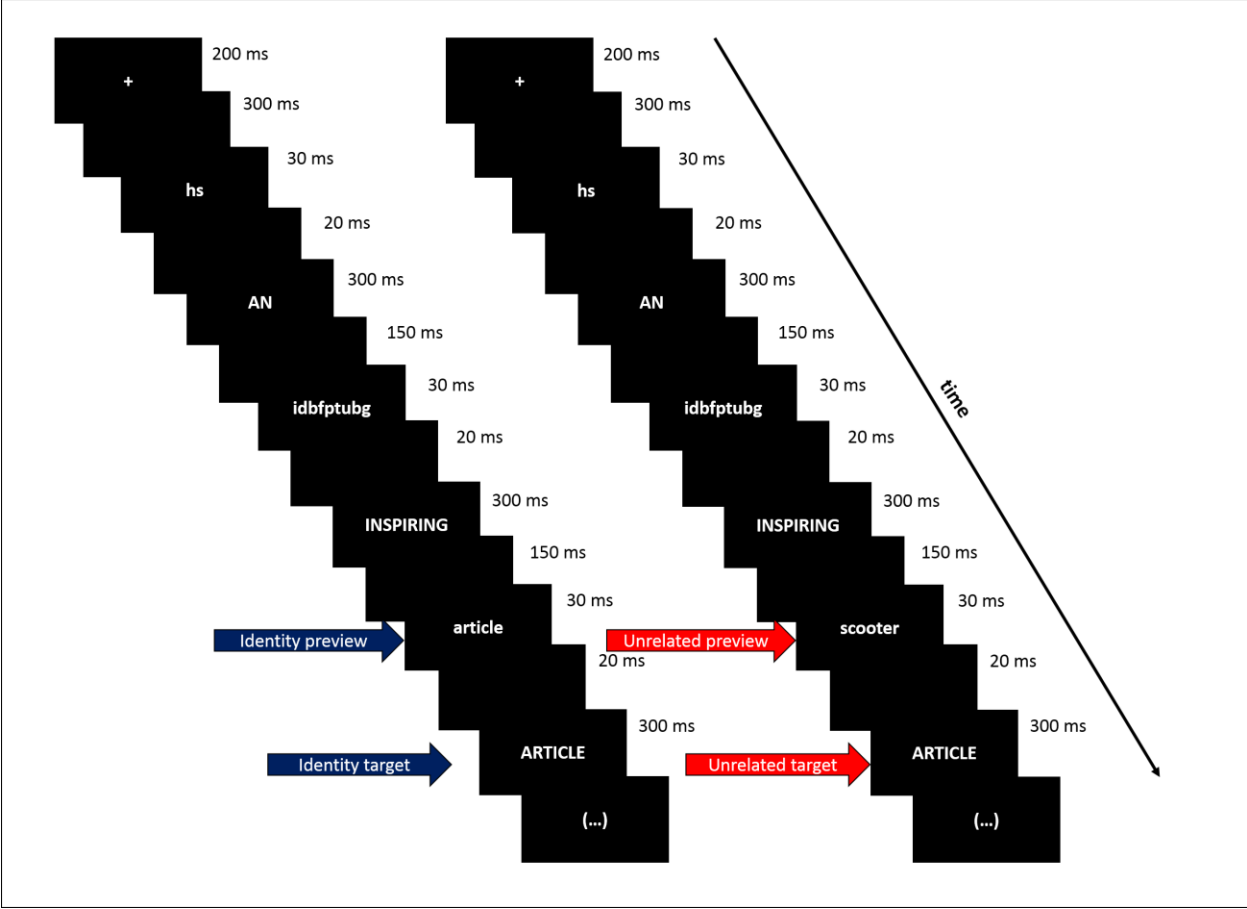
Figure 1- Experiment 1 Excerpt from a Sentence Reading trial.

At the end of the sentence a comprehension question appeared, with the participant's response triggering the onset of the next trial. Participants were encouraged to blink during the time that the question was on screen to reduce ocular artifacts during the trial.

The Isolated Word Lexical Decision Task followed the same time course as the Sentence Reading Task except that only a single preview-target pair was presented (Figure 2). The blank screen following the word cued the participant to press a button for non-word fillers and make no overt response for target words. A two second blink cue appeared on screen two and a half seconds after the target or immediately after a response to encourage participants to blink

between trials. In both tasks participants were instructed to maintain central fixation at all times during the experiment.
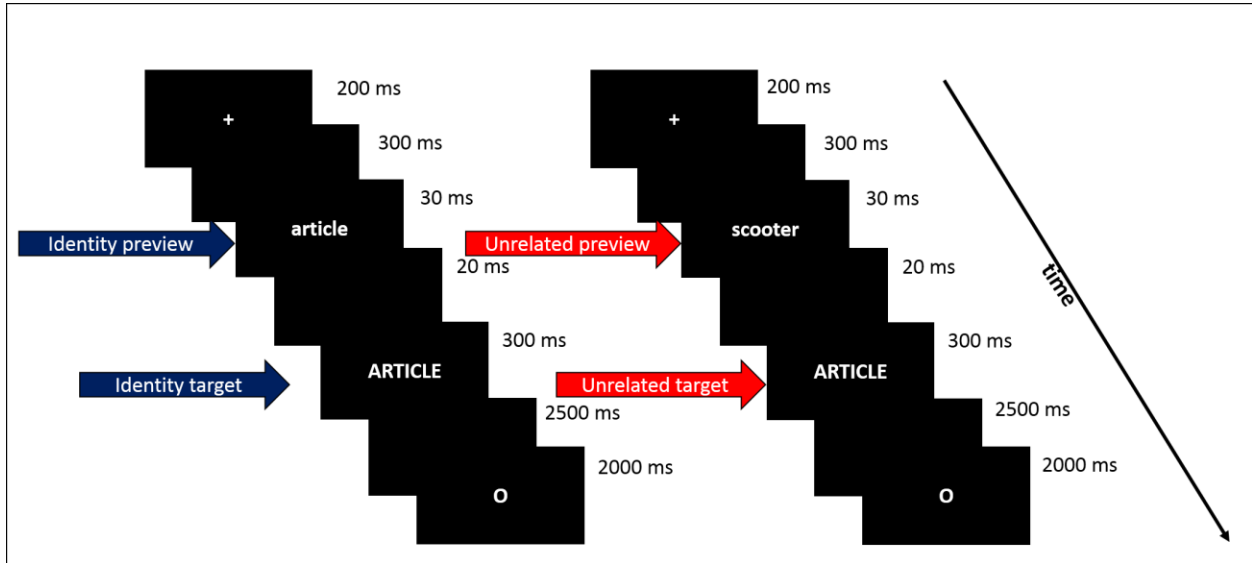
Figure 2: Experiment 1 Excerpt from an Isolated word with lexical decision trial.

EEG Recording and processing. The EEG was recorded through the Active-Two Biosemi system from 32 Ag/AgCl active electrodes positioned according to International 10/20 system at a sample rate of 512 Hz. Four additional electrodes positioned at the outer canthi and under the eyes were used to monitor eye-movements and blinks while two supplementary electrodes were placed on the mastoid bones and used for offline referencing.

Continuous EEGs were then processed offline in the Matlab plugins EEGlab (Delorme & Makeig, 2004) and ERPlab (Lopez-Calderon & Luck, 2014). EEGs were first bandpass filtered offline from .1 Hz to 30 Hz and then time-locked to target words in both conditions for epoching with a 100 ms pre-prime baseline. Epochs from both conditions were then submitted to a moving window peak-to-peak artifact rejection algorithm which rejected epochs containing voltages above 85µv and were additionally scanned visually by a research assistant who rejected any

muscle artifacts undetected by the algorithm. This resulted in an average rejection rate of 4.89% for the Sentence Reading Task and 2.94% for the Isolated Word Lexical Decision. Separate waveforms were obtained by averaging the remaining epochs in the identity preview and the unrelated preview condition and a grand average wave was obtained by averaging the ERPs of all subjects.

Statistical analysis

Difference waves were computed from the grand-averaged data by subtracting the identity preview condition from the unrelated preview condition separately for both tasks. The difference waves were submitted to a repeated-measures, two-tailed, cluster-based permutation test based on the cluster mass statistic (Bullmore et al., 1999) in the Mass Univariate ERP Toolbox (Groppe, Urbach, & Kutas, 2011). A family-wise alpha of .05 was adopted for both experiments and included in the analysis of all 30 scalp electrodes as well as all time points between 100 and 600 ms, resulting in a total of 7710 comparisons. Repeated measures t-tests were performed for each comparison in the original data and on 5000 random within-participant permutations of the data (Manly, 1997). For each permutation, t-scores equal or smaller than an uncorrected p-value of .01 (the cluster inclusion threshold) were entered into clusters with neighboring t-scores that met the same criterion. Spatial neighbors were defined as electrodes within a radius of 5.44 cm and temporal neighbors as adjacent time points. Cluster masses were obtained by summing the t-scores within each cluster and the most extreme masses were recoded to estimate the null hypothesis distribution. Finally clusters masses in the original data were ranked against those in the permutations to derive their unique p value which was assigned to each member of the cluster.

The cluster-based permutation test analysis was used because it does not require an *a-priori* definition of electrodes or timeframes of interest as does the more conventional ANOVA approach to ERP analysis. Furthermore the cluster based permutation test maintains control of the family-wise alpha level affording the possibility of a thorough exploration of the entire epoch while controlling for multiple comparisons. In our analysis time points after 600 ms were excluded to avoid component summation between ERPs elicited by the targets and ERPs elicited 500 ms later by the presentation of previews in the Sentence Reading Task.

Results

Sentence Reading Task.
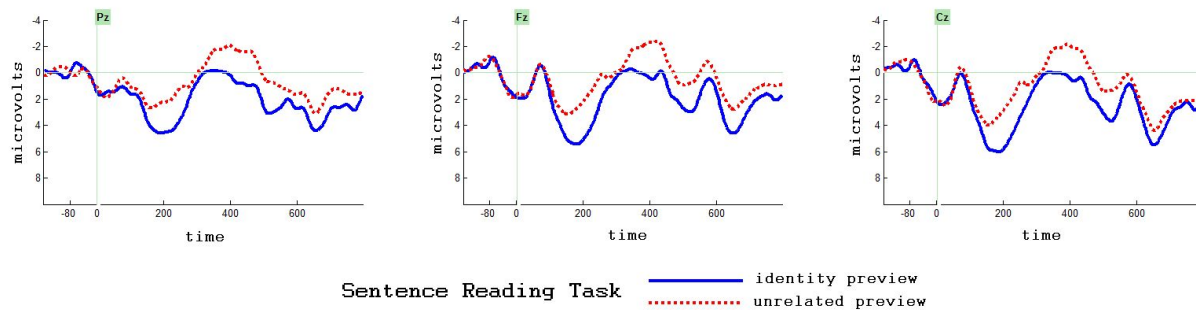
Figure **3** shows average ERP waves in select central electrodes in the identity and the unrelated preview conditions in the sentence reading task. Each electrode shows an increased negativity peaking around 200 ms for the unrelated compared to the identity preview condition and a second similar negativity around 400 ms.

Figure 3- Experiment 1 Select electrodes in the sentence reading task

Similarly the cluster based permutation analysis (Panel A, Figure 4) established two main clusters of significance. The first one (p<.001), which begins approximately 156 ms post stimulus presentation and ends by 260 ms, includes all electrodes in the left hemisphere and all frontal, central and centro-parietal electrodes in the midline and in the right hemisphere as well as Pz and P4. The second cluster (p<.05) is comprised of almost all electrodes in the left hemisphere and midline and central, centro-parietal and parietal electrodes in the right hemisphere. It begins at approximately 353 ms post-stimulus presentation in the left hemisphere and 394 ms in the right hemisphere and ends by 455 ms in the left hemisphere and 472 ms in the right.

Figure 4: Experiment 1 Cluster based permutation analyses results.

Isolated Word Lexical Decision Task. The average ERPs depicted in Figure 5 show a long lived negativity with two peaks indicating that the unrelated preview condition is more negative than the identity preview condition throughout the epoch but more so in two peaks around 200 and 450 ms.
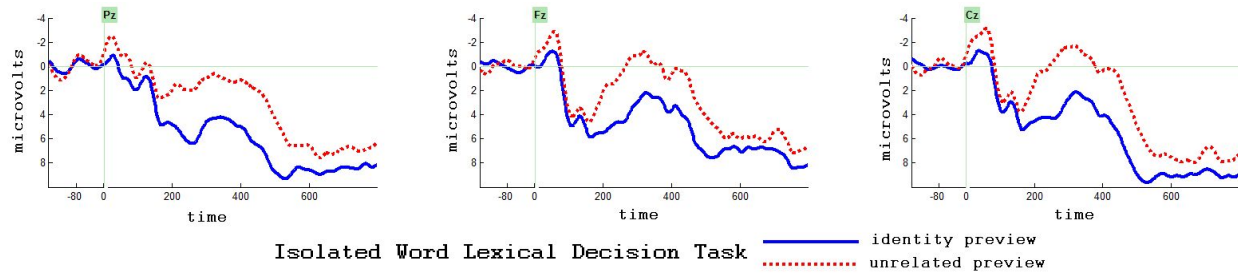
Figure 5: Experiment 1 Select electrodes in the isolated word lexical decision task

The cluster-based permutation analysis (Panel B, **Error! Reference source not found.**4) paints a similar picture in that it identifies only one large cluster of significance (p<.001) which extends from 162 ms to 537 ms and includes most electrodes around the time points corresponding to the difference wave peaks (~200 ms and ~450 ms) and mostly frontal and central electrodes around 300 ms post stimulus offset.

Task interaction. Both tasks revealed a significant masked priming effect for identity previews. The ERP for this condition peaked twice within the epoch of interest: first around 200 ms and then again around 450 ms. The isolated word lexical decision task however showed that the significant attenuation associated with identity preview persisted between the two main peaks, albeit to a weaker degree. In
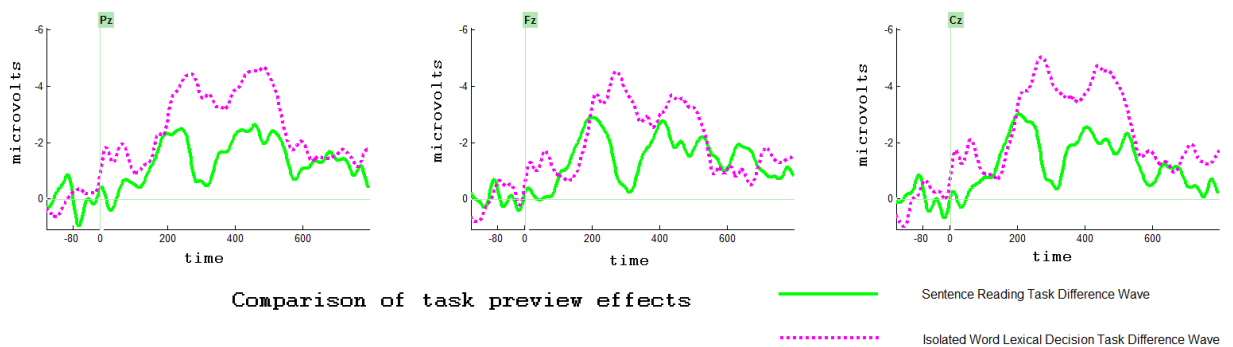
Figure 6 the difference waves computed by subtracting the identity preview condition from the

unrelated preview condition for each task are presented on the same plot to illustrate the difference in the magnitude of the effect for Sentence Reading and Isolated Word Lexical Decision.
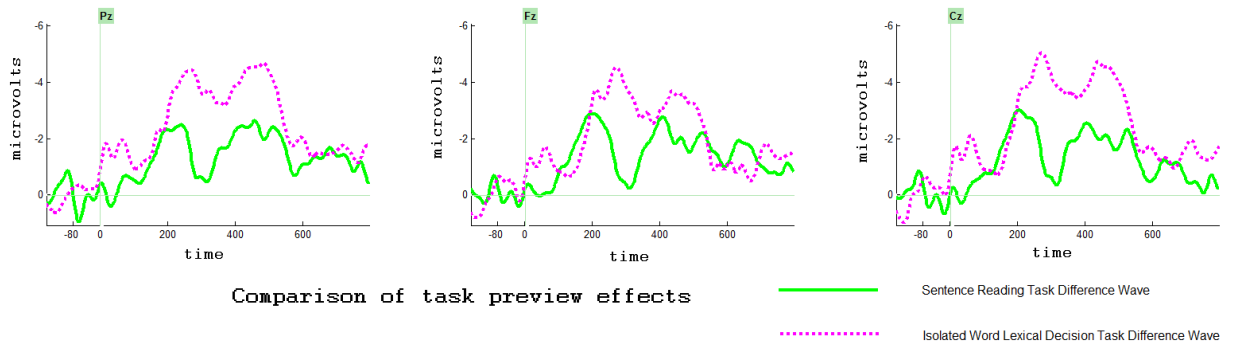
Figure 6: Experiment 1 Comparison of task differences. Each line is the difference wave of the grand average for a task, calculated subtracting the identity preview condition from the unrelated preview condition.

This difference indicates that the effect of identity preview is modulated by the reading task being performed. This possibility was examined with the calculation of a task difference wave by subtracting the grand averaged difference wave for the sentence reading task from that for the isolated word lexical decision task which revealed a protracted negativity for the isolated word lexical decision task, above and beyond that for the sentence reading task (Figure 7).
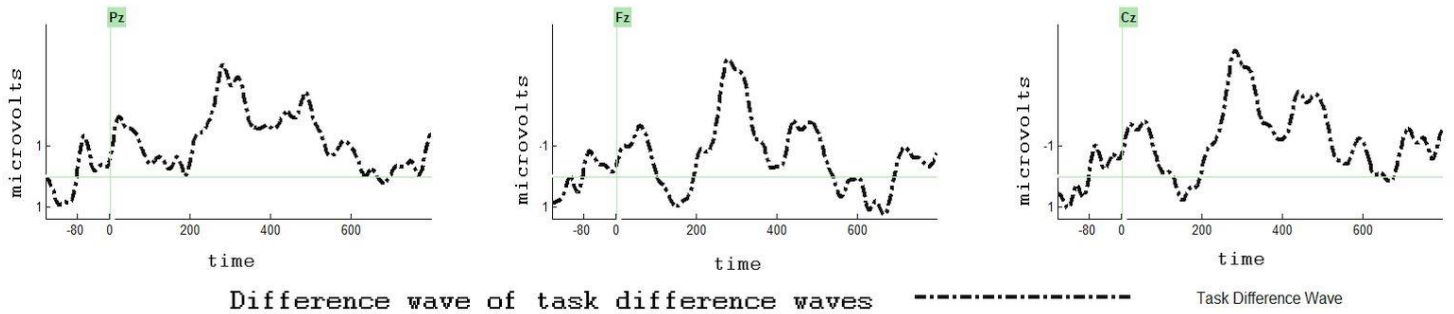
Figure 7- Expriment 1 Task Interaction Effect. The dashed line represents is the difference wave of the two task difference waves and was obtained by subtracting the sentence reading repetition effect from the isolated word during lexical decision repetition effect.

A final cluster-based permutation analysis on the task difference wave (Panel C, Bullmore et al., 1999**Error! Reference source not found.**) confirmed a significant task by repetition interaction (p< .05) between 261 ms and 335 ms which included mostly frontal and central electrodes. The interaction points to a larger and longer lasting effect of repetition on the N250 for isolated word recognition than word recognition during sentence reading and no significant difference between the tasks on the N400.

Discussion

The current findings provide the first report of both early (N250) and later (N400) effects of masked priming on word recognition during a sentence-reading task. Early effects were previously only found in isolated word-recognition tasks. Our results show integration of prime and target representations beginning around 160 ms for both the isolated word task and the sentence reading task. Similarly, in both tasks a reduced N400 showed the facilitative effect of identity preview processing on higher, lexical, levels of analysis. This effect is consistent with

previous findings from both the word in isolation and sentence reading literature (Grainger et al., 2006; Ledoux, Gordon, Camblin, & Swaab, 2007b; Nagy & Rugg, 1989; Rugg & Nagy, 1989). Earlier, several properties of sentence reading were identified as possible causes for the absence of an early neural marker of preview feature integration. Among these were the presence of intervening items, the long lags between prime and target and the reduced attentional focus to form level features were all identified of preview features in sentence reading. Here, we showed that removing lags and intervening items does indeed restore integration of lower level preview information early during target processing in sentence reading but that this effect is still reduced compared to the isolated word task. No difference between tasks was found for the later effect on the N400 component. The task difference on the early measure may reflect enhanced featural processing in the isolated word with lexical decision task. This task implicitly requires participants to examine the word form closely in order to correctly reject pseudoword foils. On the other hand, feature processing in the sentence reading task is only necessary to the extent that it will lead to recognition of the current word and may require fewer attentional resources from the reader.

In sum, the current experiment showed that masked repetition priming extends to sentence reading, the domain of parafoveal preview processing, and it suggests the demands of sentence processing determine how attentional resources are allocated as is the case for parafoveal preview processing.

Experiment 2: Behavioral Parafoveal Preview Benefit

The next step in assessing whether previewed information is extracted and integrated similarly during parafoveal preview and masked repetition priming is to replicate the classical

behavioral parafoveal preview benefit with the stimuli from the sentence reading portion of Experiment 1 where early and late neural effects of masked priming were found. In Experiment 2 we do so by measuring participants' EMs as these stimuli are presented with the contingent-display paradigm (Rayner, 1975).

Method

Participants. Twenty-eight English speakers (18 female) enrolled in an Introduction to Psychology course at the University of North Carolina at Chapel Hill participated in the study. All participants reported having normal or corrected to normal vision and no history of neurological impairment. They received course credit for their participation and signed informed consent before beginning the experiment.

Stimuli. Participants read the same set of sentences presented in Experiment 1's Sentence Reading Task but sentences were presented with the contingent display paradigm (Rayner, 1975) in which saccades crossing a pre-defined invisible boundary between words trigger a display change (Figure 8). Parafoveal availability of two critical target stimulus words per sentence was controlled by masking each word with either an identity uppercase mask (Identity Preview , e.g., ARTICLE-article) or an unrelated uppercase mask (Unrelated Preview, e.g., MOSQUITO-magician) until the invisible boundary in the blank space preceding the word was crossed and the critical word was presented in lower case. The case change between mask and target ensured that some type of display change would occur in both conditions. This way any difference between fixation durations on the unrelated and the identity preview conditions could be attributed to parafoveal processing rather than to the potentially distracting effect of a display change. As in

the Sentence Reading Task of Experiment 1, each sentence was followed by a simple True/False

comprehension question.

An insightful ARTICLE motivated the aspiring MOSQUITO to take circus classes.

An insightful article motivated the aspiring MOSQUITO to take circus classes.

An insightful article motivated the aspiring MOSQUITO to take circus classes.

An insightful article motivated the aspiring magician to take circus classes.

*boundaries are not visible to the participant
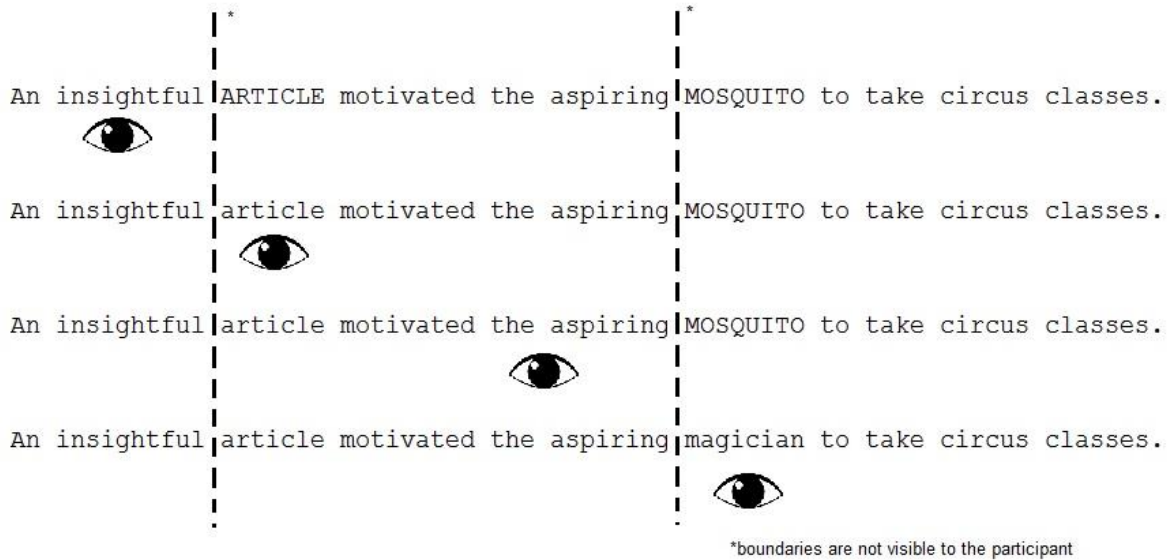
Figure 8- Experiment 2 Sample trial – The eye icon represents the participant's fixation location and dashed lines represent invisible boundaries between words.

Procedure. Participants sat in a dimly lit sound-attenuated booth with their head stabilized by a

desk-mounted head-rest and looked at a display that was placed 55 cm from their eyes. Sentences

were presented with Experiment Builder (SR Research). Participants were instructed to read the

sentences naturally to themselves, to ignore any "flicker" they might notice on the screen and to

respond to comprehension questions with a button press on a gamepad. At the beginning of each

experiment participants completed a five-trial practice block to become familiar with the task

and were given feedback on their performance by the experimenter. All stimuli were displayed

on a 24" LCD monitor with a refresh rate of 120 Hz in a black monospaced font over a white

background. Previews were presented in lower-case and targets in uppercase. Eye movements

were recorded from the participants' dominant eye using an SR Eyelink 1000. The eye-tracker

was calibrated using a 9-point procedure at the beginning of each session and again during the experiment if the between-trial calibration-check revealed excessive drift. Participants read sentences at their own pace and pressed a button on the gamepad to advance to the comprehension question. At the end of the experiment participants were asked to report whether they had noticed anything unusual about the visual display of the text and were encouraged with increasingly specific questions to reveal the degree to which they had become aware of the manipulation.

Statistical analysis

Trials in which the display change occurred more than 10 ms after the first crossing of the invisible boundary were excluded from the analysis as were trials where the participant blinked on the pre-target or target word. The remaining 76.5% of trials were included in the final analysis. Reading-time measures were then calculated for all participants and submitted to a paired sample t-test with Preview as the independent variable. *Single-fixation duration* was defined as the average of the duration of the initial, first-pass fixation on a word given that the word received only one first-pass fixation. *First-fixation duration* was calculated as the average duration of the initial fixation on a word regardless of whether the word was subsequently re-fixated. *Gaze duration* was the average of the sum of all first-pass fixation durations on a word.

Results

Figure 9 indicates that, on average, words in the identity preview condition were fixated for shorter durations than words in the unrelated preview condition across a number of measures. This effect was significant for all measures: *Single-fixation duration* [t(27)=6.12, p<.001], *First-fixation duration* [t(27)=4.67, p<.001] and *Gaze-duration* [t(27)=4.15, p<.001].
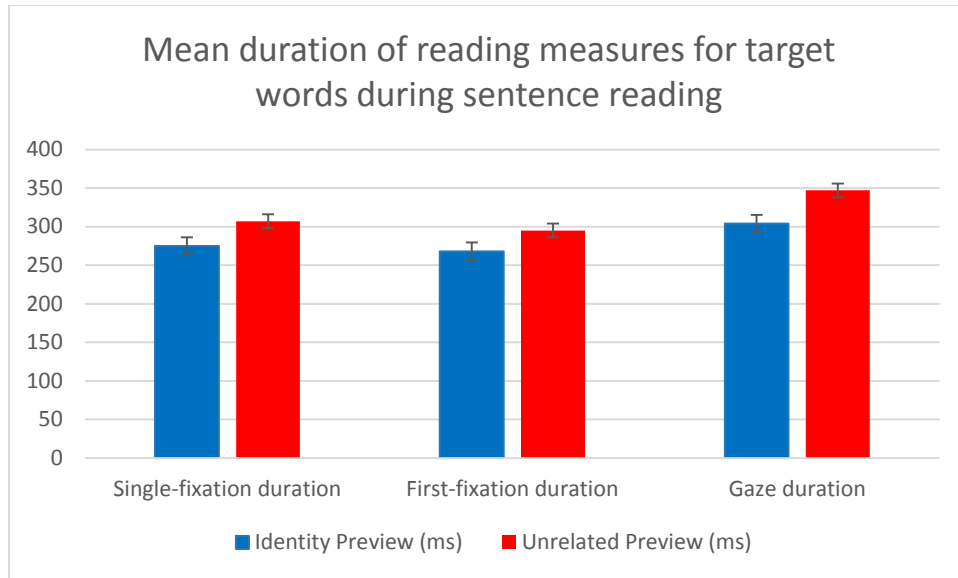
Figure 9: Experiment 2 Behavioral Parafoveal Preview Effect

Discussion

Participants showed faster reading times when an identity preview was available in the parafovea, thereby showing that the stimuli that produced masked priming benefit in Experiment 1 also produce the classic parafoveal preview benefit as measured by eye movements (Rayner, McConkie, & Zola, 1980; Rayner, 1975).

Experiment 3: Parafoveal Preview Processing with Coregistration of Behavioral and Neural Measures.

In an effort to further relate parafoveal processing and masked repetition priming the neural correlates of the parafoveal preview benefit are investigated by synchronously recording participants' EMs and EEGs as they read sentences with the contingent display paradigm. This fairly novel experimental technique, which is also known as coregistration, faces the challenge of producing a useful EEG recording in spite of the electrical noise introduced into the signal by the saccadic EMs that occur during natural reading. Here we attempt to overcome this challenge by decomposing the EEG signal into independent source components (ICA), and rejecting components that are primarily driven by ocular artifacts (Winkler, Haufe, & Tangermann, 2011).

Previous research from a task in which participants read a series of horizontally displayed words pointed to the attenuation of a posterior negativity between 200 and 280 ms as the index of processing facilitation due to parafoveal preview (Dimigen, Kliegl, & Sommer, 2012). The same study found an attenuation of the N400 that failed to reach significance. It is however unclear whether either of these findings would extend to skilled sentence reading because reading array of words likely requires a distinct strategy. Here we investigate this question with the same set of stimuli employed in Experiments 1 and 2.

Method

Participants. Twenty native English speakers (9 female, average age 22 years) from the University of North Carolina at Chapel Hill and surrounding community participated in the study. One participant was excluded from the analysis due to a corrupted file. As per the previous studies, participants reported having normal or corrected to normal vision and no

history of neurological impairment. They received approximately $20 for their participation and signed informed consent before beginning the experiment.

Stimuli. Participants were presented with the same set of stimuli as in Experiment 2.

Procedure. The experimental procedure was identical to that of Experiment 2 but participants' EEG was recorded concurrently to their eye-movements. Sentences were presented with Experiment Builder (SR Research) and TTL pulses were sent to the EEG recording computer at the beginning of each trial and every time an invisible boundary was crossed triggering a display change. Continuous EEGs were recorded as in Experiment 1.

EEG processing. The continuous EEG was processed offline in the Matlab plugins EEGlab (Delorme & Makeig, 2004) and ERPlab (Lopez-Calderon & Luck, 2014). EEGs were first high-pass filtered offline at .1 Hz and independent components were extracted with the *RUNICA* function in EEGlab. Components arising from ocular artifacts were classified with the Multiple Artifact Rejection Algorithm (Winkler et al., 2011) and visual inspection was used to identify and then correct components arising from ocular artifacts. The signal was then low-pass filtered at 30 Hz and merged with the eye-track by synchronizing the TTL signals in the EEGlab plugin EYE-EEG (Dimigen et al., 2011). Epochs were time-locked to the first target fixation after the display change and averaged across conditions to obtain Fixation Related Potentials (FRPs) for each participant in every condition. Follow-up analyses were conducted to assess whether the visual change from uppercase preview to lowercase target word itself elicited any changes in the brainwave. In order to do so, comparison FRPs were calculated for non-boundary content words that matched target words in length.

Statistical Analysis

Eye Movements. EM analysis was performed with a procedure identical to that described in Experiment 2.

Fixation Related Potentials. Cluster-based permutation analyses as described in Experiment 1 were conducted to examine the effects of preview condition and any possible effects due to detecting a salient visual change during sentence reading. An additional repeated-measures ANOVA with preview condition and electrodes as factors was computed to further explore parafoveal preview effects in select electrodes and time intervals.

Results

Eye Movements. The current experiment replicated the findings from Experiment 2 on all EM measures. Figure 10 indicates that, on average, words in the identity preview condition were fixated for shorter durations than words in the unrelated preview for *Single-fixation duration* [$t(18)=4.72$, $p<.001$], *First-fixation duration* [$t(18)=4.14$, $p<.01$] and *Gaze-duration* [$t(18)=5.47$, $p<.001$].
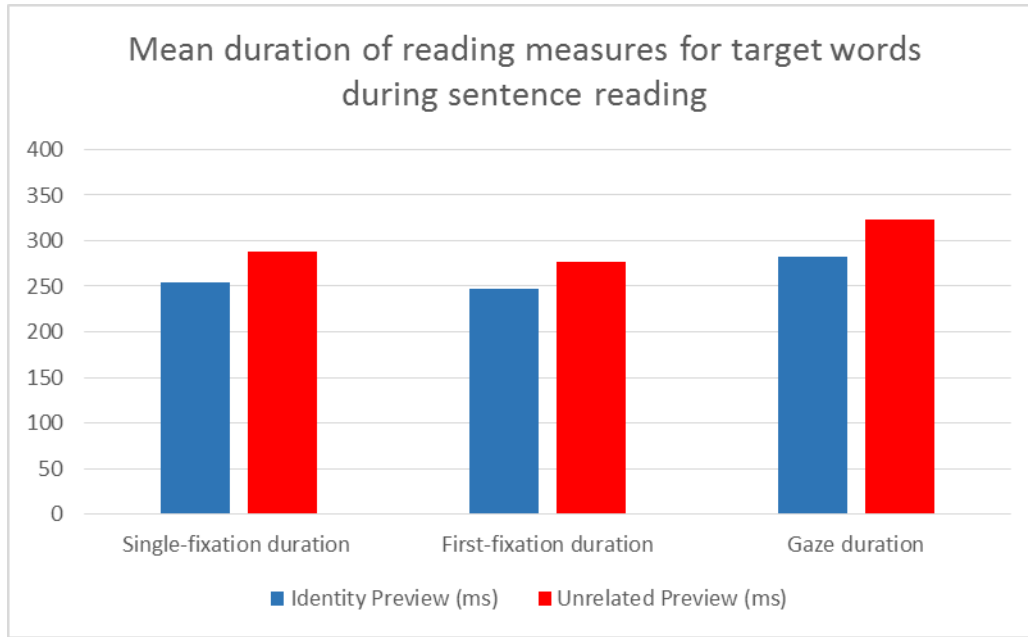
Figure 10- Experiment 3 mean EM measures for target words.

Fixation Related Potentials. Figure 11 shows a comparison between grand average FRPs in the identity preview and unrelated preview conditions. FRPs to the identity preview condition and the unrelated condition appear to diverge around 100 ms on frontal and central electrodes (See Appendix II for a topographical representation of all scalp electrodes) but this difference did not reach significance in a cluster-based permutation analysis contrasting the two conditions. This type of analysis is necessary to control for the increased false discovery rate that results from making multiple comparisons across time intervals and electrodes in the FRP and is particularly appropriate to test effects that are not hypothesis driven such as the one discussed above (Groppe et al., 2011).
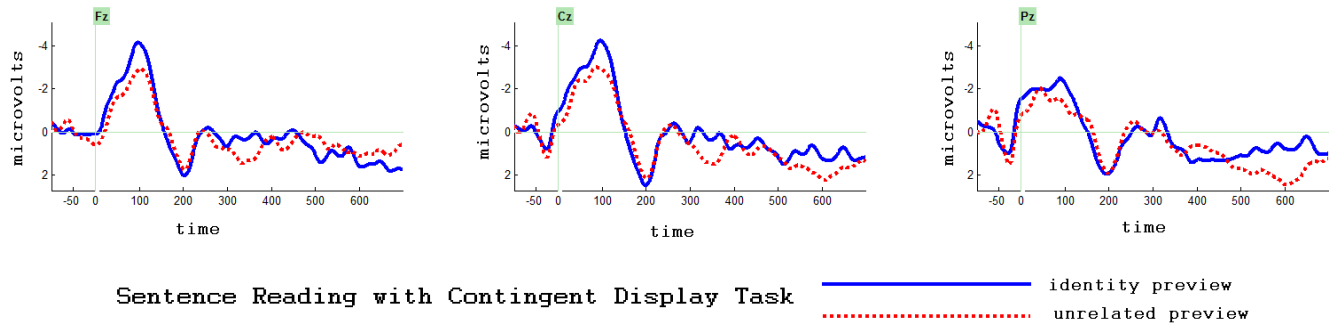
Figure 11- Experiment 3 Select electrodes for the Sentence Reading with Contingent Display Task.

Nevertheless, a traditional and less conservative factorial ANOVA approach was employed to compare main effects of preview condition and electrode as well as their interaction. The average amplitude in the 50-150 ms timeframe and sixteen frontal and central electrodes[2] were selected for the analysis upon visual inspection of the topographical array of FRPs (Appendix II). This analysis revealed a significant main effect of parafoveal preview $[F(1,19)=5.47; p<.05]$ and a main effect of electrode $[F(15, 19)= 8.52; p<.01]$[3]. There was no significant interaction of preview and electrode. This finding is reported cautiously as the timeframe and electrode selection were chosen a-posteriori and based on visual inspection. Furthermore, the timing and direction of the effect are not compatible with the neural parafoveal preview benefit reported by Dimigen et al. (2012) on word series. We performed follow-up analyses to assess whether our findings may have been affected by the experimental manipulation, specifically whether the visual change that occurred in all experimental trials disrupted normal reading.

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[2] FP1, FP2, AF3, AF4, F7, F8, F3, F4, FC1, FC2, FC5, FC6, Fz, C3, C4 and Cz.
[3] Assumption of sphericity violated, degrees of freedom have been lower-bound corrected.

Follow-up analyses on effects of visual change. We compared mean EM measures for words following a visual change (target words in both conditions which always changed from uppercase to lowercase) and words where no visual change occurred (filler words). Results showed delays in reading for words that followed a display change as measured by first fixation duration [t(18)=-8.37, p<.001][4] . The effect of display change added an average 31 ms to participants' first-fixations. When the same analysis was repeated on data from Experiment 2, results were equivalent [t(28)=-8.85, p<.0001]. We then performed a similar analysis on Experiment 3's neural data. The cluster-based permutation analysis contrasting FRPs to words following a visual change and words following no visual change is represented in Figure 12. Results show a large, positive effect of display change on all scalp electrodes. This effect is significant beginning at 201 ms after fixation until the end of the analysis window 700 ms after fixation. These results show that the visual change occurring in both conditions affected reading in an unexpected way.

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[4] One participant was excluded from this analysis due to insufficient good quality "no screen change" trials.

Cluster based permutation analysis- visual change in the contingent display task
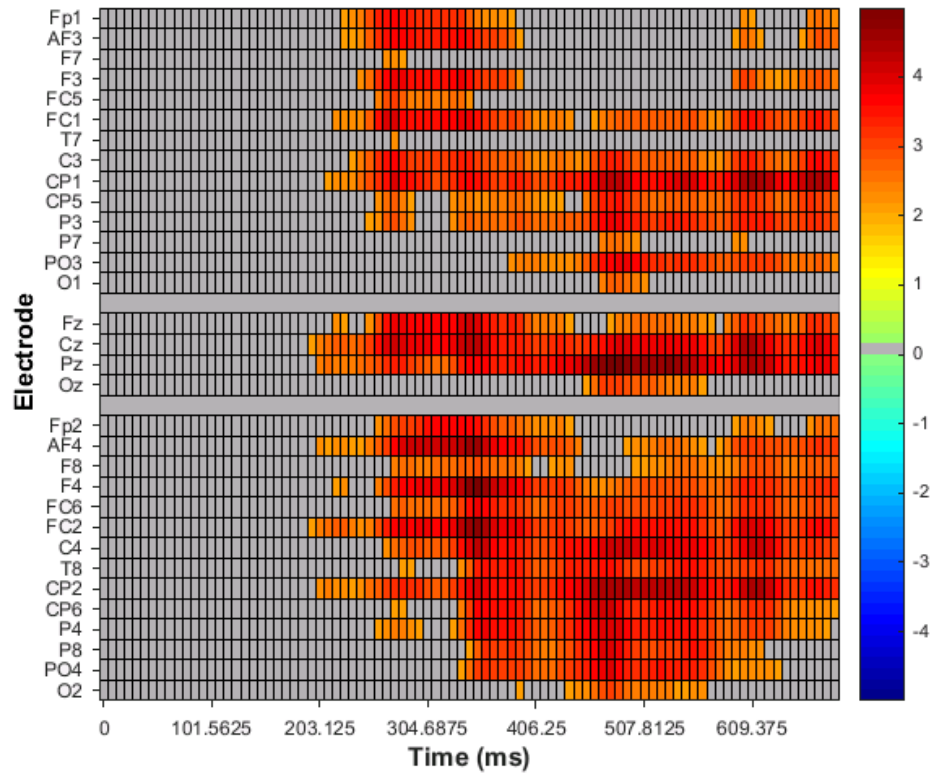
Figure 12- Experiment 3: Cluster based permutation analysis of the effect of visual changes on the FRP.

Discussion

Access to valid information in the parafovea lead to faster reading in the identity preview condition compared to the unrelated condition. The only effect of preview on neural measures was a brief and unexpected increased negativity associated with the identity condition which peaked around 60 ms. We reported this finding tentatively as it only surfaced in our least conservative analysis. Words in either condition underwent a change from uppercase to

lowercase when a display change was triggered and were read slower overall compared to words that didn't follow a display change. This finding, coupled with the large FRP positivity associated with words following a display change, points to a temporary hindrance of reading which may be due to the visual salience of the display change. Further research is needed to determine the nature of this effect. As mentioned above, Dimigen et al. (2012) manipulated parafoveal preview of word series. Their manipulation conflated display change and parafoveal availability as no display change occurred in the identity condition while a lexical change occurred in the unrelated condition. The authors argue that a visually evoked potential tied to a display change would appear before 200 ms in components associated with purely visual processing such as the N1-P1 and that the absence of effects on these early components implies no impact of the display change itself on the FRP. Our findings in this experiment suggest that at least a salient display change can impact the FRP well after these early visual components. In Experiment 4 we manipulate the saliency of the display change in order to separate display change and parafoveal preview effects.

Experiment 4: Parafoveal Processing of physically and lexically deviant previews

Experiment 4 aims to disentangle the effects of parafoveal preview processing and visual change. It does so by manipulating preview availability in a less visually salient way and by employing Principal Component Analysis (PCA) on the FRP wave to isolate distinct sources of variance.

The results of Experiment 3 showed that normal reading was disrupted when display changes were triggered by participants' eyes crossing an invisible boundary; a case change occurred for all targets and half of the time it was accompanied by change in the identity of the

target word. While saccadic suppression should limit display change awareness as the eye is moving to the target (Matin, 1974) some participants can detect changes and their reading patterns are qualitatively different from those of participants who are not aware of anything unusual happening to the text (White, Rayner, & Liversedge, 2005b). Signal detection analyses on trial by trial reports of visual change detection show that participants are less sensitive to a case change for alternating case words (i.e. ExAmPle/eXaMpLe) compared to an identity change (i.e. LaMdPeX/eXamPle) (Slattery, Angele, & Rayner, 2011) whereas our results from Experiment 3 suggest that a standard case change (i.e. EXAMPLE/example) might be too visually salient to remain unnoticed. In Experiment 4, the visual salience of the display change between preview and target is decreased by presenting both in lowercase across conditions. In the unrelated preview condition, the lexical identity of the previewed word changes as the eyes cross the boundary (e.g., mosquito/magician). In the degraded preview condition, partial overlap is obtained between preview and target by removing 10% of the black pixels that constitute the target word (e.g., magician /magician) for preview creation. Visual degradation of the stimulus in the parafovea has been shown to make parafoveal information less accessible as suggested by longer fixation durations on the target for both children (Marx, Hawelka, Schuster, & Hutzler, 2015) and adults (Gagl et al., 2014) and, unlike parafoveal masks, it does not appear to disrupt foveal processing nor lead to visual change awareness. The identity preview condition, in which no change occurs between preview and target (e.g., magician/magician), is used as a baseline measure of processing with valid parafoveal preview for both behavioral and neural measures. The effects of parafoveal processing and visual change are further analyzed by submitting the FRP to a PCA in order to assess whether distinct sources of variance are associated with the information available parafoveally.

Method

Participants. Thirty-six right-handed native English speakers (22 female, mean age 21.77 years) from the University of North Carolina at Chapel Hill and the surrounding community participated in the experiment. Participants received either one course credit or $10 per hour in exchange for their participation. Four participants' data were excluded from the analysis due to an insufficient number of trials meeting analysis selection criteria.

Stimuli. Stimuli consisted of three hundred target words embedded in the same number of sentences. Of these, forty are comprised of the sentence stimuli from Experiments 1 - 3, though only one of the two original target words was manipulated in the current experiment. Target words never occurred in first, second or last position in the sentence and, in order to maximize the likelihood of parafoveal processing of the target, were never preceded by a closed-class word. As in Experiments 2 and 3 sentences were presented with the contingent display paradigm (Rayner, 1975). Degraded stimuli were obtained by randomly exchanging 10% of the black pixels from the bitmap of the preview with white pixels with an R script adapted from Marx and colleagues (2015). Sentence frames were equally assigned to conditions and fully counterbalanced across participants. One third of the trials were followed by a True/False comprehension question and two thirds by an invitation to press a button to advance to the next trial.

Procedure. The experimental procedure was identical to that of Experiment 3 with the only difference that participants were offered additional breaks because of the increased number of trials.

EEG processing. Continuous EEG processing, artifact removal and the synchronization of EMs and the EEG was performed as described in Experiment 3. The EEG was segmented by retaining

the 100ms preceding the onset of the first progressive fixation on a target word and the 800 ms that followed fixation onset. Fixations that were shorter than 120 ms or longer than 600ms, as well as those that were followed by a regressive saccade were not included in the analysis. These criteria were necessary to exclude fixations resulting from participants quickly scanning the sentence before reading it more carefully on a second pass as well as extremely long fixations that they signal an interruption in normal reading. Though these concerns apply to Experiment 3 as well, the smaller number of trials in that experiment did not permit such stringent exclusion criteria. Additionally, only fixations that occurred immediately after the boundary change were included. FRPs were obtained by averaging data epochs for each participant within condition with a pre-stimulus baseline of 100 ms. Grand-average waves for data visualization purposes were obtained by averaging each condition across participants.

Statistical Analysis

Eye Movements. Trials in which the display change occurred more than 10 ms after the eyes crossed the invisible boundary for the first time were excluded from the analysis as well as trials in which the target word was skipped. Reading-time measures described in Experiment 2 were calculated and submitted to a repeated measure ANOVA with Preview as a single factor. Vincentile plots (Hoedemaker & Gordon, 2014; Ratcliff, 1979; Vincent, 1912) were constructed to provide a visual representation of the distribution of the parafoveal preview effect in the unrelated and the degraded preview conditions. Plots were obtained by dividing trials for each participant and condition into ten vincentiles based on first-fixation duration. The fastest 10% of trials in each condition were assigned to the first vincentile, the next 10% to the second vincentile and so forth until the slowest 10% of trials were assigned to the tenth vincentile. The average first-fixation duration of each vincentile in the identity preview condition was then

subtracted from the corresponding value in the unrelated and degraded preview conditions, thereby obtaining two sets of difference scores per participant. These were further averaged within condition across participants and displayed as connected points in the vincentile plots, with the average value of each vincentile in the identity condition as the x axis and the size of the effect on the y axis. Standard errors associated with each vincentile are depicted as bars connected to each point in the graph.

Fixation Related Potentials. Three cluster-based permutation analyses were performed on the FRPs: the contrast between the identity preview condition and the degraded preview condition tests the EEG-equivalent of the parafoveal preview benefit. Contrasting the identity preview condition and the unrelated preview condition tests whether the effect described by Dimigen (2012) for single words can be replicated in sentence reading. Finally, the contrast between degraded previews and unrelated previews assesses whether the display change in the latter condition is responsible for FRP differences above and beyond those due to lack of a valid parafoveal preview. Once the spatial and temporal loci of these effects are identified via the cluster-based permutation analyses, a repeated-measures ANOVA is performed with preview type and electrodes as factors.

Principal Component Analysis. In order to observe the contribution of overlapping components in the FRP, spatial-temporal Principal Component Analysis (PCA) was applied to the FRP data epochs (Spencer, Dien, & Donchin, 2001; Arbel, Spencer, & Donchin, 2011a). This type of approach reduces the dimensionality of the original dataset, which consisted of 36 electrodes, 502 time points and 3 conditions for each of the 32 participants, to a new set of orthogonal dimensions, thereby separating components that overlap in time or space. First a spatial PCA, using Varimax rotation, was applied to the data epochs with the input matrix

consisting of the average for each of the 36 electrodes in each condition for every participant. This type of analysis reduces the dimensionality of the dataset to a set of spatial factors, or virtual FRPs. Each factor is a linear combination of electrodes that attempts to capture variance in the data uniquely associated with scalp distribution. Next, a temporal PCA using Varimax rotation, is applied to each of the spatial factors. Here, the covariance between the time points in each spatial factor, condition and participant is analyzed and the temporal dimensionality of the data is reduced to a smaller number of temporal factors representing orthogonal patterns of temporal activity.

Results.

Eye Movements. Figure 13: Experiment 4 Eye Movement data by Preview Condition Repeated measures ANOVAs were performed for all EM measures and the omnibus test revealed a significant effect of preview type: *First-fixation duration* [F(2,31)=28.74; p<.0001], *Single-fixation duration* [F(2,31)=25.01; p<.0001] and *Gaze duration* [F(2,31)=21.95; p<.0001].
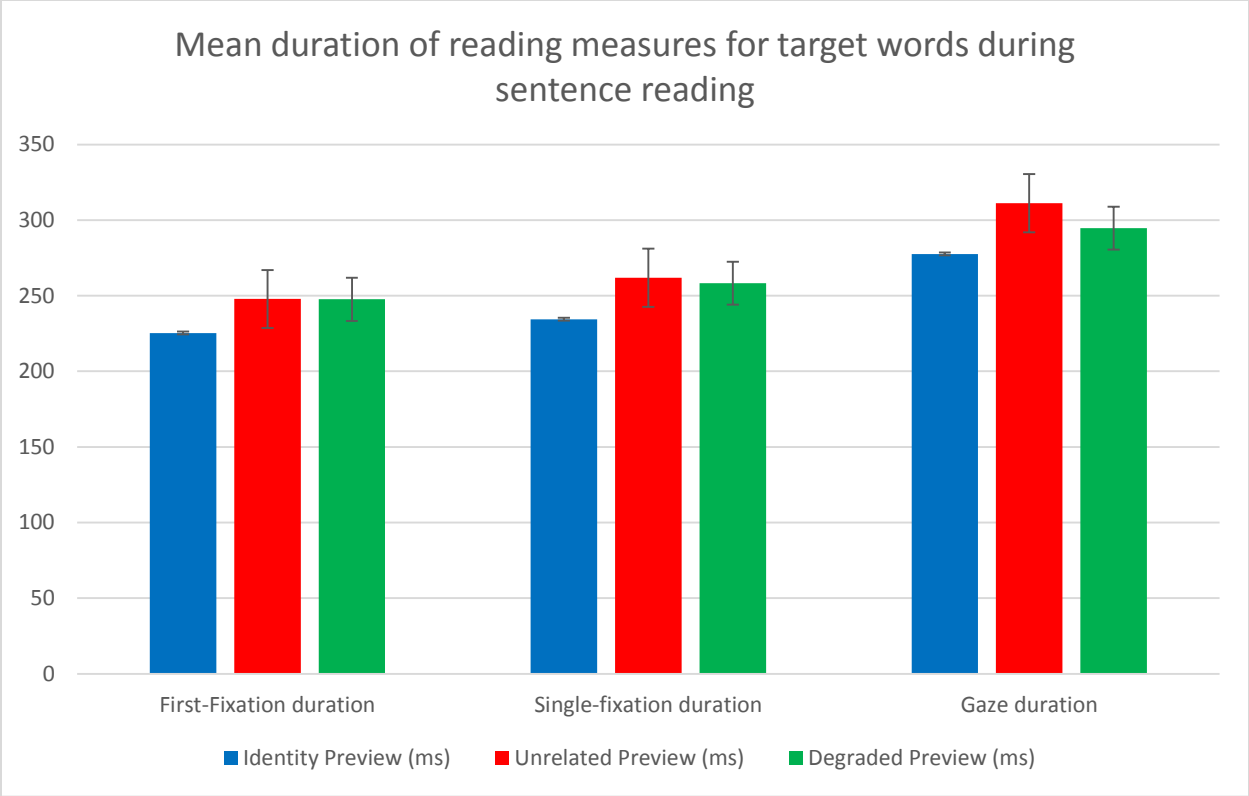
Figure 13: Experiment 4 Eye Movement data by Preview Condition

EM measure	Contrast	Std. Error	p
	Identity vs Unrelated	3.63	<.001
	Identity vs Degraded	2.63	<.001
First-fixation duration	Unrelated vs Degraded	3.75	0.99
	Identity vs Unrelated	4.74	<.001
	Identity vs Degraded	2.79	<.001
Single-fixation duration	Unrelated vs Degraded	4.81	0.46
	Identity vs Unrelated	4.34	<.001
	Identity vs Degraded	3.31	<.001
Gaze duration	Unrelated vs Degraded	5.02	0.056

Table 1: Bonferroni corrected pairwise comparisons for EM

Follow-up pairwise comparisons were performed using the Bonferroni correction and the results are summarized in Table 1. Words in the identity preview condition led to First-Fixation

durations, Single-fixation durations and Gaze Durations that were significantly shorter than those for words in the unrelated and degraded preview conditions. This pattern replicates the parafoveal preview benefit and shows that unrelated or degraded information in the parafovea results in slower reading. The next set of pairwise comparisons assess whether unrelated and degraded previews result in different patterns of eye movements. The two types of invalid preview did not significantly differ from one another in terms of average First-fixation duration or Single-fixation duration. However, the difference between degraded previews and unrelated previews on the gaze duration measure was found to be marginally significant. These findings tentatively suggest that the later stages of processing, as captured by Gaze Duration, are disrupted more by the presence of an unrelated word in the parafovea than they are by the presence of a degraded word. Most interestingly, these two types of preview differ in the distribution of their effect on first-fixation durations as illustrated in the vincentile plots below (Figure 14)**Error! Reference source not found.**.
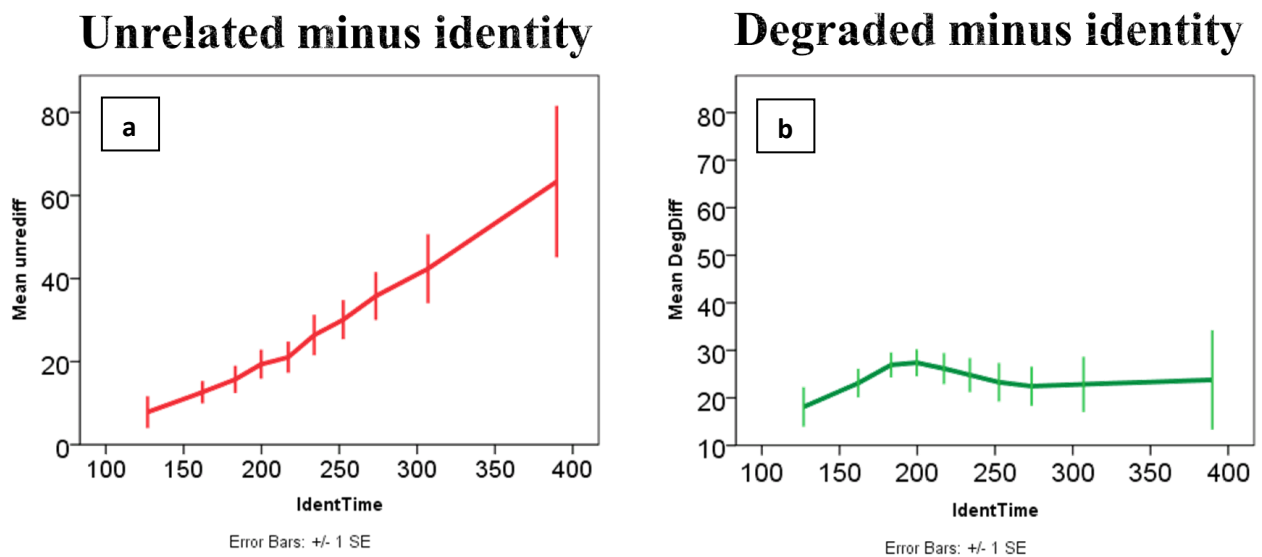
Figure 14: Experiment 4 Vincentile plots

The red line in panel a of Figure 14 shows that the effect of unrelated preview is negligible on the fastest fixations but increases linearly as fixations become longer, reaching its maximum of approximately 55 ms in the slowest 10% of trials. On the other hand, the effect of degraded preview (Panel b, Figure 14) is close to constant and remains between 20 and 30 ms across the distribution.

Fixation Related Potentials. FRPs corresponding to the three preview conditions are presented in Figure 15. An early negativity is followed by a positive deflection around 200 ms in all conditions, after which the identity and the unrelated conditions present a negative deflection which is most prominent in centro-parietal locations. This negativity is compatible with both the topography and the latency, roughly between 250 and 500 ms, of the N400. No N400 is present for the degraded condition, instead FRPs to words in this condition shows a positivity that continues until the end of the epoch. This positive deflection resembles the positivity that was associated with words following a display change in Experiment 3.
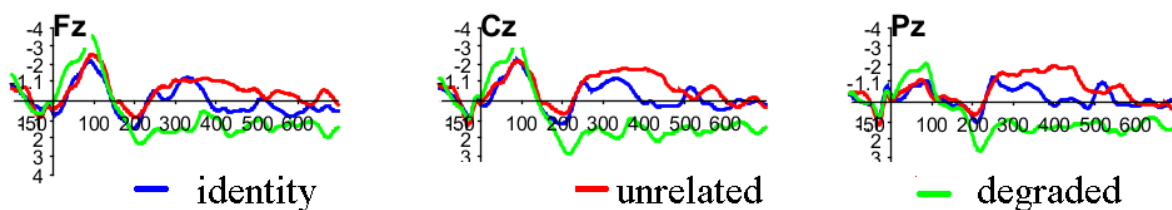
Figure 15: select electrodes of FRPs to target words

The cluster based permutation analysis comparing the identity and the unrelated condition (Panel A, Figure 16) identified a significant (p<.01) negative cluster between 336 and 502 ms on all electrodes except for F7, T7 and T8. This cluster is compatible with the notion that access to identity preview in the parafovea results in an attenuated N400 when compared to access to an

unrelated word. Panel B, Figure 16, reveals a large significant positivity between 193 and 479ms

which encompasses all electrodes indicating that FRPs to words in the degraded preview

condition are significantly more positive than those to words in the identity preview condition.

Similarly, the degraded condition is significantly more positive than the unrelated as evidenced

by the large cluster of significance beginning at 180 ms and ending 550 ms (Panel C, Figure 16).

Cluster based permutation analysis results of Experiment 4. The color blue indicates a statistically significant negativity in the FRP and the color red a statistically significant positivity. **Panel A-** one-tailed test of the difference wave obtained by subtracting the identity preview condition from the unrelated preview condition. Window included in the analysis: 200 to 500 ms. **Panel B-** two-tailed test conducted on the difference wave obtained by subtracting the identity preview condition from the degraded preview condition. **Panel C-** two-tailed test conducted on the difference wave obtained by subtracting the unrelated preview condition from the degraded preview condition.

Figure 16: Experiment 4 Cluster based permutation analyses results

While the negative deflection associated with the unrelated preview condition can be identified as an accentuated N400, the positive deflection associated with the degraded condition does not conform to N400 topology, nor is it restricted to the N400 time-frame. Instead, this positivity most resembles a P300, a positive component that has been associated with the resolution of uncertainty, context updating and attentional allocation (Sutton, 1968; Donchin 1971; Polich 1981) Given the similarity between this positivity and that observed in response to words following a display change in Experiment 4, it is possible that the distinct visual properties of the degraded previews are triggering the same type of response that was observed in Experiment 3. Despite being specifically designed to create a less visually salient display change compared to their unrelated counterparts, degraded previews are physically deviant from their context of presentation and may require additional visual analysis or attentional allocation. In order to examine the possibility that two distinct components are modulating the FRP in the unrelated and degraded preview condition, Principle Component Analysis is performed.

Principal Component Analysis. The spatial PCA retained 7 factors which together were able to account for 95% of the variance in the dataset while reducing its dimensionality by 80%[5]. Each factor, or "virtual FRP", represents a different pattern of spatial activity: the first one has a frontal distribution, the second an occipital distribution and the third one a centro-parietal distribution. Given the typical centro-parietal distribution of both the P300 and the N400, the third spatial factor (SF3) was identified as the virtual FRP of interest. The remaining factors do not appear to distinguish between the different preview conditions and are therefore of little interest to this analysis. Next, a temporal PCA was performed on each virtual FRP as described

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[5] One participant was excluded from PCA analysis because program was unable to read in its data.

in the methods section. Sixteen temporal factors were retained for Varimax rotation. Of these, the second factor is compatible with the timeframe of the N400 and the third with that of the P300.
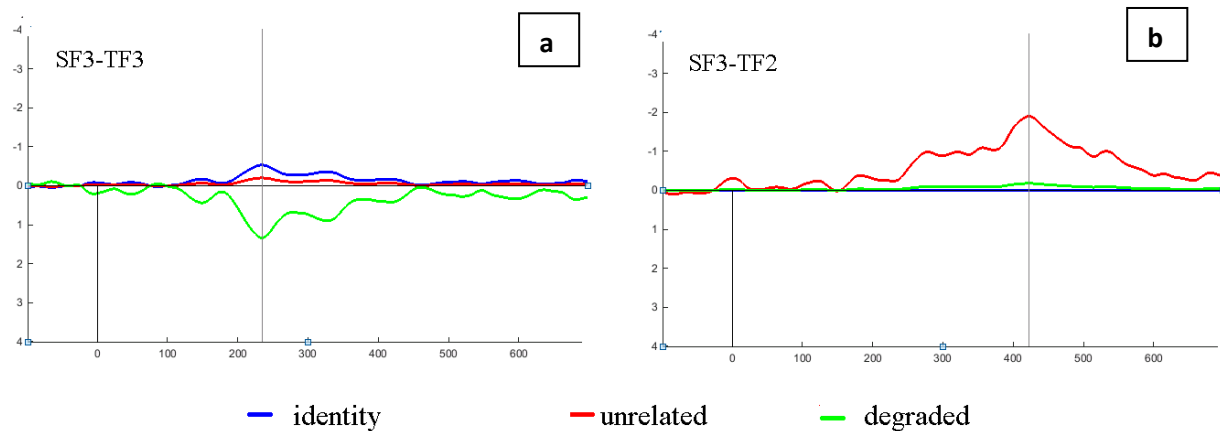
Figure 17- Experiment 4 spatio-temporal factors corresponding to the P300 (a) and the N400 (b)

Figure 17 depicts the spatio-temporal factors of interest. The P300 was identified as the third temporal factor of the third spatial factor (SF3-TF3, centro-patietal distribution with peak at 235ms) and the N400 as the second temporal factor of the third spatial factor (SF3-TF2, centro-parietal distribution with peak at 422ms). The factor scores were averaged within condition between 200 and 500 ms for the P300 and 250 and 500 ms for the N400 and were analyzed with a repeated-measures ANOVAs with preview as a sole factor. The ANOVA for the P300 revealed a main effect of preview [$F(2,30)=8.81$, $p<.001$] and Bonferroni corrected pairwise comparisons showed that the degraded preview condition was significantly more positive than both the identity preview ($p<.001$) and the unrelated preview ($p<.05$) conditions which did not differ from one another. A main effect of preview was also found for the N400 [$F(2,30)=7.90$, $p<.01$] where Bonferroni corrected pairwise comparisons revealed that unrelated condition was significantly

more negative than either the identity condition (p<.05) or the degraded condition (p<.05). The identity and degraded preview conditions did not significantly differ from one another. In sum, degraded previews affect the P300 component whereas unrelated previews affect the N400.

Relation of Eye-movement measures and Fixation Related Potentials

The EM effect distributions were superimposed on the PCA plots in order to visually compare the time course of the effects across measures.
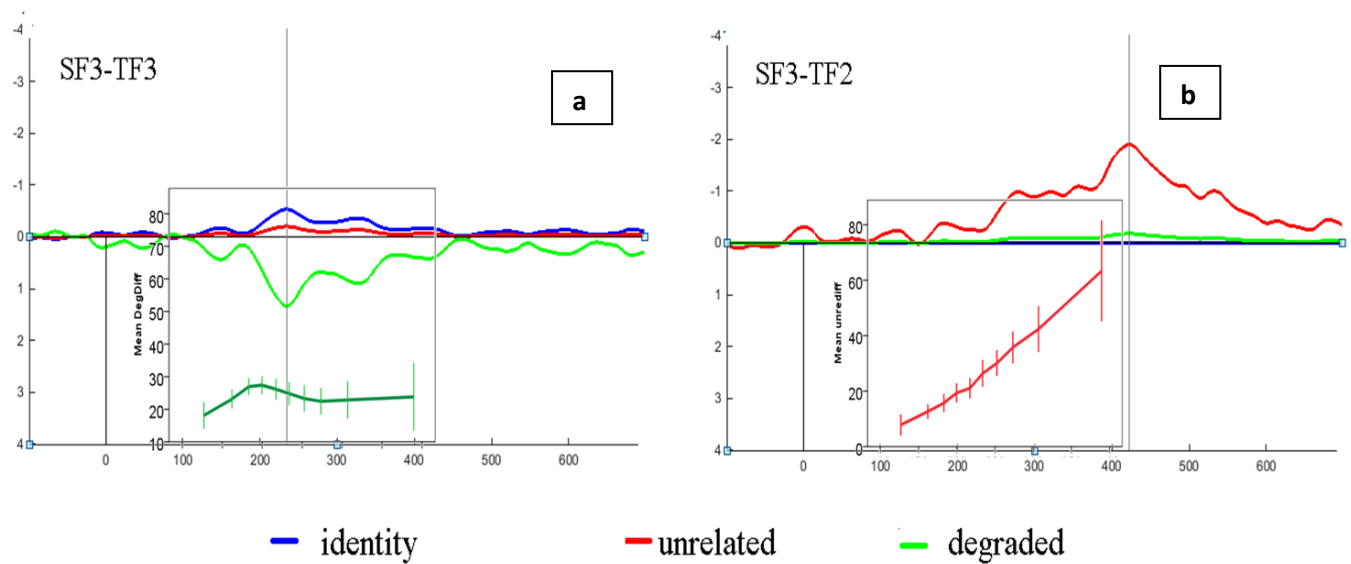
Figure 18: Experiment 4 Distribution of EM effects superimposed on FRP PCA results

Panel A of Figure 18 shows that the degraded preview effect in EMs unfolds within the timeframe of its neural equivalent, the P300, meaning that it is possible, though not certain, that the two measures arise from the same underlying process that occurs relatively early during word recognition. On the other hand, Panel B of Figure 18 shows that the EM effect in response to unrelated previews begins before the N400 response and reaches its maximum on the slowest fixations, which on average occur before the N400 peak and well before its return to baseline. This pattern replicates the temporal gap that commonly occurs between neural and behavioral

measures, and it does so despite the measures being recorded synchronously with the same experimental paradigm and participants. In this instance, it is likely that the EM and the FRP effects are indices of distinct underlying processes, though these findings do not rule out that methodological differences in other studies may affect the time course of other EM and ERP effects.

Discussion.

The current results accomplish three main goals: they explain the effect of salient visual change that was discussed in the previous experiment, they identify the neural equivalent of the parafoveal preview benefit and they establish that it likely originates from an underlying process that is distinct from that giving rise to the behavioral parafoveal preview effect.

First, we address the effect of salient visual change. In Experiment 3, both the unrelated preview and the identity preview condition showed a large increased positivity compared to words that did not undergo any case or lexical change. This was interpreted as evidence that the salient visual change occurring in both experimental conditions disrupted reading, making the small difference between identity previews and related previews uninterpretable. In Experiment 4, no change occurred in the identity preview condition and a less salient lexical change, with no case change, occurred in the unrelated preview condition. We no longer observed a large positivity when contrasting these two conditions but we did see such pattern when contrasting the identity and the degraded preview conditions. We hypothesized that a display change from a degraded preview would be less visually salient than a change from an unrelated preview, but our results show that the opposite is true. The EM results revealed that degraded previews result in longer fixations on all measures and visual inspection of the distribution of the effect suggests that short and long fixations are affected similarly, with average delays of less than 30 ms. The

large positivity associated with degraded previews in the FRPs was isolated in the PCA analysis as a centro-patietal component peaking at 235ms. This positivity was interpreted as an enhancement of the P300 component which is usually associated with rare or unexpected stimuli in a sequence but which has also been found in response to foveal words that are physically deviant during RSVP reading. In such studies, the P300 was enhanced for surprisingly large words (Kutas & Hillyard, 1980), for uppercase final words in a lowercase sentence (Arbel, Spencer, & Donchin, 2011b; Osterhout, McKinnon, Bersick, & Corey, 1996) and for visually degraded final words in non-degraded sentences (van de Meerendonk, Chwilla, & Kolk, 2013). It is thought to reflect the updating of the representational context (Arbel et al., 2011b), or the adjustment of attentional control in response to a state of indecision ("did I read that correctly?") which may trigger reprocessing of the input (van de Meerendonk et al., 2013). Our results show that this biasing of attention can take place across fixations, when the information generating uncertainty is in the parafovea. The time course of this effect overlaps perfectly with the time course of the EM effect, a finding which may indicate a common underlying process.

On the other hand, unrelated lexical information in the parafovea affects the amplitude of the N400 component. This is what we refer to as the neural parafoveal preview effect. Average durations of EMs showed a delaying effect of unrelated previews that was similar to that observed for degraded previews, though marginally larger on gaze duration, which is a later measure of processing. This pattern is consistent with the idea that degradation triggers early visual reanalysis whereas unrelated previews affect lexical processing and integration. The distribution of the EM effect was however very different from that elicited by degraded previews: the former affected slow fixations by causing a large delay of about 60 ms but showed only a negligible difference on short fixations. In contrast, the degraded previews affected

fixations throughout the distribution with a small but constant delay. In terms of the FRP effect, our results are in line with previous research examining the neural correlates of parafoveal processing across different tasks and methodologies. Firstly, they extend to sentence reading the marginally significant N400 attenuation that was described in Dimigen et al's. (2012) word series experiment, though they do not replicate the earlier attenuation (240-280 ms) reported in that study. Next, they mirror two studies, one in Spanish and one in Chinese, in which participants read sentences one word at a time in a modified RSVP protocol where valid and invalid previews were flashed as flankers to the left and right of fixation (Barber, Meij, & Kutas, 2013; Li, Niefind, Wang, Sommer, & Dimigen, 2015). In both cases, valid parafoveal previews resulted in an attenuation of the N400 when compared to invalid previews. Our study showed that this effect manifests even when the reader is in control of their rate of presentation and free to move their eyes, demonstrating that access to lexical content in the parafovea is not merely an artifact of fixed presentation rates and unusual experimental tasks. This neural response to unrelated previews was delayed compared to the equivalent EM effect, a finding which suggests that distinct underlying processes are giving rise to the two sets of measures. It is possible that the process responsible for the delay in EMs is reflected in the EEG as an earlier effect, such as that reported by (Dimigen et al., 2012), but that such effect becomes less prominent when participants read sentences compared to single words. This is indeed the pattern observed in Experiment 1, where the early (N250) effect of repetition was decreased for sentence reading compared to single word reading.

General Discussion.

Two main goals were identified for this project. The first was to assess whether similar mechanisms are at play in the extraction of information from foveal primes during masked repetition priming and from parafoveal previews during natural reading. The second goal was to relate behavioral and neural measures of lexical processing in order to further our understanding of how this process unfolds over time. In Experiment 1 we advance the first goal by showing that masked repetition priming occurs in sentence processing, the main domain of parafoveal preview processing, as well as in its native domain of isolated word recognition. We address the second goal by finding a facilitation on both early (N250) and later (N400) measures of processing in both types of tasks, thereby narrowing the temporal gap that placed lexical processing early in the EM literature and later in the ERP literature. We further showed that the early effect of repetition is larger for the lexical decision task with isolated words than it is for sentence reading, a finding that is interpreted as a greater focus on form-level characteristics in the former task. In Experiments 2 and 3 we further our first main goal by observing the parafoveal preview benefit on EMs obtained with the same set of stimuli that were used to study the masked repetition priming benefit in Experiment 1. At the same time, we address the goal of equating behavioral and neural measures by using a novel technique which allows synchronized recording of EMs and EEGs. Results from Experiment 3 speak to our second goal by showing both inflated reading times and an undetermined neural positivity in response to uppercase parafoveal previews, which are physically deviant from the rest of the sentence. In Experiment 4 we replicate this finding for physically deviant degraded previews and we establish that the EM and the FRP effects unfold over the same timeframe. We then provide evidence of a neural effect of parafoveal preview which is not temporally compatible with the behavioral effect elicited by the manipulation.

Taken together, the findings from Experiments 1-4 suggest an overlap in the processes that govern the integration of information from masked repetition primes and parafoveal previews. While in Experiment 1 we found that primed information facilitates processing on both early (N250) and a later (N400) neural measures, Experiment 4 showed that access to valid information in the parafovea only reliably affects the N400. Additionally, we reported that the presence of physically deviant stimuli in the parafovea can trigger an adjustment of attentional control which is reflected in an enhanced P300. Given their opposite polarity and differences in latency, it is improbable that the N250 attenuation in Experiment 1 and the P300 in Experiment 4 reflect similar processes. Instead, the N250 can be interpreted as a response to a mismatch between the word stimulus and the form level representation of said word, while the P300 is a response to a physically deviant stimulus that requires an adjustment in attentional resources. Interestingly, the early (N250) effect in Experiment 1 was found to be much stronger for isolated word recognition compared to sentence reading, a finding which we interpreted as an increase in focus for the properties of a word most relevant to the lexical decision task. While no significant early effect of preview was found in our sentence reading task in Experiment 4, a compatible finding was detected by Dimigen and colleagues (2012) who employed a single word reading task. If our interpretation of the reduced N250 repetition effect in sentence reading is correct, it is possible that an equivalent early effect of preview was undetected due to the different task demands of sentence reading and the increased noise introduced into the EEG by allowing participants to read naturally. Further research is needed to address this possibility.

Conclusions

This study showed that lexical information acquired through both priming and preview facilitates word recognition as evidenced by an attenuation of the N400 component. The process

that gives rise to this attenuation likely reflects later stages of word recognition and is distinct from the earlier facilitation that affects EMs during reading. A difference in the underlying process, rather than a difference in methodology, is identified as the cause of the temporal gap that is observed between behavioral and neural measures of reading. This same gap is closed when physically deviant stimuli trigger a reallocation of resources, a process that is attentional, rather than linguistic, in nature.

APPENDIX A: EXPERIMENT 1 SENTENCE READING TASK STIMULI.

Symbols # and $ indicate target words.
AN UNKNOWN #THIEF HAS STOLEN MY MOTHER'S PRECIOUS $GUITAR AND MANDOLIN.
THE CHEAP #DRESSER WHERE SAM'S NEW BLACK $WALLET WAS SUDDENLY BROKE.
EMILY'S PRIMARY #HOBBY WAS PRACTICING ON HER ELEGANT $PIANO AFTER DINNER.
THE TIRED #CHEMIST CARRIED THE WHITE $ENVELOPE INSIDE BEFORE OPENING IT.
FRANK'S LATEST #BUDGET IMPROVEMENTS PLEASED THE COMMITTEE $LAWYER WHO APPROVED THEM.
SIERRA BORROWED DIANE'S #NECKLACE FOR THE TEAM'S FANCY $CEREMONY ON SATURDAY.
EVERY DEVELOPING #TREND DESCRIBED IN THE ESTABLISHED $MAGAZINE PUZZLED ALLISON.
SEEING A LARGE #STAIN ON THE BEDROOM $CARPET ENRAGED FRANCINE TERRIBLY.
ALMOST EVERY #VOTER RECOGNIZED THEIR PREFERRED $SYMBOL PRINTED ON THE BALLOT.
THEY SHARED SOME FRENCH #SHRIMP AND THEN DISCUSSED $POETRY FOR HOURS.
NO MORE #BUTTER WAS LEFT WHEN THE DEMANDING $VISITOR HAD BREAKFAST.
IN SARAH'S #CABIN EMILY FOLDED HER PURPLE $SKIRT AND WHITE SWEATER.
THE DISTRACTED #DENTIST SCREAMED AS THE ASSISTANT'S $SLEEVE CAUGHT ON FIRE.
YESTERDAY AN UNHAPPY #CITIZEN REPLACED THE RUINED $CEMENT NEAR THE PLAYGROUND.
A DOZEN #SHEEP GRAZED BY THE SECLUDED $RESORT WHERE BILLY WORKED.
MAYA AND HER INTERNATIONAL #GUEST HAD THEIR FAVORITE $AUTHOR IN COMMON.
DURING YESTERDAY'S UNEXPECTED #STORM NEIL MOVED HIS PORCH $COUCH INDOORS.
LUKE RECOGNIZED JENNIFER'S #PURSE FROM THE CLOTH $FLOWER SEWN ON IT.
A LARGE #GORILLA AT THE ZOO TOOK LYNN'S $BRACELET FROM HER.
AN INSIGHTFUL #ARTICLE MOTIVATED THE ASPIRING $MAGICIAN TO TAKE CIRCUS CLASSES.
WHEN THE LONELY #SOLDIER BENT DOWN, THE DARK $PUPPY APPROACHED HIM.
AFTER A BRIEF #SHOWER RACHEL WANTED A SUMMERY $BEVERAGE WITH ICE.
AFTER EVERY #CONCERT THE BAND WENT TO HAROLD'S $BASEMENT TO UNWIND.
THE TURKISH #GROCER HAD SOME SERIOUS $TEMPER RELATED ISSUES TO ADDRESS.
ERIKA TOOK CAMERON'S #ASPIRIN AND HIS COLORED $BLANKET AFTER HE LEFT.
THE BROWN #INSECT DIED UNDER THE ORANGE $SPONGE IN ANNA'S HAND.
THE ELDERLY #MINER LIKED HIS WIFE'S $GRAVY MORE THAN HER TURKEY.
AFTER A PROLONGED #HOCKEY MATCH JOE ORGANIZED $LAUNDRY AND IRONED SHIRTS.
THAT EXPENSIVE #JACKET OF HIS REQUIRES $PATIENCE TO WASH AND DRY.
A BATTERED #TRAILER HIT AMIR'S NEWLY INSTALLED $FENCE AND DESTROYED IT.
WITH ERIK'S #APPROVAL DEREK WILL REPLACE THE ANTIQUE $STOVE DOWNSTAIRS.
A SMALL #DISASTER OCCURRED WHEN MIKE MADE TROPICAL $SALAD FOR LUNCH.
THE NEWBORN #KITTEN SLEPT AS THE AFTERNOON $SUNLIGHT ENTERED THE ROOM.
THE BLOND #SINGER ULTIMATELY PURCHASED THE GREEN $COTTAGE BY THE LAKE.
WHEN THE ENORMOUS #WHALE APPEARED THE SURPRISED $COACH TOOK MANY PICTURES.
THE YOUNG #LECTURER GOT AN ASTONISHING $PROPERTY FROM HIS DECEASED FATHER.
USING JOSEPH'S #LADDER LAURA TORE DOWN HER OLDEST $POSTER OF MADONNA.
YELLING, THE ARROGANT #BUILDER MOVED THE ELECTRIC $TRACTOR BY THE BARN.
THE EXPERIENCED #DANCER ADDED A SUBTLE $SPICE TO HER SCONES.

APPENDIX B: EXPERIMENT 1 LEXICAL DECISION TASK STIMULI

Target word	Unrelated Prime	Target word	Unrelated Prime
sloth	topaz	solitude	illusion
tiger	chalk	dentist	torture
label	atoms	booth	odors
cluster	horizon	rally	shark
dictator	drawback	brush	pilot
sheep	motor	brick	cloud
scenario	fraction	drummer	lineage
border	cruise	wheat	panic
gateway	scenery	marathon	forestry
fence	angle	tooth	brand
fever	theme	rainbow	package
bacon	apple	patron	sunset
alliance	sympathy	savanna	poultry
spider	needle	beard	flash
vehicle	shelter	forger	roster
grave	entry	agency	powder
document	medicine	mackerel	designer
cylinder	treasure	rhythm	permit
mechanic	boundary	budget	avenue
score	panel	bonus	theft
category	football	airplane	appendix
shield	armory	theology	prestige
lemon	spoon	button	barrel
album	attic	particle	moisture
wedding	nursery	skill	sport
ginger	buffet	crown	shame
penny	cigar	vagabond	notation
trace	alarm	quest	syrup
furnace	highway	accent	treaty
mound	razor	outbreak	carriage
costume	protein	emphasis	magazine
flour	sweat	cubicle	tribute
blazer	gender	brain	sheet
bicycle	doorway	uniform	missile
basket	statue	ration	remedy
pause	wheel	outlet	bunker
birthday	mobility	parsley	plaster
guardian	envelope	crease	ledger
ceiling	expense	divinity	pedigree
reptile	steamer	whale	serum

APPENDIX C: EXPERIMENT 3 FRPs FOR ALL ELECTRODES

Legend:

Identity Condition

Unrelated Condition
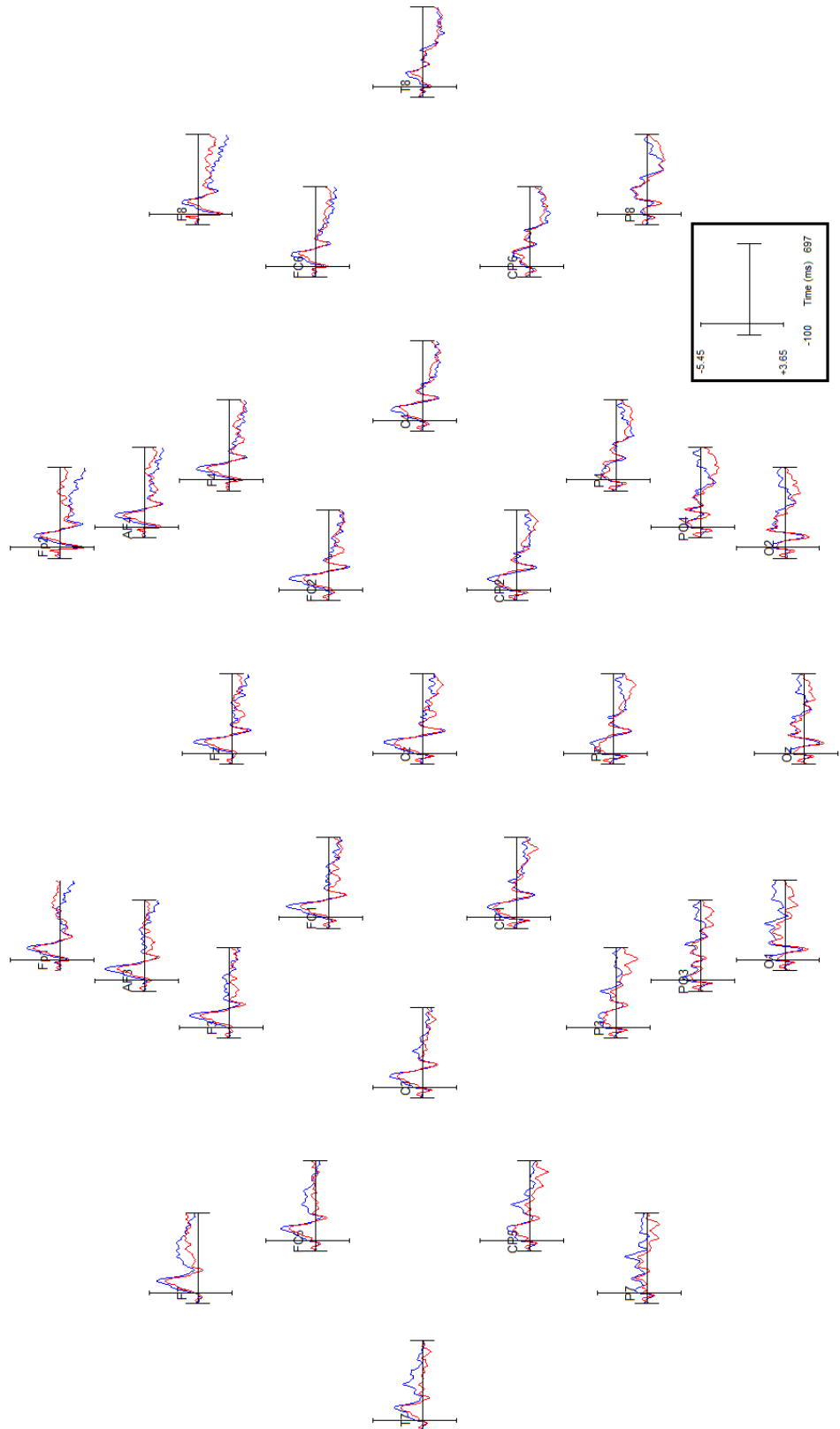
APPENDIX D: EXPERIMENT 4 STIMULI

Sentence frame (# precedes target word)	Unrelated preview
Hannah did not get a chance to read my #document yesterday.	tumbling
The experienced dancer added a subtle #spice to her scones.	onion
If Justin squinted he could see the bright #kayak far away.	llama
Luke wears #sandals and shorts no matter what season it is.	roadway
My introductory #drama class had me design sets for the play.	typed
The uncontrollable #wildfire made the firefighter worry about his colleagues.	euphoria
Yesterday Tasha installed #granite countertops in her kitchen for aesthetic purposes.	archery
Amir got a large #refill of his drink at the show.	driver
Shelby visited highly ranked #clinics to diagnose her constant cough.	persona
Heather loves to drink warm #eggnog in the fall and winter.	globes
Serena was given an orange #leaflet which promoted a new salon.	condoms
The Turkish grocer had some serious #temper related issues to address.	volume
Yesterday an unhappy citizen replaced the ruined #cement near the playground.	cattle
The young lecturer got an astonishing #property from his deceased father.	chestnut
A dozen sheep grazed by the secluded #resort where Brenton worked.	toilet
The brown insect died under the orange #sponge in Kimberly's hand.	cowboy
The newborn kitten slept as the afternoon #sunlight entered the room.	forecast
From the many options available, Bernard picked #basil scented dish soap.	realm
After every concert the band went to Benjamin's #basement to unwind.	heredity
An unknown thief has stolen my mother's precious #guitar and mandolin.	reward
Blake was not able to find her favorite #leggings today.	enslaved
The moody #members of the poker club stopped the game.	company
Vicky dislikes #tomatoes on sandwiches but loves them in salads.	skirmish
After a prolonged hockey match Thomas organized #laundry and ironed shirts.	academy
In the narrow #gully, small remains of fish could be seen.	minks
Hidden under a double #panel, were Megan's secret safe and money.	niece
Alana decided to attend #therapy to begin processing her grief.	records
The river caused the total #erosion of the bridge's posts.	barrage
Luis showed off the flexible #sword he got from a craftsman.	beets
After forming a coalition, the tired #laborers worked in better conditions.	backyard
The Browns slept in a smoky #motel room on vacation.	vines
The article stated that the recommended #vaccine is easy to administer.	prairie
The family asked for a larger #suite in the hotel.	blues
The distracted dentist screamed as the assistant's #sleeve caught on fire.	sleigh
The little child loves to eat fresh #trout for dinner.	poles
Luke recognized Jennifer's purse from the cloth #flower sewn on it.	rabbit
Erika took Yolanda's aspirin and her colored #blanket after she left.	payment
During yesterday's unexpected storm William moved his porch #couch indoors.	chain
Samira's primary hobby was practicing on her elegant #piano after dinner.	clock
At the farmers market, all of the leftover #fruits were bruised.	wreath
They were low on chocolate but still had bountiful #apricot cake.	discord

Every summer and fall Jason goes to the county's #chili competitions.	diner
Natalia placed #linens on the daybed so Harriet could sleep.	castle
The arrogant #crewmen on the ship caused a disagreement during breakfast.	handbag
A trained #medic was called to the scene of Jeffrey's accident.	downs
On her birthday, Amanda received the black #jeans she wanted.	teens
The rusted #muffler on Janel's car finally fell off today.	unnicorn
Only approved #uniforms can be worn at my private school.	matchbox
Erin prefers #mustard to ketchup or other sauces on her burger.	warlord
Jasmin's optimistic #sister sees the best in everything and everyone.	bikini
The international #traveler was not accustomed to tipping in restaurants.	drummers
Grant's catch #sizzled on the camping pan after a long day.	perfume
The visiting #choir sung an aria shortly after the sermon.	loser
Purchasing discounted #thread became easier once shops started to sell online.	lunacy
Though typically #skeptics, Herman and Ginger believed the mysterious tale.	latitude
The Greeks inscribed #numerals on tablets to keep track of purchases.	monorail
After a brief shower Rachel wanted a summery #beverage with mint.	medicine
After the event, #ribbons were awarded to those who participated.	twister
After his grueling #trial, Brian said goodbye to his wife.	caste
Raul buys expensive #cologne that reminds him of his dad.	equator
Ronald requested multiple #servings of mashed potatoes and pulled pork.	skeleton
In his thick #agenda, Harold writes down his daily schedule.	chores
In the advanced #napkin folding class you'll learn to make swans.	avocado
After many agonizing #injuries, Yvonne decided to retire from professional sports.	crusader
Under the skillful #monarch, the impoverished empire became industrialized and prosperous.	maidens
Lisa felt quite #feverish after spending a weekend hiking and camping.	unlisted
With a slightly smaller #nozzle the pressure in the hose improved.	thirst
Using Joseph's ladder Laura tore down her oldest #poster of Madonna.	salary
The elderly woman discovered #coyotes going through her garbage cans.	bishops
Late in the season, #rosebuds began to bloom in the yard.	pipeline
Because of her serious #peanut allergy, Lucinda cannot eat fast-food.	almond
Samira struggled to distinguish #verbs from adjectives in her assignment.	midst
With projects of unpredictable #duration one should set process goals.	diameter
A family with multiple #incomes should hire a good accountant.	recluse
Darcy received an antique #locket from her godmother on her confirmation.	mailer
The segment featured copper #lamps as accent pieces in designer homes.	deeds
Oliver wears his expensive #blazer when he wants to feel sophisticated.	giants
These public service announcements #pertain to most families in Charlotte.	caprice
While the retired referee watched TV, he sliced #cabbage and bread.	courage
The new girl had a terrible #fever that was extremely unhealthy.	nerve
Joan stood on the beautiful #terrace to look at the sky.	robbery
The janitor cleaned up greasy #residues and spills in the kitchen.	syphilis
Earlier Scott spotted a wild #rhino standing in a nearby lake.	discs
The courthouse structure had classical #columns that framed its façade.	wetness
Because she is a skilled #hunter, Sydney is constantly outdoors.	sender

The producer had the recurrent #fantasy that he would become rich.

The couple had never prepared #lobster before their trip to Main.

During finals week, students bought #caffeine pills to stay awake.

Kristy always complained about Paula's #noisy alarm when they were roommates.

A nearby #jeweler sold Matthew the ring he'd been looking for.

A small band of people #embarked on a cross-country biking trip.

On Saturday Charles bought an expensive #cashmere sweater at the mall.

The enthusiastic child created a detailed #cartoon with a talking bird.

Arthur thought that Russia's most praised #delicacy was high quality caviar.

After his suspension, Dale underwent repeated #hearings and lengthy debriefings.

After breaking both of her tiny #wrists, Victoria stopped wrestling.

Dean could not find any working #outlets in his classroom.

After collecting all of their practice #balls, the soccer team relaxed.

When visiting foreign countries, diplomats often watch #operas and ballets.

For his birthday Darren made an impressive #donation to a shelter.

The increased #violence in the city worried Jessica and her family.

In his yard, Simon discovered a large #colony of ants.

The little child ate a cream filled #doughnut and drank soda.

On his birthday, Bradley received an emotionless #letter from his father.

Before leaving, Peter wrote down an essential #deadline for his staff.

Delphine developed an irrational fear of remote #lodges after watching psycho.

The new medicine could not relieve Celeste's terrible #sinus pressure.

Friday Jonah went to the store and bought #pumpkins as decorations.

After much consideration, Susan now takes her daily #vitamins and supplements.

Baking can be reduced to a few common #ratios of ingredients.

To please their instructor they performed the intense #routine again.

Some improvised #shrines appeared at the scene of the disaster.

As an architecture #lover, Malcolm was looking forward to Paris.

He lied to Marcy about being a known #composer in Europe.

With tiny #helpers, Santa made and delivered the toys to children.

An enormous #batch of cookies was sent over to Selena's house.

The well trained #courier took tourists through Chapel Hill and Raleigh.

Inside the abandoned #quarry they found a suitcase full of drugs.

Yesterday Brock applied matching #burgundy paint on the walls and doors.

Terry retrieved the dusty #trophy from the attic to show Keith.

Valerie was given a light #stroller for her children to use.

An insightful article motivated the aspiring #magician to take circus classes.

The tired chemist carried the white #envelope inside before opening it.

Sophia collected sponsored #freebies at the school's summer internship fair.

The firefighter gave a shiny truck #sticker to the students.

In Sarah's cabin Emily folded her purple #skirt and white sweater.

Yelling, the arrogant builder moved the electric #tractor by the barn.

After graduating, Julius cleaned out his messy #locker and drove home.

They shared some French shrimp and then discussed #poetry for hours.

A small disaster occurred when Catalina made tropical #salad for snack.

misstep	
mockery	
peculiar	
gouge	
culture	
copybook	
dipstick	
enemies	
walkaway	
paperboy	
client	
typhoon	
cargo	
tremor	
platters	
embolism	
cervix	
warhorse	
choice	
checkout	
dashed	
ledge	
novelist	
charcoal	
parish	
agonies	
bouncer	
visor	
prophecy	
rockers	
youth	
sniffer	
nature	
outcasts	
tenors	
catalyst	
mosquito	
mattress	
syndrome	
trainee	
stair	
lettuce	
testes	
rocket	
pants	

Sierra borrowed Angela's necklace for the team's fancy #ceremony on Saturday.   forehead
An extreme #fisher used a bow and arrow to fish.   primer
Vince's questionable #humility caused people to view him as conceited.   folklore
Mary hates #treading water but her swimming coach highly recommends it.   specters
After getting her thick #eyebrows waxed, Ashley went home and bathed.   yearbook
Bobbi skimmed cheap #catalogs hoping to find a good deal.   admirals
Tiger cubs observe older #males in order to learn social behaviors.   flair
The children read about #primary colors today in art class.   corncob
The view of the glistening #sandbank took Andrew's breath away.   slowness
The nanny used a portable #heater to warm the kids' rooms.   broiler
The elderly miner liked his wife's #gravy more than her turkey.   daisy
The director went on a short #rampage during dress rehearsal.   cinders
A battered trailer hit Clarissa's newly installed #fence and destroyed it.   flame
The blond singer ultimately purchased the green #cottage by the lake.   content
Frank's latest budget improvements pleased the committee #lawyer who approved them.   curler
Veronica has the terrible #habit of chewing her pens and pencils.   saver
Seeing a large stain on the bedroom #carpet enraged Lauren terribly.   carrot
No more butter was left when the demanding #visitor had breakfast.   sunburn
When the lonely soldier bent down, the dark #puppy approached him.   aisle
With Robert's approval James will replace the antique #stove downstairs.   cloud
Among the specialist's many recommendations was to stop drinking #protein shakes.   poppies
Fortunately they quickly found out about the newly formed #tumor cells.   facet
The rowdy #talent show showcased many acts of juggling and humming.   vortex
Martha's charming #grandson made holiday decorations for her to display.   argument
A controversial #tariff was placed on many Japanese high tech imports.   rocker
Jane's relentless #sarcasm is sometimes perceived as a nuisance by people.   regimes
Because the skunk was quite #clever, it dug under the fence.   tonsil
The colorful #mango stands out in the gray shopping bag.   stool
The practiced #satire that the comedian used highlighted his political views.   spokes
Wendy's undeniable #empathy allows her to console grieving friends and family.   catcher
Their favorite #arcade was just across the street from the school.   wagons
As a famous #expert in neurology, David received a prestigious prize.   rookie
Rose bought expensive #lingerie for Aubrey as a birthday present.   courtesy
During our summer #cookout the pit master roasts a pig.   summons
Taylor remembers complicated #lyrics but struggles with remembering basic history facts. effort
Jessica buys dance #apparel second hand because she outgrows it quickly.   planets
Tina prefers putting #jelly and butter on her morning waffles.   torso
That expensive jacket of his requires #patience to wash and dry.   shortage
The quarter sized #turtle escaped its tank and ran away.   quirks
The Spanish King #banished his council after the war was over.   seaboard
Adding some white #vinegar to the washer will remove unpleasant smells.   dioxide
She found herself #restless when she was reading modern poems.   terror
The President highlighted #obesity as a healthcare concern in today's society.   attuned
During the protracted #prologue, the essayist established the antagonist's background. recourse
Multiple pieces of compelling #evidence were shown in the courtroom.   conquest

This morning Carlton selected #sweets to bring to the sleepover party.   height
Nia showed a different #attitude after being grounded for a week.   nutshell
Dan held a spontaneous #workshop for people who played percussion.   junction
Almost every voter recognized their preferred #symbol printed on the ballot.   gravel
Larry burned his sensitive #tongue while drinking freshly made tea.   shaker
The goalkeeper had great #reflexes and was fast on his feet.   poolroom
Before becoming a capable #surgeon, Victor studied medicine for eight years.   officer
Brandon had a persistent #headache that didn't respond to medication.   deadwood
On Sundays, Erica cooks #supper for her family and friends.   pecans
Jess befriended a Chilean #steward on her flight back from Santiago.   barrack
After attending the frightening #carnival, Bianca experienced nightmares and cold sweats.   outcomes
Bella bought a special #album for the pictures from her graduation.   oaths
Out of curiosity Daniel researched #nudist beaches on the Canary Islands.   safari
The scientist used the isolated #iceberg for his environmental research.   trapper
When the enormous whale appeared, the surprised #coach took many pictures.   tooth
The new professor tolerated less #nonsense than the previous one.   forehead
Last year Campbell bought thirteen #acres of land in the countryside.   gloom
Because he has a fractured #scapula, Kevin cannot play baseball.   mallard
Ralph served as the first #lookout during a game of paintball.   offence
Anna likes to eat dessert #pretzels with cinnamon and cream cheese.   pinewood
Jen made the beautifully intricate #lattice structure on the pie.   flyover
Leaked information about a growing #rebel force worried the commander.   onset
The construction of the narrow #tunnel was halted by the flood.   glands
Because Nicole bought a comprehensive #warranty, her computer was replaced.   lisitings
While waiting for the interminable #dialysis to be over, Mariah knitted.   lambskin
The cheap dresser where Lynne's new black #wallet was suddenly broke.   prince
Her dad built Kristen an enormous #playroom for her toys.   watchmen
My uncle Willis was an accomplished #athlete before tearing his acl.   visions
Brea decided to use the nicer #forks for her dinner party.   teeth
The aging salesman enjoyed the increased #headroom in his new car.   ejection
Cory is part of an amazing #quartet that plays bluegrass music.   skimmer
The new owner performed a complete #overhaul of his football team.   foxhound
Lucy and Eugene trekked to their #scenic wedding site last week.   fatten
Before leaving for vacation, the teacher #managed to submit the grades.   boatmen
Addison was surprised by the strong #grape flavor of the drink.   arrow
While Antoine was unconscious, the local #pastor prayed for his recovery.   sucker
Every developing trend described in the established #magazine puzzled Naomi.   dialogue
After having the flu, Michael noticed lowered #stamina during his runs.   ballads
Sunday Julia went to the newly built #tavern to watch Creed.   cereal
In her bag, Clarence kept a modest #pouch for coins.   canal
Because of the constant rain, the shiny #enamel began to rust.   gnomes
On Saturday, Kyle searched for the ancient #comet in the sky.   prism
Tim did not think that he could #afford his dream car.   abides
Her profile listed a preference for contemporary #fiction over other genres.   penalty
The judge called the defendant into the private #chamber to talk.   welfare

The fans reacted to the scandal with tremendous #faith and strength.   tribe
Brenda broke her toe by dropping a heavy #dumbbell on it.   latchkey
Lamar's famous #cousin will be coming to visit for Thanksgiving.   beacon
Every month, the sales representative had extreme #quotas to meet.   status
The little girl planned on bringing the squirming #piglet home.   obsess
Maya and her international guest had their favorite #author in common.   blouse
A large gorilla at the zoo took Felice's #bracelet from her.   chipmunk
Kristy spent a year working at a vast #dairy farm.   rugby
Maurice and Julie requested a copy of the recently #analyzed dataset.   undercut
Tucker loved the orange candy because of its classical #tangy flavor.   jumpy
The brilliant #writer was known to be passionate about his work.   wolves
Genevieve grew #orchids in her greenhouse to give out as gifts.   vampire
Carla's greatest #downfall was her extreme pride which left her friendless.   radiance
The temperamental #copier is always broken so teachers often read handouts.   creeds
Even a severe #phobia of spiders can be cured with exposure.   maggot
The retired #admiral warmly welcomed the reporter into his house.   magical
Tatiana inspected #refugee camps in Turkey and Greece this summer.   fishery
The spreading #venom from Sam's snake bite caused her to suffocate.   halls
Using fresh #chives will improve the flavor of the omelet.   thorns
Maurice's deep #sadness was immediately dispelled after receiving the good news.   perjury
The unruly #audience kept interrupting the production of the show.   crossbar
As morning approached, #droplets of dew formed under the gardenia's leaves.   capacity
Gerald's business distributes #statues to landscaping businesses in and around Toronto. condemn
Helen tried different #noises that usually make her baby laugh uncontrollably.   virtue
During the holiday #luncheon, the first grade class performed a play.   trickery
Jake wanted his groomsmen's #vests to match his purple bowtie.   guilt
During recess, Jamie #mistook one of her teachers for her mom.   veranda
The researcher picked #Brazil as the location for his next experiment.   ensued
In a recent #primates exhibit, apes and spider monkeys were displayed.   silencer
In her precious #journal, Taylor wrote her dreams and aspirations.   trooper
Although Cecil appreciates #musicals, he cannot stand people singing along.   severity
My parents discovered #bingo last week and now they are hooked.   pasta
During Cedric's summer #escapade, he was taught how to sail.   lymphoma
His parents had multiple #theories regarding the cookie jar's disappearance.   honeydew
She discovered the emotional #memoir Greta had written during her illness.   hooter
Large amounts of stacked #timber obstructed Melissa's view of the fields.   accent
Vincent found a large #rodent under the kitchen sink at home.   pewter
The principal had interesting #concepts about how to teach discipline.   facility
Because of a slight #blemish, the convertible sold for less money.   erasers
Sally cut up several #onions for the stew she was making.   Topeka
To repair her damaged #heels Heather uses a soothing lavender lotion.   plaza
Because of its dropping #ratings, the television series was cancelled.   javelin
The little girl accidentally #killed the caterpillar during the soccer game.   enroll
Natalie made a complicated #solution today in her science class.   stooping
The teacher created a small #booklet for one of her students.   foreman

The craftsman built a cedar #coffin for his deceased father.   cooker
The test revealed the common #grain sensitivity that Roxanne had noticed.   props
Carla bought a cherry #macaroon at the corner pastry shop.   segments
After taking off his thick #bandages, Myles felt whole again.   township
The new tenants removed intricate #cobwebs from the fan and windows.   knocker
The students were assigned multiple #chapters for homework in biology.   squealer
People come up with many #excuses when returning library books late.   sundown
Nobody believed that the latest #suspect was telling the truth.   capsule
The construction worker accidentally dropped #metal rods from the roof.   admit
The journalist became a fueling #agitator in the global warming debate.   metaphor
During his legislature Clark fiercely #upheld his strict moral values.   weirdo
Jerome noticed that the dense #shrubs were attracting bees and butterflies.   stench
The tech firm sought a responsible #investor to create their portfolio.   gasoline
Kyle saw a brightly colored #lizard as he walked to school.   octane
The director is wearing a patterned #shawl to cover her shoulders.   limbo
The talented artist painted a lively #mural of Rio de Janeiro.   locus
The young farmer placed a massive #cowbell on his favorite bull.   tyranny
Rhonda constructs castles out of enormous #crates and old linens.   tipper
After buying a pair of expensive #rackets, Harry was excited.   ragtime
After the heavy snow, the brick #sidewalk became a safety hazard.   landings
Because he had a very good #alibi, Jonathan was released.   demon
Mary's boss is planning a moderate #decrease in personnel this quarter.   muffling
Marco became frustrated with his useless #degree in animal communication.   survey
Dale blamed his irritation on recent #hormone fluctuations due to medication.   playoff
As he drove, Patrick's last #dollar flew out of the window.   humans
At the ballpark, Rebecca loves to devour #hotdogs and chips.   colonel
Carla keeps her diploma as a celebratory #memento of achievement.   buddies
The resident advisor told students that real #candles were not allowed.   justice
On his birthday, Nick received a silk #necktie and a fedora.   marshes
On Thanksgiving, Edgar only eats the crisp #crust of the pie.   coeds
Mark started his search for a dependable #cashier for the store.   dissent
The Garfields complained when their very expensive #baggage was lost.   acidity
The car that Wanda received was a silver #compact sedan.   culprit
The actor used wires to create a realistic #illusion of levitation.   instance
The crowd was excited to watch the breathtaking #acrobat perform.   glossy

REFERENCES

Arbel, Y., Spencer, K. M., & Donchin, E. (2011a). The N400 and the P300 are not all that independent. *Psychophysiology, 48*(6), 861-875.

Arbel, Y., Spencer, K. M., & Donchin, E. (2011b). The N400 and the P300 are not all that independent. *Psychophysiology, 48*(6), 861-875.

Barber, H. A., Meij, M., & Kutas, M. (2013). An electrophysiological analysis of contextual and temporal constraints on parafoveal word processing. *Psychophysiology, 50*(1), 48-59.

Bornkessel, I., & Schlesewsky, M. (2006). The extended argument dependency model: A neurocognitive approach to sentence comprehension across languages. *Psychological Review, 113*(4), 787.

Bullmore, E. T., Suckling, J., Overmeyer, S., Rabe-Hesketh, S., Taylor, E., & Brammer, M. J. (1999). Global, voxel, and cluster tests, by theory and permutation, for a difference between two groups of structural MR images of the brain. *Medical Imaging, IEEE Transactions On, 18*(1), 32-42.

Chauncey, K., Holcomb, P. J., & Grainger, J. (2008). Effects of stimulus font and size on masked repetition priming: An event-related potentials (ERP) investigation. *Language and Cognitive Processes, 23*(1), 183-200.

Davis, C., & Forster, K. I. (1994). Masked orthographic priming: The effect of prime-target legibility. *The Quarterly Journal of Experimental Psychology, 47*(3), 673-697.

Dehaene, S., Naccache, L., Cohen, L., Le Bihan, D., Mangin, J., Poline, J., & Rivière, D. (2001). Cerebral mechanisms of word masking and unconscious repetition priming. *Nature Neuroscience, 4*(7), 752-758.

Delorme, A., & Makeig, S. (2004). EEGLAB: An open source toolbox for analysis of single-trial EEG dynamics including independent component analysis. *Journal of Neuroscience Methods, 134*(1), 9-21.

Dimigen, O., Kliegl, R., & Sommer, W. (2012). Trans-saccadic parafoveal preview benefits in fluent reading: A study with fixation-related brain potentials. *NeuroImage, 62*(1), 381-393.

Dufau, S., Grainger, J., & Holcomb, P. J. (2008). An ERP investigation of location invariance in masked repetition priming. *Cognitive, Affective, & Behavioral Neuroscience, 8*(2), 222-228.

Duñabeitia, J. A., Molinaro, N., Laka, I., Estévez, A., & Carreiras, M. (2009). N250 effects for letter transpositions depend on lexicality:'casual'or 'causal'? *Neuroreport, 20*(4), 381-387.

Eimer, M., & Schlaghecken, F. (2002). Links between conscious awareness and response inhibition: Evidence from masked priming. *Psychonomic Bulletin & Review, 9*(3), 514-520.

Engbert, R., Nuthmann, A., Richter, E. M., & Kliegl, R. (2005). SWIFT: A dynamical model of saccade generation during reading. *Psychological Review, 112*(4), 777.

Ferrand, L., Grainger, J., & Segui, J. (1994). A study of masked form priming in picture and word naming. *Memory & Cognition, 22*(4), 431-441.

Forster, K. I., & Davis, C. (1984). Repetition priming and frequency attenuation in lexical access. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 10*(4), 680.

Gagl, B., Hawelka, S., Richlan, F., Schuster, S., & Hutzler, F. (2014). Parafoveal preprocessing in reading revisited: Evidence from a novel preview manipulation. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 40*(2), 588.

Grainger, J., & Holcomb, P. J. (2009). Watching the word go by: On the time-course of component processes in visual word recognition. *Language and Linguistics Compass, 3*(1), 128-156.

Grainger, J., Kiyonaga, K., & Holcomb, P. J. (2006). The time course of orthographic and phonological code activation. *Psychological Science, 17*(12), 1021-1026. doi:PSCI1821 [pii]

Groppe, D. M., Urbach, T. P., & Kutas, M. (2011). Mass univariate analysis of event-related brain potentials/fields I: A critical tutorial review. *Psychophysiology, 48*(12), 1711-1725.

Hauk, O., Davis, M. H., Ford, M., Pulvermüller, F., & Marslen-Wilson, W. D. (2006). The time course of visual word recognition as revealed by linear regression analysis of ERP data. *NeuroImage, 30*(4), 1383-1400.

Henderson, J. M., & Ferreira, F. (1990). Effects of foveal processing difficulty on the perceptual span in reading: Implications for attention and eye movement control. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 16*(3), 417.

Henderson, J. M., & Ferreira, F. (1993). Eye movement control during reading: Fixation measures reflect foveal but not parafoveal processing difficulty. *Canadian Journal of Experimental Psychology/Revue Canadienne De Psychologie Expé Rimentale, 47*(2), 201.

Henderson, J. M., Pollatsek, A., & Rayner, K. (1989). Covert visual attention and extrafoveal information use during object identification. *Perception & Psychophysics, 45*(3), 196-208.

Holcomb, P. J., & Grainger, J. (2006). On the time course of visual word recognition: An event-related potential investigation using masked repetition priming. *Cognitive Neuroscience, Journal Of, 18*(10), 1631-1643.

Huang, Y. T., Hopfinger, J., & Gordon, P. C. (2014). Distinguishing lexical-versus discourse-level processing using event-related potentials. *Memory & Cognition, 42*(2), 275-291.

Inhoff, A. W. (1989). Parafoveal processing of words and saccade computation during eye fixations in reading. *Journal of Experimental Psychology: Human Perception and Performance, 15*(3), 544.

Inhoff, A., Eiter, B., Radach, R., & Juhasz, B. (2003). Distinct subsystems for the parafoveal processing of spatial and linguistic information during eye fixations in reading. *The Quarterly Journal of Experimental Psychology Section A, 56*(5), 803-827.

Kiyonaga, K., Grainger, J., Midgley, K., & Holcomb, P. J. (2007). Masked cross-modal repetition priming: An event-related potential investigation. *Language and Cognitive Processes, 22*(3), 337-376.

Kouider, S., & Dehaene, S. (2007). Levels of processing during non-conscious perception: A critical review of visual masking. *Philosophical Transactions of the Royal Society of London.Series B, Biological Sciences, 362*(1481), 857-875. doi:Q8G05208M6626H04 [pii]

Kutas, M., & Federmeier, K. D. (2000). Electrophysiology reveals semantic memory use in language comprehension. *Trends in Cognitive Sciences, 4*(12), 463-470.

Kutas, M., & Hillyard, S. A. (1980). Event-related brain potentials to semantically inappropriate and surprisingly large words. *Biological Psychology, 11*(2), 99-116.

Ledoux, K., Gordon, P. C., Camblin, C. C., & Swaab, T. Y. (2007a). Coreference and lexical repetition: Mechanisms of discourse integration. *Memory & Cognition, 35*(4), 801-815.

Ledoux, K., Gordon, P. C., Camblin, C. C., & Swaab, T. Y. (2007b). Coreference and lexical repetition: Mechanisms of discourse integration. *Memory & Cognition, 35*(4), 801-815.

Li, N., Niefind, F., Wang, S., Sommer, W., & Dimigen, O. (2015). Parafoveal processing in reading chinese sentences: Evidence from event-related brain potentials. *Psychophysiology, 52*(10), 1361-1374.

Lopez-Calderon, J., & Luck, S. J. (2014). ERPLAB: An open-source toolbox for the analysis of event-related potentials. *Frontiers in Human Neuroscience, 8*

Marx, C., Hawelka, S., Schuster, S., & Hutzler, F. (2015). An incremental boundary study on parafoveal preprocessing in children reading aloud: Parafoveal masks overestimate the preview benefit. *Journal of Cognitive Psychology,* (ahead-of-print), 1-13.

Matin, E. (1974). Saccadic suppression: A review and an analysis. *Psychological Bulletin, 81*(12), 899.

McDonald, S. A. (2005). Parafoveal preview benefit in reading is not cumulative across multiple saccades. *Vision Research, 45*(14), 1829-1834. doi:http://dx.doi.org/10.1016/j.visres.2005.01.008

Miellet, S., O'Donnell, P. J., & Sereno, S. C. (2009). Parafoveal magnification: Visual acuity does not modulate the perceptual span in reading. *Psychological Science, 20*(6), 721-728. doi:10.1111/j.1467-9280.2009.02364.x [doi]

Misra, M., & Holcomb, P. J. (2003). Event–related potential indices of masked repetition priming. *Psychophysiology, 40*(1), 115-130.

Morrison, R. E. (1984). Manipulation of stimulus onset delay in reading: Evidence for parallel programming of saccades. *Journal of Experimental Psychology: Human Perception and Performance, 10*(5), 667.

Naccache, L., Blandin, E., & Dehaene, S. (2002). Unconscious masked priming depends on temporal attention. *Psychological Science, 13*(5), 416-424.

Naccache, L., & Dehaene, S. (2001). The priming method: Imaging unconscious repetition priming reveals an abstract representation of number in the parietal lobes. *Cerebral Cortex (New York, N.Y.: 1991), 11*(10), 966-974.

Nagy, M. E., & Rugg, M. D. (1989). Modulation of Event-Related potentials by word repetition: The effects of Inter-Item lag. *Psychophysiology, 26*(4), 431-436.

Nakayama, M., Sears, C. R., & Lupker, S. J. (2010). Testing for lexical competition during reading: Fast priming with orthographic neighbors. *Journal of Experimental Psychology: Human Perception and Performance, 36*(2), 477.

Osterhout, L., McKinnon, R., Bersick, M., & Corey, V. (1996). On the language specificity of the brain response to syntactic anomalies: Is the syntactic positive shift a member of the P300 family? *Journal of Cognitive Neuroscience, 8*(6), 507-526.

Posner, M. I., & Snyder, C. R. (2004). Attention and cognitive Control1. *Cognitive Psychology: Key Readings, ,* 205.

Pulvermüller, F., Assadollahi, R., & Elbert, T. (2001). Neuromagnetic evidence for early semantic access in word recognition. *European Journal of Neuroscience, 13*(1), 201-205.

Rayner, K. (1975). The perceptual span and peripheral cues in reading. *Cognitive Psychology, 7*(1), 65-81.

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

Rayner, K., McConkie, G. W., & Zola, D. (1980). Integrating information across eye movements. *Cognitive Psychology, 12*(2), 206-226.

Reichle, E. D., Pollatsek, A., Fisher, D. L., & Rayner, K. (1998). Toward a model of eye movement control in reading. *Psychological Review, 105*(1), 125.

Rugg, M. D. (1983). Further study of the electrophysiological correlates of lexical decision. *Brain and Language, 19*(1), 142-152.

Rugg, M. D., & Nagy, M. E. (1989). Event-related potentials and recognition memory for words. *Electroencephalography and Clinical Neurophysiology, 72*(5), 395-406.

Schroyens, W., Vitu, F., Brysbaert, M., & d'Ydewalle, G. (1999). Eye movement control during reading: Foveal load and parafoveal processing. *The Quarterly Journal of Experimental Psychology: Section A, 52*(4), 1021-1046.

Sereno, S. C., & Rayner, K. (1992). Fast priming during eye fixations in reading. *Journal of Experimental Psychology: Human Perception and Performance, 18*(1), 173.

Sereno, S. C., Rayner, K., & Posner, M. I. (1998). Establishing a time-line of word recognition: Evidence from eye movements and event-related potentials. *Neuroreport, 9*(10), 2195-2200.

Slattery, T. J., Angele, B., & Rayner, K. (2011). Eye movements and display change detection during reading. *Journal of Experimental Psychology: Human Perception and Performance, 37*(6), 1924.

Smith, M. C., Besner, D., & Miyoshi, H. (1994). New limits to automaticity: Context modulates semantic priming. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 20*(1), 104.

Spencer, K. M., Dien, J., & Donchin, E. (2001). Spatiotemporal analysis of the late ERP responses to deviant stimuli. *Psychophysiology, 38*(02), 343-358.

van de Meerendonk, N., Chwilla, D. J., & Kolk, H. H. (2013). States of indecision in the brain: ERP reflections of syntactic agreement violations versus visual degradation. *Neuropsychologia, 51*(8), 1383-1396.

White, S. J., Rayner, K., & Liversedge, S. P. (2005a). Eye movements and the modulation of parafoveal processing by foveal processing difficulty: A reexamination. *Psychonomic Bulletin & Review, 12*(5), 891-896.

White, S. J., Rayner, K., & Liversedge, S. P. (2005b). Eye movements and the modulation of parafoveal processing by foveal processing difficulty: A reexamination. *Psychonomic Bulletin & Review, 12*(5), 891-896.

Winkler, I., Haufe, S., & Tangermann, M. (2011). Automatic classification of artifactual ICA-components for artifact removal in EEG signals. *Behavioral and Brain Functions : BBF, 7*, 30-9081-7-30. doi:10.1186/1744-9081-7-30 [doi]