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A beautiful day in the neighborhood: An event-related potential study of lexical relationships and prediction in context

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ABSTRACT

Two related questions critical to understanding the predictive processes that come online during sentence comprehension are (1) what information is included in the representation created through prediction and (2) at what functional stage does top-down, predicted information begin to affect bottom-up word processing? We investigated these questions by recording event-related potentials (ERPs) as participants read sentences that ended with expected words or with unexpected items (words, pseudowords, or illegal strings) that were either orthographically unrelated to the expected word or were one of its orthographic neighbors. The data show that, regardless of lexical status, attempts at semantic access (N400) for orthographic neighbors of expected words are facilitated relative to the processing of orthographically unrelated items. Our findings support a view of sentence processing wherein orthographically organized information is brought online by prediction and interacts with input prior to any filter on lexical status.

Introduction

The feeling that one knows what a conversation partner is about to say or what words are coming up in a text is familiar to most people. Indeed, offline tests, such as the often-used cloze probability measure (Taylor, 1953), reveal that even individual sentences can be strongly constraining, allowing many or most people to complete those sentences with exactly the same lexical item. For example, given the sentence frame "Psycholinguists debate about when and how language comprehenders use contextual information to predict upcoming __________" a majority of this article's readers would be likely to provide "words" as a completion. Such contextual predictability has been shown to have a facilitative effect on behavioral measures of word processing (including naming and lexical decision times; for example, Fischler & Bloom, 1979; McClelland & O'Regan, 1981), eye movements during natural reading (e.g., Frisson, Rayner, & Pickering, 2006), and brain activity (e.g., Kutas & Hillyard, 1980, 1983, 1984). However, psycholinguists *do* debate about what these patterns suggest about the role of prediction in shaping the rapid, on-line analysis of language during normal comprehension. Does the subjective sense of sometimes being able to predict what one will hear or read arise because some words – actually analyzed in a feed-forward, stimulus-driven manner – are easier to integrate with their contexts? Or, if the language comprehension system instead uses top-down, contextual information to actively generate features of likely upcoming words, what are the consequences of this generation for bottom-up processing of incoming words?

Theoretical frameworks and models vary widely both in *what* information they assume might be predicted and also in *when* in the course of bottom-up processing those predictions are believed to have their effect. Theorists at one extreme argue that there are *a priori* reasons to question the availability and usefulness of predicted information, given that language is generative and that words that are

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sufficiently constrained to be predictable have been argued to be rare in natural contexts (e.g., Gough, 1991; Gough, Alford, & Holley-Wilcox, 1981; Jackendoff, 2002). For instance, the example sentence above could felicitously have ended with "nouns" or "information", among other words. Accordingly, in a number of theoretical frameworks, initial stages of word recognition (both visual and auditory) are postulated to take place in a wholly or largely stimulus-driven fashion (e.g., Forster, 1989; Gaskell & Marslen-Wilson, 1997; Perry, Ziegler, & Zorzi, 2007). The CDP+ model (Perry et al., 2007), for example, manages to be highly accurate at reproducing certain aspects of word recognition (e.g., reading latencies for words and non-words) without representing semantics at all, let alone context effects of any kind.

In frameworks that limit the role of prediction in online language processing, contextually based predictions about specific upcoming items, if they are formed at all, are assumed to have their effects only during late stages of processing (i.e., processing that occurs after the recognition of a word is already complete.) In their classic paper, Stanovich and West (1983), for example, explain decreased lexical decision times for sentence-congruent completions via an automatic spread of activation in the semantic network accruing from the context words. This spread of activation is confined to the semantic system and does not result in the pre-activation of specific lexical items or orthographic wordforms (a separate process, which is able to pre-activate specific lexical items, is assumed to be too slow to participate in comprehension at its natural speed).

However, even if prediction cannot always be successful, there are also arguments for the position that the language comprehension system would benefit from trying to use all the information it has available as soon as possible in order to most effectively deal with a rapid, noisy, often ambiguous input signal (e.g., Federmeier, 2007; Pickering and Garrod, 2007; Otten, Nieuwland, & Van Berkum, 2007; Van Berkum, Brown, Zwitserlood, Kooijman, & Hagoort, 2005). Further, given that communication often takes place with familiar conversation partners and in the context of a large body of shared knowledge and experience (e.g., Tanenhaus & Brown-Schmidt, 2008), not to mention social, environmental, and discourse-related cues, it may be more possible to predict upcoming meaning and word information than has sometimes been assumed. Accordingly, some models postulate an important role for top-down processes, including information derived from prediction, in all stages of word processing.

In the connectionist dual-path model of syntax acquisition and sentence comprehension (Chang, Dell, & Bock, 2006), for example, the system used for language production is also active during listening, predicting the phonological form of upcoming words in the input stream as part of its learning mechanism. By minimizing error between the words that the model predicts while it is listening and those that it actually hears, the model develops both a learned syntax and an ability to produce novel utterances. In the dual-path model, therefore, prediction not only takes place both during comprehension and production but is also critical to the acquisition of syntactic knowledge (comprehension tasks are not specifically simulated by the model, but Chang et al. (2006) explicitly state that prediction must take place during comprehension as a means of training the production model).

Empirical support for models that posit a role for top-down, predictive processes in on-line input processing has come from a variety of domains. In auditory language comprehension, listener judgments showing lexical effects on ambiguous phoneme perception (i.e., perceiving a mix between a /p/ and /b/ as /p/ in the presence of the context /lʌg/) or compensation for coarticulation (i.e., taking into account the articulatory properties of an immediately preceding phoneme in perception of an input phoneme) have been taken as support for interactive models such as TRACE (Elman & McClelland, 1988; McClelland & Elman, 1986; although see Norris, McQueen, & Cutler, 2000; Pitt & McQueen, 1998 for arguments against top-down involvement in the same types of processing). In the visual domain, eye-movement studies of natural reading have found that highly predictable targets are fixated for less time when visually similar items have been pre-viewed in parafoveal vision, which is taken as evidence that the match between the visual information in the preview and a specific predicted target word facilitates target processing when that position in the text is reached (Balota, Pollatsek, & Rayner, 1985). In fact, highly predictable words can even be skipped entirely (Ehrlich & Rayner, 1981; Rayner & Well, 1996), strongly suggesting that prediction about upcoming words in a visually presented sentence rapidly affects processing of input items. Further, a Bayseian model of lexical constraint has been shown to be highly successful in predicting fixation durations during naturalistic reading (McDonald & Shillcock, 2003), suggesting that even fairly limited context (i.e., one preceding word) may be enough to make predictions about upcoming lexical forms that are strong enough to affect eye movements.

Another important source of evidence for early influences of context-based predictions in word processing has come from measures of brain electrical activity in the form of event-related potentials (ERPs). It has long been known that semantic contextual information reduces the amplitude of the N400, a component observed between 200 and 500 ms post-stimulus-onset (Kutas & Hillyard, 1980). The N400 constitutes part of the normal response to potentially meaningful items in any stimulus modality (for a review, see Federmeier & Laszlo, in press) and its amplitude is thought to represent the level of lexical-semantic activation in the comprehension network (Holcomb, Grainger, & O'Rourke, 2002; see also Laszlo & Federmeier, 2007, 2008). The N400 seems to reflect initial attempts at lexico-semantic access, which unfold automatically and implicitly. N400 facilitation can be observed with masking (Deacon, Hewitt, Yang, & Nagata, 2000; Kiefer, 2002; Misra & Holcomb, 2003), during the attentional blink (Rolke, Heil, Streb, & Hennighausen, 2001), during some stages of sleep (Brualla, Romero, Serrano, & Valdizan, 1998), and even in coma (Kotchoubey et al., 2005). Further, patient studies reveal that N400 repetition effects (reduced N400s for the second presentation of an item in a word list; Rugg & Nagy, 1987) are elicited by individuals with amnesia (Olichney et al., 2000). In contrast, effects of repetition on the Late Positive Complex (LPC, a later component linked to more attentionally-demanding aspects of processing in both memory and language studies) are absent in amnesia, and thus more closely linked to patients' subjective experiences (i.e., their inability to explicitly note these repetitions). The N400 thus provides a functionally specific window into early aspects of lexico-semantic processing that are obligatorily elicited by stimuli such as spoken words and letter strings.

Electrophysiological evidence suggesting that at least the semantics of not-yet-presented words can be activated by sentential context first came from the finding that anomalous sentence-final words that are semantically related to expected sentence completions elicit N400 responses of reduced amplitude relative to equally unexpected, but semantically unrelated, completions (e.g. smaller N400s to *pines* than to *tulips* as a completion for "*They wanted to make the hotel look more like a tropical resort. So, along the driveway, they planted rows of...*"; Federmeier & Kutas, 1999; cf. Kutas, Lindamood, & Hillyard, 1984). Strikingly, this facilitation for unexpected but related endings increases with increasing contextual constraint, despite the fact that more constraining contexts render unexpected items even less plausible (Federmeier & Kutas, 1999). That is, N400 facilitation for unexpected but semantically related words goes counter to plausibility, patterning instead with the relationship between the presented word and the predicted (but never encountered) one and the strength of the (unrealized) prediction. This strongly suggests that the semantic features of expected words become active prior to stimulus presentation. Such influences of prediction are seen not only for visual word recognition during word-by-word reading, but also during the comprehension of natural speech (Federmeier, McLennan, de Ochoa, & Kutas, 2002).

Other results suggest that not only semantic but also morpho-syntactic and phonological features of upcoming words can be pre-activated by sentence contexts. In several studies using gender-marked languages, such as Spanish (Wicha, Bates, Moreno, & Kutas, 2003; Wicha, Moreno, & Kutas, 2003, 2004) and Dutch (Otten et al., 2007), ERP differences have been seen for articles (Wicha et al., 2003, 2004) or adjectives (Otten et al., 2007) as a function of whether or not they agree in gender with the predicted (but not-yet-presented) noun that they modify. Similar results have been seen for English determiners, which do not contain gender information but do have an alternation based on phonological properties of the noun that they modify (i.e., *a* is used with words that begin with consonant sounds whereas *an* is used with those that begin with vowel sounds). Smaller N400s are elicited in response to articles that would be phonologically appropriate with an expected noun than to those that would not (e.g., N400s are larger to *a* than *an* in the sentence "*It was raining outside, so before I left the house I made sure to take A/AN umbrella.*"), and, again, this effect tracks the level of predictability of the yet-to-be-presented noun (Delong, Urbach, & Kutas, 2005). Reduced N400s in response to articles that matched the predicted noun were observed even when the cloze probability of that predicted noun was moderate (i.e., between 60% and 80%) or low (i.e., between 20% and 40%). Results like these suggest that sentence contextual information may be routinely used to pre-activate fairly specific features of likely upcoming lexical items.

The accruing evidence for rapid, specific prediction across behavioral, eyetracking, and brain measures suggests specific questions for further research. First, what kinds of information can be brought online by prediction? The evidence just discussed suggests that predictions can be quite lexically specific. Does prediction then also bring on-line specific orthographic and even visual properties of likely upcoming words, as seems to be suggested by the eye-tracking literature (e.g., Balota et al., 1985)? A second, related question asks at what stage of processing this pre-activated information begins to have its effects. Must important aspects of word recognition be completed before top-down information sources have their influence, as predicted by autonomous models? Or, as hypothesized by interactive models, can top-down influences shape the bottom-up recognition of words? Recent ERP data (Laszlo & Federmeier, 2007, 2008) have shown that N400 responses are elicited by not only words and orthographically regular pseudowords (e.g., Rugg & Nagy, 1987) but even by illegal strings of letters, suggesting that aspects of the processing indexed by the N400 precede the point at which the system has ceased processing non-words for meaning. Prediction-based effects on the N400, therefore, might be occurring early in the analysis of visual words, although the extant ERP data on prediction in sentence processing (all collected using real words) cannot directly speak to this question.

To examine these outstanding questions about the nature and dynamics of prediction during sentence processing, therefore, in the present study we asked participants to read highly constraining sentences that ended either with their expected completion, with an orthographic neighbor of that completion, or with an orthographically unrelated item (e.g., "The genie was ready to grant his third and final wish/dish/clam.") If, as predicted by theories such as those of Stanovich & West (1983), only general semantic information can be brought online in time to participate in the pre-attentive bottom-up processing of incoming text, then N400 amplitudes should prove insensitive to orthographic neighborhood status, patterning only with contextual plausibility. However, if orthographically organized information is brought online by sentence context, then, despite their similar lack of fit to the context, orthographic neighbors of expected completions may be processed differently than orthographically unrelated items.

The likely nature of any such difference depends on assumptions about how orthographic and lexical information are represented in the language processing system. Some models, such as the original Interactive Activation Model (McClelland & Rumelhart, 1981; Rumelhart & McClelland, 1982) and its successors (e.g., Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001; Perry et al., 2007) instantiate a lexical level of representation with lateral inhibition between neighbors. In such models, the activation of a lexical item through prediction would be expected to lead to concomitant inhibition of its orthographic neighbors, rendering their processing more difficult. We assume that expecting a specific lexical item should lead to activation of that item; thus, in our experiment, this predictive activation should lead to larger N400s to unexpected words when these are neighbors (e.g., "dish", as compared to non-neighbors, such as "clam") of the predicted completion. This pattern is expected based on a framework in which N400 amplitude is representative of the ease of accessing and/or integrating an input into the sentential context; items that have been inhibited should be harder to access and integrate, resulting in larger N400s to those items.

Alternatively, if orthographic features of the wordform "dish" are pre-activated or rendered more likely through the prediction of the orthographically quite similar item "wish," we could expect to see downstream facilitation of "dish", as indicated by a decreased N400 to "dish" as opposed to "clam." Results like this would indicate that prediction-related activation extends to the level of orthography and is not counteracted by lexical-level inhibition, which would seem to be more compatible with models in which lexical items are not connected (e.g., some early versions of the Logogen Model; Morton, 1964, 1969) or in which there are no formal lexical representations available to inhibit each other (e.g., Harm & Seidenberg, 2004; Seidenberg & McClelland, 1989; although even in models without formal lexical representations, some inhibition could occur as, for example, between the word initial W consistent with WISH and the word initial D consistent with DISH).

The extant literature examining how visual word recognition is affected by orthographic neighbors does not indicate a clear conclusion from which to make predictions about the likely direction of any observed effects of orthographic relationship (for a review, see Rastle, 2007; also see Monsell & Hirsh, 1998 for a similar discussion of findings in the domain of auditory word recognition). A number of studies have used the lexical decision task and manipulated factors such as orthographic neighborhood size (i.e., Coltheart's *N*) in an attempt to determine whether lexical priming is facilitatory or inhibitory but, as Rastle (2007) points out, across the literature all three possible actions of lexical items on their neighbors have been observed: no effect (e.g., Coltheart, Davelaar, Jonasson, & Besner, 1977), facilitation (e.g., Andrews, 1989), and inhibition (e.g., Grainger & Jacobs, 1993). Task-specific strategic factors have been suggested as contributing to the conflicting patterns observed across studies (Grainger & Jacobs, 1996); for example, participants might sometimes base their lexical decisions on the summed level of activity in the network, rather than the activation of the specific item, and these "fast guesses" could lead to facilitative patterns for high *N* words, even in the presence of inhibitory connections between items. Because the present study uses a different task and a multidimensional measure that allows a clearer separation of more automatic aspects of lexico-semantic activation (as indexed by the N400) from more strategic, controlled aspects of processing (expected to manifest on the LPC), the results promise to provide an important complement to this body of work examining whether the activation of a particular lexical item has a facilitative or inhibitory influence on its neighbors. The N400 is already known to be sensitive to orthographic neighborhood size (e.g., Holcomb et al., 2002; Laszlo & Federmeier, 2007, 2008) and thus can be reasonably expected to show effects of interactions between orthographic neighbors. One important aspect of the experimental design we employ is that orthographic neighborhood size is exactly matched across conditions. Thus, we can safely link any observed effects to the manipulation of orthographic relationship, uncontaminated by any variation in *N*.

The question of what information becomes available through predictive processing (and how those representations interact – that is, through inhibition or facilitation) is related to our second question of interest – namely, at what functional level of word processing does prediction-based information begin to make contact with incoming stimulus information? Therefore, in the present study we cross the manipulation of orthographic relationship with a manipulation of lexical type, by including sentence completions that are orthographically regular pseudowords (either neighbors or non-neighbors of the expected word; e.g., wush or horm, in the example sentence above) and orthographically illegal strings (again, that are either neighbors or non-neighbors of the expected completion, as in wrsh or tknt in the example above). If effects of orthographic similarity are observed for words but not for pseudowords and illegal strings, this would suggest that orthographic inputs have to be lexically represented in order for prediction-based activations to have an impact on processing. If, instead, both words and pseudowords – but not illegal strings (which, in this experiment were chosen to have the lowest possible neighborhood density, to ensure their minimal similarity to lexically represented items) – show effects of orthographic similarity, this would mean that items have to be word-like, but not necessarily lexically represented, in order to be affected by predicted information. Finally, effects of orthographic neighbor status on all three stimulus classes would support a model in which prediction can impact the processing of even items that are dissimilar from words, as long as those items contain predicted orthographic features.

Methods

Participants

Data were analyzed from 24 participants (7 female, age range 18–28 years, mean age 20). Data from one additional participant was discarded due to unsatisfactory levels of ocular artifact. All were right-handed, monolingual speakers of English with normal or corrected to normal vision and no history of neurological disease or defect. Participants were graduate or undergraduate students at the University of Illinois. All participants were compensated with money or course credit.

Stimuli

The stimuli were composed of sentence frames ending with words, pseudowords, or illegal strings; words could be expected or unexpected, whereas all other stimulus types were (by definition) unexpected. Among the unexpected stimulus classes, half of each were orthographic neighbors of the expected word and half were non-neighbors. A few examples of all the possible stimulus types are presented in Table 1. To create the stimuli, we algorithmically searched all the 3–5 letter items in the Medical

Table 1
Example Stimuli.

Sentence frame	Expected completion	Unexpected word: neighbor	Pseudoword neighbor	Illegal string: neighbor	Unexpected word: non-neighbor	Pseudoword non-neighbor	Illegal string: non-neighbor
BEFORE LUNCH HE HAS TO DEPOSIT HIS PAYCHECK AT THE	BANK	BARK	PANK	BXNK	–	–	–
EVERY MORNING HE GETS UP AT SIX AND GOES FOR A TEN MILE	RUN	RUG	RON	RCN	–	–	–
IT WAS A BEAUTIFUL SUMMER DAY WITH NOT A CLOUS IN THE	SKY	SPY	SMY	SKO	–	–	–
SHE LOVES THE WAY THE LEAVES CHANGE COLORS IN THE	FALL	–	–	–	HOOK	JANK	TKNT
THE SIDES OF THE CANDLE WERE COVERED WITH DRIPPING	WAX	–	–	–	MUD	JUN	BKW
THE GENIE READY TO GRANT HIS WISH THIRD AND FINAL	WISH	–	–	–	CLAM	HORM	RQCK

Note that not every type of completion was used in each sentence frame.

College of Wisconsin Orthographic Wordform Database (Medler & Binder, 2005). We found every word that had both a word and a pseudoword neighbor with exactly the same number of orthographic neighbors as that base word (e.g., WISH, DISH, and WUSH all have exactly seven neighbors, and DISH and WUSH are both neighbors of WISH.) This stringent criterion left us with exactly 116 sets of items. We then identified illegal string neighbors of all the base words that had the minimum possible *N* (e.g., WRSH has only two neighbors, WISH, and WASH). Using illegal strings with the minimum possible *N* ensured that these strings would be minimally similar to items represented in the lexicon, thus providing the strongest possible test of when predictive information can begin to interact with bottom-up information obtained from a perceived sentence completion. Because these strings were as un-word-like as possible (among stimuli consisting of 3–5 letters), observing an effect of the orthographic relationship of these low *N* illegal strings to the expected sentence completion would be evidence that pre-activated information can interact with bottom-up processing before inputs have been filtered on the basis of being word-like.

In addition to the 116 orthographically related sets of sentence completions, we created an additional 116 sets of items, matched to the first 116 for *N*, where the base word, second word, and pseudoword all had the same number of neighbors but were not orthographically related (e.g., MOB, TAR, and YAG all have 17 neighbors but are not orthographically related to the expected ending). We again identified 116 illegal string items with *N* matched to the 116 illegal string items from the neighbor set. We thus had 232 words to be used as expected endings in our sentence frames (116 for the orthographically related sets and 116 for the orthographically unrelated sets), 116 words to be used as unexpected endings that are neighbors of the expected endings, 116 pseudowords that are neighbors of expected endings, 116 illegal strings that are neighbors of the expected endings, 116 words to be used as unexpected endings that are non-neighbors of the expected endings, 116 pseudowords that are non-neighbors of expected endings, and 116 illegal strings that are non-neighbors of the expected endings. The lexical characteristics of all seven ending types are given in Table 2.

Table 2
Mean lexical characteristics of all seven ending types.

Item type	Length	Log frequency	Orthographic neighborhood
Expected word	3.86	2.88	11.3
Unexpected word: neighbor	3.86	3.1	11.3
Unexpected word: non-neighbor	3.82	2.6	11.2
Pseudoword: neighbor	3.86	0	11.3
Pseudoword: non-neighbor	3.82	0	11.2
Illegal string: neighbor	3.86	0	2.6
Illegal string: non-neighbor	3.82	0	2.6

Written frequencies were obtained from the web version of the English CELEX (http://cetex.mol.n/.accessed 2007.) while *N* was obtained from the on-line version of the Medical College of Wisconsin Orthographic Wordform Database (Medler & Binder, 2005). Note that although different sets of items were used as neighbor and non-neighbor endings, the lexical characteristics of neighbor and non-neighbor endings are quite tightly matched.

After identifying all the words that were to be used as expected endings, we wrote sentence frames designed to be highly constraining for those words. Cloze probability of the sentences was assessed in a paper-and-pencil norming task conducted using 22 undergraduates at the University of Illinois (12 males, mean age 19.3 years, range 18–23 years); participants were drawn from the same pool of participants that the ERP participants were eventually drawn from, but no individual participated in both the norming and ERP studies. Mean cloze probability for the expected words was 89% (range 36%–100%) and did not differ for the orthographically related and unrelated word sets ($t_{115} = 1.288$, $p = .20$, CI = 0.03 ± 0.08). Cloze probability of all unexpected endings was 0. The mean constraint of the sentences written for the neighbor (90%, range 59%–100%) and non-neighbor (87%, range 36%–100%) items also did not differ ($t_{115} = 1.24$, $p = .22$, CI = 0.03 ± 0.08).

Sentence frames were presented to participants in a randomly ordered list. Every participant saw a total of 232 sentences: 58 ending with expected words, 29 ending with unexpected word neighbors, 29 ending with unexpected word non-neighbors, 29 ending with pseudoword neighbors, 29 ending with pseudoword non-neighbors, 29 ending with illegal string neighbors, and 29 ending with illegal string non-neighbors. We arranged our counterbalancing over four lists so that, across participants, every sentence frame was completed with an expected word, unexpected word, pseudoword, or illegal string an equal number of times.

Procedure

Once EEG setup was complete, participants were seated in a comfortable chair 100 cm away from the computer monitor on which stimuli were presented and given a demonstration of the trial structure. During the demonstration, participants were instructed to minimize eye movements, blinks, and muscle movement except for during a response and blink interval, which was indicated by the presence of three white question marks on the screen. Additionally, participants were instructed to keep their eyes on a fixation arrow in the center of the screen as much as possible throughout the experiment. Finally, participants were informed that their task in the experiment was simply to indicate whether each sentence they read was a "normal English sentence." It was made explicit that there were no typographical errors in the experimental sentences, and that some of the sentences would be grammatically correct but not make sense, and that those sentences were to be responded to with "no." The instructions were designed to make sure that participants understood that the correct response to sentences containing unexpected orthographic neighbors was "no", such that we could then use participants' responses to ascertain that they noted when neighbors of expected items, and not expected items themselves, were being presented (to ensure that any effects of neighborhood relationship were uncontaminated by participants misreading the words).

Participants made responses during the response and blink interval with response buttons in each hand; "yes" and "no" response hands were counterbalanced across participants. Participants had as much time as they desired to make their behavioral response, and were encouraged to blink or move their eyes during the response interval, but were strongly discouraged from blinking before the response interval began. After the demonstration, participants engaged in a practice block of sentences with similar characteristics to those employed in the experiment proper in order to familiarize themselves with the pace and structure of the task. Behavioral responses were monitored during the practice to ensure that participants understood the instructions.

In both the practice and the experiment proper, a fixation arrow was continuously present in the center of the screen. Each sentence was preceded for 1000 ms by the word READY printed in red, as a warning that a sentence was about to begin, followed by a blank screen presented for a randomly jittered duration of between 500 and 1000 ms (used to reduce the contamination of the ERPs by slow, anticipatory potentials). Sentences were then presented one word at a time in the center of the screen, directly above the fixation arrow. Words were presented in all capital letters in white 24 point font on the black background of a CRT computer monitor. Each word (with the exception of sentence-final items) appeared for 250 ms and was followed for 250 ms by a blank screen. Although 500 ms per word is slower than estimates of natural reading pace in college students (e.g., 200 ms per word; Sereno & Rayner, 2003), it is similar to the pace of natural speech (Levelt, Roelofs, & Meyer, 1999) and close to the timing that college-age participants self-select for word-by-word reading (Ditman, Holcomb, & Kuperberg, 2007). The final word, pseudoword, or string in each sentence was followed for 1000 ms by a red cross reminding participants to not blink and then a set of three white question marks that indicated the onset of the response interval and that remained on the screen until participants made a response. Participants did not make any behavioral response until the white question marks appeared on screen. The succeeding trial began immediately after a button press was made.

Electroencephalogram (EEG) recording and analysis

EEG was recorded from 26 Ag/AgCl electrodes embedded in an electrode cap and arranged on the scalp in a geodesic array. All EEG electrodes were referenced online to the left mastoid process and then digitally rereferenced offline to the average of the left and right mastoids. The electro-oculogram (EOG) was recorded using a bipolar montage of electrodes placed at the outer canthi of the left and right eyes; blinks were monitored using an electrode at the sub-orbital ridge. EEG and EOG were recorded with a band-pass of 0.02–100 Hz and sampled at a rate of 250 Hz with a gain of 10,000×. All electrode impedances were kept strictly below 2.5 kΩ. Trials containing eye movement or drift artifacts were rejected prior to averaging with a threshold individualized to each participant by inspection of that participant's raw waveforms, and blinks were corrected using a procedure described by Dale (1994). Artifact rejection resulted in an average loss of 3.5% of trials per participant. Event-related potentials were computed at each electrode time-locked to the onset of each of the seven critical stimulus types. Average ERPs contain a 100 ms pre-stimulus baseline and continue for 920 ms post-stimulus onset. Measurement of ERP peak amplitude and mean amplitude was conducted on data digitally filtered offline with a bandpass of 0.2–20 Hz.

Results

Behavioral data

Mean performance on the sentence comprehension task was 96.9% ($\sigma = 2.8\%$). This high level of performance on the comprehension task indicates that participants were able to recognize when neighbors of expected completions, and not expected completions themselves, were presented. Accuracy was quite comparable across all seven categories of interest, as can be seen in Table 3. A repeated measures Analysis of Variance (ANOVA) with factors of lexical type (word, pseudoword, or illegal string) and orthographic relationship revealed that there was no effect of lexical type or orthographic relationship on performance, and no interaction between the two (for the main effect of lexical type, $F_{2,46} = 1.53$, $p = .23$; for the main effect of orthographic relationship and the interaction between lexical type and orthographic relationship, F's < 1).

Table 3
Mean behavioral performance on all seven item types

Item type	Expected word	Unexpected word: neighbor	Pseudoword: neighbor	Illegal string: neighbor	Unexpected word: non-neighbor	Pseudoword: non-neighbor	Illegal string: non-neighbor
Accuracy	0.937	0.967	0.981	0.968	0.968	0.984	0.977

ERP data

The N400 was measured as mean amplitude over all channels between 250 and 450 ms post-stimulus onset. Only trials in which participants correctly classified the sentence were included in the averages. Based on past research, we expect N400 amplitudes to be sensitive to both expectancy (Kutas & Hillyard, 1984) and orthographic neighborhood size (Holcomb et al., 2002), which, in the present study was lower by design for illegal strings than for words and pseudowords (for which neighborhood size was matched). Of critical interest was whether N400 amplitudes would also prove sensitive to the orthographic relationship of the unexpected items to the expected completion.

Mean amplitude in a later window (450–750 ms) was also measured to assess effects on the Late Positive Complex (LPC), a component that has been associated with more explicit aspects of semantic processing (e.g., Besson, Kutas, & Van Petten, 1992) and that has been specifically associated with the processing of orthographic errors in other studies (e.g., Vissers, Chwilla, & Kolk, 2006). Participants were likely to notice the presence of unexpected words and unexpected classes of stimuli, and both behavioral results and participant debriefing indicated that participants also noticed when sentence completions were one letter different from the expected completion. Thus effects of expectancy, stimulus type, and neighbor status might all be expected in this time window.

All ANOVAs use a repeated measures design with degrees of freedom adjusted by the Greenhouse–Geisser correction for violation of the assumption of sphericity. All confidence intervals are at an alpha level of 0.05. Effect sizes given are η^2, computed as the ratio of the sum of squares for the factor of interest divided by the sum of the sums of squares of the repeated measures Subject factor and the interaction term between the factor of interest and the Subject factor. Although electrode is included as a factor in all ANOVAs, main effects of electrode are not reported as they are of no theoretical significance.

The N400 window: 250–450 ms

We first verified that we had replicated the classic N400 expectancy effect by comparing mean amplitude N400s elicited by expected and unexpected words (collapsed across neighbor status). Expected words did elicit substantially smaller N400s than did unexpected words ($F_{1,23} = 45.18$, $p < .0001$, CI 2.34 ± 0.70), and the effect of expectancy interacted with electrode site ($F_{25,575} = 11.37$, $p < .0001$), driven by the fact that, as is typical for the N400, the effect of congruency was largest over central-parietal channels. We also verified that N400 responses to expected items in the sentence frames written for neighbor and non-neighbor completions did not differ ($F_{1,23} = .67$, CI -0.31 ± 0.79), consistent with their matched cloze probability and constraint. In what follows, then, we will focus exclusively on the responses to unexpected items.

Analysis began with an omnibus ANOVA with factors of lexical type (unexpected word, pseudoword, and illegal string), orthographic relationship (neighbor, non-neighbor), and electrode site. As can be seen in Fig. 1, words and pseudowords elicited similar N400s in this window, whereas illegal strings elicited smaller N400s overall. Additionally, similar effects of orthographic relationship were observed in the N400 window for all three lexical types. The omnibus ANOVA revealed main effects of lexical type ($F_{2,46} = 17.40$, $p < .0001$) and orthographic relationship ($F_{1,23} = 43.53$, $p < .0001$, CI 1.39 ± 0.43), and interactions of both of these factors with electrode site (for lexical type $F_{50,1150} = 9.68$, $p < .0001$, for orthographic relationship $F_{25,575} = 8.85$, $p < .0001$), driven by the fact that both effects were larger over central posterior electrode sites, as is typical of N400 effects. The interaction between orthographic relationship and lexical type was not reliable ($F_{2,46} = 1.69$, $p = .20$), nor was the three-way interaction ($F_{50,1150} = 0.60$).

Because characterizing the effects of orthographic relationship was of particular importance in this study, we further examined the effects of orthographic relationship with planned pairwise comparisons at each level of lexical type. All three pairwise comparisons were reliable (for unexpected words, $F_{1,23} = 32.54$, $p < .0001$, CI 1.95 ± 0.34; for pseudowords, $F_{1,23} = 12.83$, $p = .0016$, CI 1.15 ± 0.65; for illegal strings, $F_{1,23} = 5.81$, $p = .0243$, CI 1.07 ± 0.91). The size of this effect did not differ across lexical type, as indicated by pairwise comparisons of difference waves, computed by subtracting on a point by point basis the waveforms elicited by non-neighbor items of a lexical type from neighbor items of the same lexical type: for unexpected words vs. pseudowords, $F_{1,23} = 2.77$, $p = .11$, CI 0.82 ± 0.97; for unexpected words vs. illegal strings,

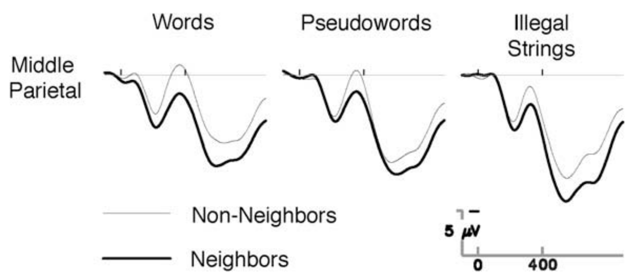

Fig. 1. Neighbors of expected completions elicit smaller N400s (and, indeed, broadly more positive waveforms) than do non-neighbors of expected completions, regardless of lexical status. Middle Parietal channel shown.

$F_{1,23}$ = 2.67, p = .12, CI 0.89 ± 1.09; for pseudowords vs. illegal strings $F_{1,23}$ = 0.02, CI 0.07 ± 1.14.

Pairwise follow-up analyses exploring the main effect of lexical type indicated that although mean N400 amplitude did not differ between unexpected words and pseudowords ($F_{1,23}$ = .78, CI −0.22 ± 0.50; see Fig. 2), both unexpected words and pseudowords elicited larger N400s on average than did illegal strings (for unexpected words, $F_{1,23}$ = 30.97, p < .0001, CI −1.59 ± 0.58; for pseudowords $F_{1,23}$ = 17.47, p = .0004, CI −1.37 ± 0.66). The pairwise differences between unexpected words and illegal strings and between pseudowords and illegal strings were maximum over central-parietal electrode sites, as indicated by interactions of the effect of lexical type with electrode site in both cases (for unexpected words, $F_{25,575}$ = 15.72, p < .0001; for pseudowords $F_{25,575}$ = 10.02, p < .0001). The overall smaller amplitude of the N400 to illegal strings as compared with that to words and pseudowords can be seen in the waveforms shown in Fig. 3. This pattern of larger N400s for items with higher neighborhood density (words and pseudowords) than those with lower neighborhood density (illegal strings) replicates prior work examining words in both lists (e.g., Laszlo & Federmeier, 2007; Rugg & Nagy, 1987) and sentences (Laszlo & Federmeier, 2008).

The LPC window: 450–750 ms

Again we began by verifying that we had obtained classic expectancy effects by starting with a comparison of expected and unexpected words (unexpected words collapsed over neighbor status). This comparison yielded a main effect of expectancy ($F_{1,23}$ = 4.80, p = .0388, CI 0.75 ± 0.70), and an interaction of expectancy with electrode ($F_{25,575}$ = 9.89, p < .0001), which was driven by the fact that the congruency effect was largest over posterior channels, as is typical for LPC effects. The effect of expectancy is visible in Fig. 2, where it can also be seen that this

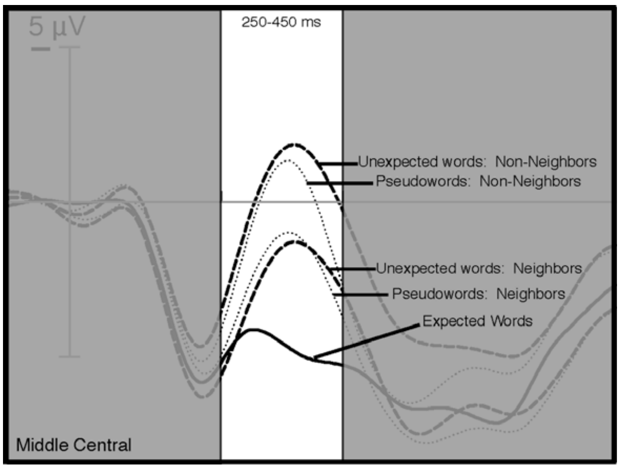

Fig. 2. Expected words, unexpected word neighbors, pseudoword neighbors, unexpected word non-neighbors, and pseudoword non-neighbors at the middle central (Cz) electrode site. The 250–450 ms N400 window is highlighted. Unexpected words are always dashed lines, and pseudowords are always dotted lines. Note that neighbor status, not lexical type, is what determines N400 amplitude.

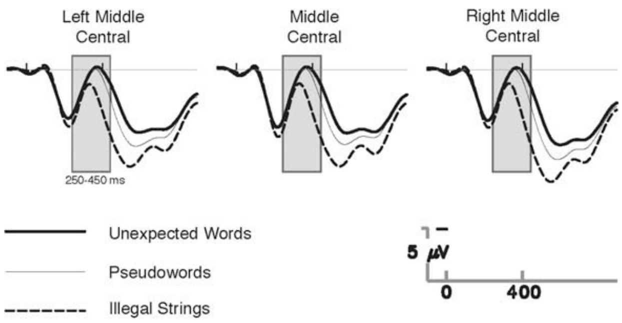

Fig. 3. Unexpected words and pseudowords (collapsed over neighbor status) elicit waveforms that are quite similar in the 250–450 ms N400 window, shown here shaded in light gray. The two begin to more strongly dissociate in the subsequent 450–750 ms LPC window. Illegal strings, which were, by design, lower in orthographic neighborhood size than words and pseudowords, elicit more positive responses than words or pseudowords in both the N400 and LPC window. A representative selection of middle central channels are shown.

effect is driven by the reduced LPC to unexpected word non-neighbors as compared to both expected words and unexpected word neighbors. This pattern is different from that seen in the N400 window, in which both neighbor and non-neighbor unexpected word completions elicit more negative responses than do expected words. We also again verified that the waveforms elicited by expected items completing the sentences written as frames for neighbor completions and the sentences written as frames for non-neighbor completions were comparable ($F_{1,23}$ = 2.54, p = .13, CI −0.48 ± 0.61).

We next focused in on LPC amplitudes to unexpected items using an omnibus ANOVA identical to that computed in the N400 time window, which included factors of lexical type (word, pseudoword, and illegal string), orthographic relationship (neighbor, non-neighbor), and electrode site. As can be observed in Fig. 3, regardless of orthographic relationship, illegal strings elicited the largest LPCs, followed by pseudowords, then words (Fig. 4). The ANOVA revealed main effects of lexical type ($F_{2,46}$ = 35.84, p < .0001) and orthographic relationship ($F_{1,23}$ = 29.14, p < .0001, CI 1.37 ± 0.87), both of which interacted with electrode site (for lexical type, $F_{50,1150}$ = 8.61, p < .0001; for orthographic

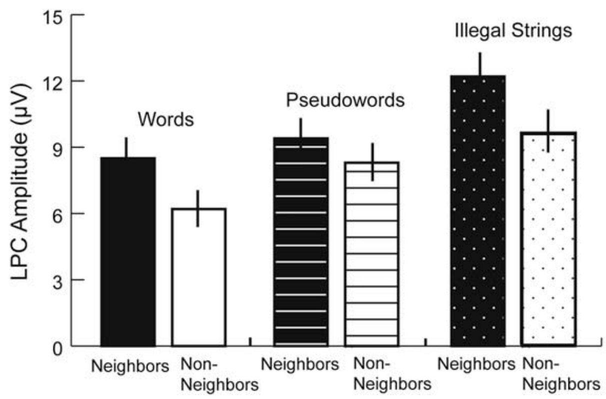

Fig. 4. Mean Late Positive Complex (LPC) amplitude over the Middle Parietal electrode site in the 450–750 ms epoch. Words elicit the smallest LPCs, then Pseudowords, then Illegal Strings. Non-neighbors elicit smaller LPCs than neighbors, regardless of lexical status.

relationship, $F_{25,575} = 7.78$, $p < .0001$), driven by the fact that these main effects were largest over more posterior channels. Neither the interaction of lexical type with orthographic relationship ($F_{2,46} = 3.11$, $p = .05$) nor the three-way interaction ($F_{50,1150} = 1.70$, $p = .14$) was reliable. The effects of orthographic relationship on the LPC at each level of lexical type are visible in Fig. 4.

We again conducted planned, pairwise comparisons of the effect of orthographic relationship at each level of lexical type. As in the N400 time window, all three comparisons were reliable (for unexpected words, $F_{1,23} = 9.33$, $p = .0056$, CI 1.27 ± 0.86; for pseudowords, $F_{1,23} = 6.53$, $p = .0177$, CI 0.82 ± 0.67; for illegal strings $F_{1,23} = 29.16$, $p < .0001$, CI 2.0 ± 0.77). We then compared the mean amplitudes of the effect of orthographic relationship on the three levels of lexical type by pairwise comparisons of the difference waves (described above). Whereas the size of the orthographic effect was similar across lexical type on the N400, it differed as a function of lexical type on the LPC – largest for illegal strings, intermediate for words, and smallest for pseudowords (for illegal strings, $\eta^2 = .11$, for words $\eta^2 = 0.06$, for pseudowords $\eta^2 = 0.02$.) This resulted in a reliable difference in the size of the effects of orthographic relationship for pseudowords and illegal strings ($F_{1,23} = 6.03$, $p = .022$, CI −1.17 ± 0.95), but not for words and pseudowords or for words and illegal strings (for words vs. pseudowords, $F_{1,23} = 0.88$, CI 0.45 ± 0.96; for words vs. illegal strings, $F_{1,23} = 2.39$, $p = .14$, CI −0.72 ± 0.93).

As before, the main effect of lexical type was explored with pairwise comparisons, which indicated that the mean amplitude of waveforms elicited by all three lexical types differed from each other in this window (for unexpected words vs. pseudowords, $F_{1,23} = 16.67$, $p = .0005$, CI −0.86 ± 0.43; for unexpected words vs. illegal strings, $F_{1,23} = 57.37$, $p < .0001$, CI −2.12 ± 0.57; for pseudowords vs. illegal strings, $F_{1,23} = 24.56$, $p = .0001$, CI −1.26 ± 0.53). The LPC elicited by words was the smallest, followed by pseudowords, and then illegal strings. Fig. 3 again shows this pattern and also highlights the difference in the stimulus type patterns seen for the N400 and LPC time windows, with words and pseudowords eliciting very similar N400s but clearly separable LPCs. There were reliable interactions with electrode site for all three pairwise comparisons (for unexpected words vs. pseudowords, $F_{25,575} = 5.72$, $p = .0016$; for unexpected words vs. illegal strings, $F_{25,575} = 18.58$, $p < .0001$; for pseudowords vs. illegal strings, $F_{25,575} = 3.54$, $p = .0358$). In all cases, the interactions with electrode were driven by larger differences being present over parietal channels.

Comparison of N400 and LPC scalp topographies

As can be seen in Fig. 1, the effect of orthographic relationship appears in the waveforms as a broad positivity for neighbors of expected items, as compared with the waveforms elicited by orthographically unrelated completions. We were interested in determining whether the effect of orthographic relationship during the N400 window was distinct from that observed in the LPC window, so we conducted a distributional analysis of the scalp topography of the effect of orthographic relationship in both time windows. First, we formed a difference wave that represented the effect of orthographic relationship (neighbor completions minus non-neighbor completions, collapsed across lexical type.) Next, we computed an ANOVA with factors of time window (N4 or LPC), hemisphere (left or right), laterality (lateral or medial), and anteriority (prefrontal, frontal, central, or posterior.) The distributional ANOVA indicated a significant three-way interaction of time window, anteriority, and laterality ($F_{3,69} = 6.12$, $p = .0040$). Effect distributions were similar over lateral sites, but over medial sites, where both effects were more prominent overall, the LPC had its characteristically more posterior skew. No other interaction of time window with any other combination of factors was reliable.

Discussion

As described in the introduction, the goal of this experiment was to further delineate the nature of predictive processing mechanisms in language comprehension by examining, first, whether the information brought online by prediction is specific enough to affect processing based on orthography, and, second, at what functional stage of word recognition pre-activated information begins to interact with bottom-up processing of visually presented sentence completions. To investigate these questions, we collected EEG while participants were presented with constraining sentences that could be completed either with an expected word or an unexpected completion (word, pseudoword, or illegal string) that was either an orthographic neighbor of the expected word or orthographically unrelated to the expected word.

In answer to the first question, we found that the processing of orthographic neighbors of expected (but never presented) sentence completions was facilitated, as evidenced by reduced N400 responses to unexpected neighbors as compared to responses to orthographically unrelated completions with similarly poor semantic fit to the sentence contexts. This finding indicates that information pre-activated by sentence context is specific enough to influence the processing of inputs based on their orthography. As evidence for a considerable degree of specificity in predictive processing, this effect of orthographic relationship complements and extends past findings suggesting that semantic (Federmeier & Kutas, 1999), morphological (Otten et al., 2007; Wicha et al., 2003, 2004), and phonological (Delong et al., 2005) information about an expected sentence completion are all pre-activated by context.

Our finding that N400s are reduced in response to orthographic neighbors of expected completions additionally bears on the question of whether lexical interactions are facilitative or inhibitory by suggesting that, at least during the reading of high constraint sentences, the activation of features of a particular lexical item results in facilitated processing of that item's orthographic neighbors at the lexical-semantic level. As discussed in the introduction, findings of facilitative effects of orthographic similarity have been controversial: although some behavioral findings have pointed to facilitative effects from neighbors (e.g., Andrews, 1989), such findings have sometimes been interpreted as arising from influences of task-specific strategies (e.g., "fast guess" lexical decisions responses) on an inherently inhibitory system (e.g., Grainger & Jacobs, 1996). Thus, a comprehension system with inhibition between lexical items has been an important feature of a number of prominent models of visual word recognition (Coltheart et al., 2001; Grainger & Jacobs, 1996; McClelland & Rumelhart, 1981; Perry et al., 2007; Rumelhart & McClelland, 1982). However, our data suggest instead that – at least during word recognition in context – the activation of a particular item can result in facilitated processing of its neighbors at implicit, pre-strategic levels of processing, as indexed by the N400. As we described in the introduction, this pattern is more compatible with models that either do not require inhibition between lexical items (e.g., Morton, 1964, 1969) or that do not formally represent lexical items at all (e.g., Harm & Seidenberg, 2004; Seidenberg & McClelland, 1989). It would seem difficult for models that require lexical neighbors to inhibit each other to explain the apparent facilitation for orthographic neighbors we observe here.

Of course, the fact that lexical neighbors may tend to become active in concert, while facilitative in the context of the present study, could create processing difficulties in other circumstances. The present data, as well as past data from our lab (Laszlo & Federmeier, 2007, 2008) and others (Coltheart et al., 1977; Holcomb et al., 2002) support the idea that items with high orthographic neighborhood sizes activate the lexical-semantic network more widely than similar items with lower orthographic neighborhood size. Overall N400 amplitudes are strongly graded by neighborhood size, with larger responses to higher *N* items. The more widespread activation engendered by a high *N* item should make saying "no" to high *N* non-words more difficult in a lexical decision task (as has been widely observed; for example, Coltheart et al., 1977) and may, more generally, induce downstream competition and/or selection difficulties. Thus, if, for example, lexical decisions are based on the overall state of the network (e.g., the "semantic stress"), rather than an assessment of the activation of the individual states of particular lexical items, higher neighborhood density may be associated with processing difficulties even if there is no inhibition (or, instead, even facilitative influences) between individual lexical items. This view is, again, more similar to that often used in models without formal lexical levels of representation (e.g., Plaut, 1997) or models with no formal inhibition between lexical neighbors (e.g., Norris, 2006).

The possibility that there may be no formal level of lexical representation seems to agree with the second major finding of the experiment, namely that facilitative effects of orthographic similarity to a predicted sentence ending are also obtained for items that are not themselves lexically represented (pseudowords), and even for items chosen to be as dissimilar as possible from extant lexical representations (our low *N* illegal strings). The fact that we observed indistinguishable prediction-based effects across lexical type would seem to suggest that the locus of those effects is prior to any point in the comprehension stream where items that are not lexically represented or do not contain characteristics typical of lexically represented items (i.e., are orthographically irregular or illegal) cease to be processed for meaning. Our data are in agreement with past work suggesting that specific predictions can be made about upcoming items based on sentence context (e.g., Delong et al., 2005; Wicha et al., 2003, 2004), but extend those findings by suggesting that the information brought online by prediction begins to influence the bottom-up processing of inputs prior to word recognition being complete. Effects of contextual information on the N400 prior to word recognition have also been seen in the auditory modality (Van Petten, Coulson, Rubin, Plante, & Parks, 1999). These findings contrast with the predictions of autonomous models, which relegate effects of contextual information to later, post-recognition processing stages (at which point the processing of lexically represented items would be expected to diverge notably from that of items that are not lexically represented).

Our finding that effects of orthographic similarity to a predicted ending extend to items not represented in the lexicon suggests that these effects arise because prediction affects the availability of specific orthographic features of likely upcoming items – features that are shared by unexpected word neighbors and pseudoword and illegal string neighbors alike, despite their differences in lexical status. However, the N400 seems to be a functionally specific measure of processing related to the initial access of stimulus meaning, and does not directly reflect the processing of visual features or even orthography (i.e., effects of orthographic similarity in word pair priming paradigms manifest, not on the N400, but rather on the earlier N250 component; Holcomb & Grainger, 2006). Thus, we must infer that the availability of orthographic features, as affected by prediction, has downstream consequences for how wordforms are mapped onto semantics, which are reflected in the N400 amplitude modulations that we observe.

Although the mechanism responsible for the lexical-semantic facilitation we see in response to orthographic neighbors of expected sentence completions remains unclear, the literature offers some likely possibilities. One is a classical connectionist mechanism, wherein facilitation is brought about by spreading activation between representations consistent with the predicted upcoming lexical item. The second, while still consistent with implementation in a connectionist network, instead relies on the strengthening of connections (or prior probabilities) between semantic features consistent with the predicted upcoming item and orthographic features associated with those semantics. We will refer to this as the "Bayseian" view, as it seems consistent with an ideal observer approach, such as that taken in Norris' (2006) Bayseian reader (see also McClelland, 1998, for more details on how a Bayseian system can be implemented as a connectionist network.)

In the classical connectionist comprehension system, it seems likely that the pre-activation of specific orthographic features through prediction results in feedback between the active orthographic representation and the specific semantic features associated with the predicted word. This serves to focus and strengthen the semantic attractor and also primes particular pathways through the word recognition system, linking active orthographic features to active semantics. In contrast, in a Bayesian system, the primary result of activating semantic features consistent with the sentential context might be to increase the prior probability of associated orthographic features. This increase of prior probability could be implemented in a connectionist network, among other ways, by temporarily increasing the connection weights between the activated semantics and associated orthography, which would then serve to facilitate the processing of context consistent orthography.

In both the Bayesian and the classical connectionist system, one consequence of the pre-activation of the semantic representation, in concert with either more active or more easily activated orthography, may be that when a neighbor of the expected completion is presented, the high level of overlap between the orthographic features of that stimulus and the predicted, orthographic features creates a tendency for the neighbor stimulus to fall into the semantic attractor for the expected completion. For example, the processing of a sentence context that is strongly predictive of WISH results in pre-activation of WISH's orthographic features, or in the Bayesian case, in those features being more likely to become active given a particular input. When presented with DISH, WUSH, or WRSH, then, the 75% match between what is expected and what is presented is enough for the network to, initially, access pre-activated semantic features of WISH in response to its neighbor. The facilitated pathway between orthography and semantics created by prediction may have the effect of expanding the set of stimuli included in the primed semantic attractor. Indeed, this kind of behavior might be advantageous for a system that is often confronted with unreliable or noisy input to decipher (e.g., text messages that have been hastily composed and therefore are badly spelled, or billboards flying by at 65 MPH on the interstate).

It is important to note that, although under this view the input DISH/WUSH/WRSH is to some extent being processed as if it were WISH, we do know that participants eventually realize that they were presented with a neighbor of what was expected and not the expected completion itself, given that ERP averages were limited to trials on which participants made correct judgments (about which they were highly accurate overall). Furthermore, we know that even at the earlier, implicit processing stage indexed by the N400, the system is differentiating between the expected word and its neighbors, because N400 amplitudes to expected completions (in this example, WISH) are markedly more reduced than those elicited by the (facilitated) unexpected orthographic neighbors. Thus, irrespective of the mechanism at work that allows prediction to facilitate the early lexico-semantic analysis of strings to create reduced N400s to neighbors as compared with non-neighbors, processing remains sufficiently tuned to afford a clear distinction between a predicted item and an orthographic neighbor that overlaps with 66.6–80% of its low-level features (66% in the case of three letter completions, 80% in the case of five letter completions). And, again, this distinction happens in stages of processing that continue to apply even to strings that are unfamiliar and not word-like.

Although lexical type did not influence the effect of orthographic relationship in the N400 window, there was an interaction of lexical type with orthographic relationship in the later time window encompassing the LPC (which also has a different scalp distribution from the N400). Whereas the N400 is thought to represent relatively automatic, pre-attentive semantic processing (for reviews, see Federmeier & Laszlo, in press; Kutas & Federmeier, 2000), the LPC is a functionally and neurally separable ERP component (see, e.g., Olichney et al., 2000) that has been linked to more explicit aspects of processing in a number of domains, including verbal memory and language comprehension. In particular, the LPC has been associated with the realization that some item types in an experiment are being presented much more frequently than they are observed in naturalistic settings (e.g., Rugg, 1990) or the realization that an input has been mis-spelled (Vissers et al., 2006). Each of these functional roles for the LPC has interesting implications for the interaction of lexical type and orthographic relationship that we observed in our late ERP epoch.

The idea that LPC effects may index a mismatch between experimental and natural frequency is supported by, for example, the fact that low frequency words elicit large LPCs when they are repeated in a list whereas high frequency words do not (Rugg, 1990). This view could explain the gradation of LPC amplitudes across lexical classes that we observe here, if the frequency of item components (i.e., bigram or trigram frequency), as well as whole item frequency, plays a role in determining LPC amplitude. As depicted in Fig. 4, LPCs were smallest to words, intermediate to pseudowords, which are unlikely to occur outside the experiment but which have familiar subcomponents, and largest to illegal strings, which do not occur outside of the experimental context and have the minimum possible number of subcomponents that do.

The fact that we observed the largest LPC responses to illegal strings that were neighbors of expected completions also seems consonant with Vissers et al.'s (2006) interpretation that the LPCs they observed in response to mis-spelled words in high constraint sentences represented conscious realization by participants that mis-spelled items were related to what was expected, but nonetheless not what was expected (importantly, Vissers et al. observed essentially *no* effect of mis-spelling on the N400 component in their study, making clear that it is possible for participants to notice that a mis-spelling has occurred without any concomitant effect on the lexical-semantic processing indexed by the N400.) In fact, during debriefing every participant in the present study claimed to have noticed by the end of the practice block that sometimes items that were only one letter away from what they expected were presented as sentence completions. Such explicit recognition of the orthographic similarity between the neighbors and the predicted completion would thus be expected to enhance the LPC response to the neighbor (as compared with the non-neighbor) ending, and this might be especially pronounced for illegal strings that do not resemble words – and thus clearly cannot be the intended ending for the sentence.

Conclusions

As we have emphasized throughout, the two main questions under investigation in this experiment were (1) whether orthographic information can become pre-activated by sentence contextual information and (2) at what stage in the bottom-up processing of a sentence completion information derived from prediction begins to interact with information gained from the input. We found that regardless of lexical status, orthographic neighbors of expected sentence completions elicited smaller N400s than did orthographically unrelated items, which seems to suggest that contextual pre-activation does extend to orthographic information. Because we observed indistinguishable effects of orthographic relationship at every level of lexical type we examined (word, pseudoword, illegal string) it would appear that predictive information begins to interact with the bottom-up processing of a sentence completion before words are recognized, and, indeed, before unfamiliar or irregular strings have ceased being processed for meaning.

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