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Finding the Right Word: Hemispheric Asymmetries in the Use of Sentence Context Information

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Abstract

The cerebral hemispheres have been shown to be differentially sensitive to sentence-level information; in particular, it has been suggested that only the left hemisphere (LH) makes predictions about upcoming items, while the right (RH) processes words in a more integrative fashion. The current study used event-related potentials to jointly examine the effects of expectancy and sentential constraint on word processing. Expected and unexpected but plausible words matched for contextual fit were inserted into strongly and weakly constraining sentence frames and presented to the left and right visual fields (LVF and RVF). Consistent with the prediction/integration view, the P2 was sensitive to constraint: words in strongly constraining contexts elicited larger P2s than those in less predictive contexts, for RVF/lh presentation only. N400 responses for both VFs departed from the typical pattern of amplitudes graded by cloze probability. Expected endings in strongly and weakly constraining contexts were facilitated to a similar degree with RVF/lh presentation, and expected endings in weakly constraining contexts were not facilitated compared to unexpected endings in those contexts for LVF/rh presentation. These data suggest that responses seen for central presentation reflect contributions from both hemispheres. Finally, a late positivity, larger for unexpected endings in strongly constraining contexts, observed for these stimuli with central presentation was not seen here for either VF. Thus, some phenomena observed with central presentation may be an emergent property of mechanisms that require interhemispheric cooperation. These data highlight the importance of understanding hemispheric asymmetries and their implications for normal language processing.

For over a century, language processing has been recognized as one of the most prominent examples of hemispheric asymmetry in cerebral function. The fact that language function can be severely disrupted after damage to the left hemisphere (LH), whereas language deficits after right hemisphere (RH) damage are often much more subtle, led to the initial inference that most or all language processing arises from LH functions. More recently, an extensive body of evidence from behavioral, neuropsychological, electrophysiological, and hemodynamic neuroimaging studies has demonstrated not only that language comprehension is composed of bilateral processes, but also that the two hemispheres make qualitatively different contributions to comprehension (see, e.g., Beeman & Chiarello, 1998). Such findings underscore the necessity of uncovering the nature of, and the differences between, the processing computations

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performed by each hemisphere in order to gain a complete understanding of how normal language processing unfolds. Indeed, such investigations hold the promise of helping to resolve long-standing debates about the nature of the cognitive architecture underlying human sentence comprehension, as the complex and often inconsistent data patterns that have been observed may be a reflection of multiple mechanisms acting when only a single mechanism has been assumed.

While there have been important advances in our understanding of how each hemisphere processes individual words (e.g. Chiarello, 1998), the engagement of the two hemispheres during the more normal circumstances of sentence or discourse processing is much less well understood. Studies of RH damaged patients have revealed language deficits at these higher levels of processing (e.g. Beeman, 1998). Damage to the RH often results in specific problems with understanding the main idea or gist of a discourse (Gardner, Brownell, Wapner, & Michelow, 1983), forming some types of inferences (Brownell & Martino, 1998), comprehending non-literal language (Winner & Gardner, 1977), and appreciating jokes (Brownell, Michel, Powelson, & Gardner, 1983). Clearly, the right hemisphere makes some contribution to understanding discourse, and many neuroimaging studies have substantiated the neuropsychological work by showing RH involvement in similar kinds of higher-level language processes (e.g. Bottini et al., 1994 and Coulson & Williams, 2005).

In apparent contrast to findings from the patient literature, data from behavioral measures have been taken to suggest that RH processing may be driven wholly or largely by word-level (i.e. lexical associative) relationships and thus may be insensitive to the message-level information available from sentence or discourse contexts (Faust et al., 1993, 1995). The LH, then, on such views, has been taken to be solely responsible for message-level interpretation (though also sensitive to lexical-level relationships, e.g. Chiarello, Burgess, Richards, & Pollock, 1990). Studies investigating these questions with healthy adult participants have employed the visual half-field (VF) presentation technique, in conjunction with behavioral tasks such as lexical decision judgments. In the VF method, critical stimuli are presented in either the left or right half of the visual field, which ensures that stimulus apprehension occurs in the contralateral hemisphere (for more detail, see Banich, 2002). In turn, this unilateral apprehension biases even later stages of processing toward the hemisphere that receives the information (though, of course, information is processed to some degree in both hemispheres of healthy participants with an intact corpus callosum, in contrast to the more fully unilateral processing that occurs in VF studies with commissurotomized patients). Decades of studies employing this technique have found robust and highly replicable hemispheric processing asymmetries, attesting to the effectiveness of the procedure.

The earliest studies providing support for the “message-blind” RH found that the LH, but not the RH, was affected by manipulations involving sentence-level meaning (reviewed in Faust, 1998). More recently, Faust and colleagues have revised their message-blind RH hypothesis after obtaining results suggesting that the RH can sometimes differentiate words that are and are not congruent with the sentence at the message level (Chiarello, Liu, & Faust, 2001; Faust, Bar-lev, & Chiarello, 2003). In one study, the effects of lexical association and message-level information were examined by comparing lexical decision response times to sentence-final target words preceded by associated or non-associated primes embedded in several types of contexts (Faust, Bar-lev, & Chiarello, 2003). Normal congruent sentences (e.g. ‘*The mother quickly took the sick child to the* ***doctor/aunt***.’), sentences with an incongruent final word (e.g. ‘*The devoted mother fed the sick child the* ***doctor/aunt***.’), scrambled (random) sentences (e.g. ‘*To took the quickly mother child the sick to the* ***doctor/aunt***.’), and syntactically well-formed but nonsensical sentences (e.g. ‘*The store jumped from the sick child to the* ***doctor/aunt***.’) were constructed in order to systematically vary the amount of message-level information available to readers. Patterns of facilitation and inhibition relative to lexical decisions to targets in baseline “neutral” contexts (e.g. ‘*The next word that will appear on the screen is* ***doctor/ aunt***.’) were similar for the two VFs: facilitation was found for associated targets in congruent and random contexts, whereas inhibition was found for associated targets in incongruent contexts. Inhibition was also observed for non-associated targets in congruent (LVF/rh and RVF/lh) and incongruent (RVF/lh) contexts. One difference in the pattern seen across the two VFs was that associated targets were facilitated in syntactic nonsensical contexts when presented in the LVF/rh, whereas no such facilitation was observed for RVF/lh presentation. Because both hemispheres were sensitive to basic sentence-level congruity (with both showing facilitation for lexical associates in congruent sentences and general inhibition in incongruent sentences), the view that the RH was completely “blind” to higher-level meaning information was discarded. Faust and colleagues maintain, however, that because such context effects were larger for targets presented in the RVF, the LH must be the primary substrate for message-level computations, with RH processing biased toward the appreciation of word-level relationships.

The idea that the linguistic ability of the RH is largely driven by lexical-level processing seems at odds with the neuropsychological data suggesting a critical role for the RH in discourse processes. Recent work by Long and colleagues, however, with both brain-intact and commissurotomized participants, has taken steps toward reconciling these literatures. Using VF presentation combined with a recognition memory priming paradigm, they showed that although both hemispheres were sensitive to discourse topic information and selected topic-appropriate meanings of ambiguous words, the LH was additionally sensitive to the propositional structure of the texts; this finding held for both the brain-intact participants and for the three commissurotomy patients (Long & Baynes, 2002). A later paper extended these findings (Long, Baynes, & Prat, 2005), again leading to the conclusion that the propositional structure of a text is represented in the LH but that discourse-level information is available to both hemispheres, a proposal consistent with RH involvement in the processing of higher-level meaning information.

Whereas behavioral studies have found conflicting evidence for message-level effects on words apprehended in the LVF/rh, electrophysiological studies have consistently indicated that RH and LH word processing are influenced by sentence-level information to a similar degree. For example, Federmeier, Mai, and Kutas (2005) showed that for stimuli presented to either VF, there were nearly identical sentential constraint effects on the N400, a well-studied event-related potential (ERP) component that shows specific sensitivities to lexico-semantic manipulations (for a review, see Kutas & Federmeier, 2000). The N400 is thought to be generated bilaterally (perhaps with a greater left than right contribution) in a large portion of the temporal lobe (Van Petten & Luka, 2006), probably including perisylvian regions that correspond to Wernicke’s area (and its homologue) as well as areas of the anterior medial temporal lobe associated with semantic memory.

In Federmeier, Mai, & Kutas (2005), sentences were constructed to minimize lexical association and hence the influence of word-level priming. Instead, the predictability (as determined by cloze probability[1]) of the sentence-final critical words was manipulated through constraint at the sentence message level (e.g. ‘*She was suddenly called back to New York and had to take a cab to the* ***airport***.’ [strongly constrained] versus ‘*She was glad she had brought a book since there was nothing to read at the* ***airport***.’ [weakly constrained]). VF-based differences in the impact of constraint were observed on the frontal P2, a component thought to reflect some aspects of higher-order visual and attentional processing (see, e.g., Luck & Hillyard, 1994). P2 amplitude was affected by the constraint manipulation only with RVF/lh presentation. However, at the level of semantic processing, strongly constrained completions

[1]As discussed in the Method section, the cloze probability of a word refers to the percentage of people who would complete a sentence frame with that particular word, determined empirically (Taylor, 1953).

elicited smaller amplitude N400 responses than did weakly constrained completions in both VFs, and there was no VF-based difference in either the size or timing of this effect (though the N400 distribution was shifted contralateral to VF of stimulus presentation, presumably reflecting the contribution of partially non-overlapping neural generators resulting from the VF-induced processing bias). This finding is similar to prior reports (e.g. Federmeier & Kutas, 1999a) demonstrating that ERP responses to highly expected stimuli and responses to wholly unexpected stimuli are often strikingly similar across the two VFs. Such similarity in the N400 "range" across the two hemispheres mitigates some of the concerns raised about behavioral work (where standing differences in response time and accuracy across the two VFs can make it difficult to interpret and compare effect sizes), and provides evidence that both hemispheres are sensitive to message-level context information.

Further evidence that the RH is capable of message-level processing was obtained in an ERP study (Coulson, Federmeier, Van Petten, & Kutas, 2005) that varied sentence congruity and lexical association independently, equating cloze probability across associated versus non-associated conditions in sentence contexts similar to those used in Faust, Bar-lev, & Chiarello (2003). The responses for both VFs showed robust priming for lexical associates out of context. When the same word pairs were placed into sentence contexts, however, congruency dominated the response for words presented in both VFs (in contrast to the findings of Faust, Bar-lev, & Chiarello, 2003, where inhibition was found for non-associated targets even in congruent sentences, presumably because in their stimuli, non-associated targets were much less expected in the contexts than associated targets). Thus, the data provided evidence, not only that both hemispheres can process message-level information, but also that both preferentially do so when higher-level information is available. However, there were some differences in the pattern of results across the VFs, with more priming for the lexical associates in sentence contexts when these were presented in the LVF. Such differences suggest that while both hemispheres are able to effectively process at the message level, there are asymmetries in how that message-level information is used to shape word processing.

The available electrophysiological evidence suggests that the primary difference between the use of message-level information by the two hemispheres is that the LH is biased toward top-down, predictive processing whereas the RH is biased toward bottom-up, integrative processing (Federmeier, in press). This view holds that, rather than being blind to message-level information, the RH uses the context information, in conjunction with local lexical-semantic information, to make sense of what is presented to it. In contrast, the LH is thought to use context information to activate features of likely upcoming stimuli, prior to their actual occurrence. This hypothesis explains the pattern of results obtained by Federmeier and Kutas (1999a), in which incongruent sentence endings that were semantically related to the most expected (predictable) sentence completions showed facilitation only with RVF/lh presentation (whereas LVF/rh responses patterned with plausibility). The prediction/integration view maintains that the facilitation for the same-category anomalies arises because they share features with the most expected (but never presented) completions to the contexts – features that have become activated through predictive processing in the LH but not in the RH. This explanation is similar to that of Schwanenflugel & Shoben (1985) and Schwanenflugel & LaCount (1988) for findings in behavioral studies employing central presentation, as well as Federmeier & Kutas (1999b), an ERP study with central presentation.

Predictive and integrative strategies have different costs and benefits for language processing. For example, whereas predictive processing may tend to be more efficient and robust under many circumstances, integrative processing offers the advantage of greater flexibility when plausible, but unexpected, items are encountered. In a recent study, Federmeier, Wlotko, De Ochoa-Dewald, and Kutas (in press) examined the costs and benefits of prediction in an ERP experiment (using centrally-presented words) that independently manipulated sentential

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constraint and sentence-final word expectancy. Strongly and weakly constraining sentence contexts were completed with either the most expected word (as determined by the cloze procedure) or an unexpected but plausible word (equated for cloze probability across the two constraint conditions) that was unrelated to the most expected ending and also to any of the words in the sentence context (see Table 1 for examples). In contrast to Federmeier & Kutas (1999b), where N400 facilitation was observed for incongruent (and hence unexpected) words that were related to an expected completion, especially in highly constraining contexts where there is greater potential for prediction, no difference in N400 amplitude was observed between unrelated and unexpected words completing strongly versus weakly constraining sentence frames (e.g. '*He bought her a pearl necklace for her* ***collection***.' versus '*He looked worried because he might have broken his* ***collection***.'). This suggests that the scope of facilitation for the N400 seen in Federmeier & Kutas (1999b) does not extend to unexpected items that do not share semantic features with the expected completion, and that the N400 primarily reflects the processing benefit that arises when there is a match between a word and the featural information engendered by its context. In the same data set, however, there were also electrophysiological responses that seemed to index the possible costs of predictive processing. A late positive wave over frontal channels differentiated unexpected words in strongly constraining contexts from unexpected words in weakly constraining contexts, as well as from the expected words. While the functional significance of this positivity is as of yet unclear, Federmeier, Wlotko, De Ochoa-Dewald, and Kutas (in press) linked it to processes involved in inhibiting or revising a strong prediction when an unexpected item is encountered.

Still open is the question of how the processes involved in producing the patterns observed in Federmeier, Wlotko, De Ochoa-Dewald, & Kutas (in press) are distributed across the hemispheres. The present study employs the design from the Federmeier et al. (in press) experiment in conjunction with the VF presentation technique in order to assess the contribution of the two cerebral hemispheres to the processing of words with varying levels of preceding context information and varying levels of expectancy within that context. The stimuli consist entirely of plausible sentences, which sets this study apart from most prior work with the VF method. Also, because sentential constraint and level of expectancy are crossed in this stimulus set, we are able to examine the response of the hemispheres across a fuller range of cloze probability than has been examined before (with any method), as the stimuli include not only highly expected and highly constrained endings (with high cloze probability, which are expected to yield small N400s in both VFs) and unexpected endings (with cloze probability near zero, which are expected to yield large N400s in both VFs), but also words that constitute the most expected ending for weakly constrained contexts (with low to moderate cloze probability, which elicit N400s of moderate size with central presentation).

This design will also allow further investigation of the effects of sentential constraint and expectancy on the P2. Prior work has shown that both variables can affect the P2 (Federmeier & Kutas, 2002; Federmeier, Mai, & Kutas, 2005), but only for RVF/lh presentation. Because constraint and expectancy are varied independently in this study, the individual and joint effects of these variables on the processes indexed by the P2 can be examined across the two hemispheres.

An additional important comparison for this study will be that of the unexpected sentence endings in strongly constraining versus weakly constraining sentence contexts. Because these two types of sentence endings are equated in terms of cloze probability and are the same lexical items, any observed difference between them can be attributed to how the prior context (manipulated through sentential constraint) has been used to shape expectancies for upcoming words. With central presentation, similar N400 responses were observed to the two ending types, and it will be instructive to see whether processes indexed by this response are similar in the two VFs, as some accounts suggest that the RH should activate a broader range of possible completions than the LH (e.g. Jung-Beeman, 2005). Also of key interest will be the responses elicited by LVF/rh and RVF/lh unexpected words in the time frame of the positivity observed with central presentation. If, indeed, only the LH uses context information predictively, then only this hemisphere should prove sensitive to the relationship between a presented unexpected item and the unseen most expected completion. In other words, the kind of revision/inhibition processes that Federmeier, Wlotko, De Ochoa-Dewald, and Kutas (in press) linked to the frontal positivity should only be needed if strongly constraining context information has led to the preactivation of features associated with the expected completion – engendering a mismatch when a plausible, but semantically distinct, unexpected item is encountered. The RH, instead, would be expected to process the two unexpected ending types similarly, as their bottom-up (lack of) fit to the context, as indexed by cloze probability, is the same.

Method

Participants

Thirty-two right-handed native speakers of English who reported no history of exposure to other languages before age 5 participated in the study in exchange for course credit at the University of Illinois at Urbana-Champaign. Sixteen of the participants were female and sixteen were male. The mean age was 19.1 years, with a range of 18 to 22 years. All participants were right-handed as assessed by the Edinburgh Inventory (Oldfield, 1971); 17 reported having left-handed or ambidextrous family members. All participants reported normal or corrected-to-normal vision and none reported a history of neurological or psychiatric disorders. Data were collected from an additional nine participants who were eligible for the study, but were not analyzed due to excessive eye movement artifacts. All participants gave written informed consent and all protocols were approved by the Institutional Review Board at the University of Illinois at Urbana-Champaign.

Materials

The experimental stimuli, identical to those of Federmeier, Wlotko, De Ochoa-Dewald, & Kutas (in press), consisted of 282 sentence frames, half of which were strongly constraining and half of which were weakly constraining (as determined by cloze probability norming, described below). Each sentence was associated with both its most expected ending (the word with the highest cloze probability for that sentence) and an unexpected but plausible ending (with a cloze value near 0). The endings of the sentences served as the critical words for the experiment, leading to four conditions: expected endings in strongly constraining sentence frames (SC-EE), expected endings in weakly constraining sentence frames (WC-EE), unexpected endings in strongly constraining sentence frames (SC-UE), and unexpected endings in weakly constraining sentence frames (WC-UE). Table 1 shows examples.

To determine the cloze probability of the endings in their sentence frames, a norming procedure was conducted with native English speakers at the University of California, San Diego. Sentence frames (368 total) were divided into four lists of 92 each; three of the four lists were completed by 18 participants and one list was completed by 19 participants. In accordance with standard cloze norming procedures, participants were asked to read each sentence frame and to write down the word they "would generally expect to find completing the sentence fragment". In an extension of the standard procedure, similar to that used in Schwanenflugel & Shoben (1985), the instructions directed participants to then give two additional plausible completions. Thus, cloze probabilities could be computed not only for the first completion of the sentence frame, but also for a larger set of "next best" completions, which allows a sampling of a wider range of context-induced expectancies, and helps to avoid the possibility that some of our unexpected items are actually one of a larger set of items participants would tend to use to complete a particular fragment.

From the resulting database, we selected 141 strongly constraining sentence frames, for which the best completion had a cloze value of 67% or greater, and 141 weakly constraining sentence frames, for which the best completion had a cloze value of 42% or less. Sentence frames of the two types were matched for length (average of 10 words per sentence in each type) and the two types of expected items were also controlled for word frequency (Francis & Kucera, 1982) and word length. These values, as well as ratings for concreteness, imagability, and familiarity, were retrieved from the MRC Psycholinguistic Database (Wilson, 1988). Unexpected endings were then created, each of which was paired with both a strongly constraining and a weakly constraining sentence frame. Across constraint, then, lexical properties of the unexpected endings were perfectly controlled[2]. Stimulus characteristics are presented in Table 2.

Several experimenters judged each of the unexpected endings to be both plausible in its sentence frame and to come from a different semantic category from (and thus share relatively little feature overlap with) the corresponding expected ending for that sentence frame. Mean association strength (as assessed by the Edinburgh Associative Thesaurus, Kiss, Armstrong, Milroy, & Piper, 1973; approximately 90% of the experimental stimuli were in the database) between the expected and unexpected endings for each sentence frame was less than 0.005 for both constraint conditions (and did not differ). To assess association between the sentence endings and the words in the sentence frames, the number of sentences containing at least one moderate to strong associate (0.2 or greater) of the sentence completion was tallied. Overall, there were few words in the sentence contexts associated with the critical words: 4% for SC-EE and 1% for the other three conditions. Mean association strength between the sentence ending and all of the other words in the sentence frame was also less than 0.005 for all four conditions (SC-EE, WC-EE, SC-UE, WC-UE), and this was true for both forward and backward association.

Stimuli were divided into four lists, such that each participant saw each sentence frame and corresponding critical word only once[3]; within each list, half of the frames from each constraint condition were completed by the expected ending and half were completed by the unexpected ending. Half of the expected and half of the unexpected endings in each list were presented in the RVF and half in the LVF. Stimulus characteristics were matched across conditions within each list (and each VF). Critical words were rotated around lists so that every sentence frame was completed by its expected and unexpected ending in both VFs across all lists. The order of sentence frames was determined pseudo-randomly[4] and then presented in the same order to each participant.

Procedure

Participants were seated in a dimly lit room 100 cm in front of a 21” CRT computer monitor. Each trial began with a warning sign (several pluses in the center of the screen) presented for 500 ms; the duration of the blank screen between the warning sign and the first word of the trial varied randomly from 500 to 1200 ms to avoid averaging in slow potentials associated with anticipation of sentence onset. Each word appeared in a Helvetica 22-point font with black text on a white background. All words subtended an approximate maximum of .4 degrees of vertical visual angle and an approximate maximum of 3.2 degrees of horizontal visual angle. Sentences were presented word-byword in the center of the screen, except for each sentence-

[2]In a small set of cases, there were minor changes in the inflection of lexical items (e.g. one singular, one plural) across their uses in the two constraint conditions.

[3]Across the stimulus set, a few words were repeated (e.g., appeared as both a highly constrained expected ending and, for a different sentence, a weakly constrained expected ending). These repetitions were minimized within each list and were never presented in close succession.

[4]The condition that no more than three consecutive sentence completions be presented in the same visual field was imposed.

final word, which was presented with its inner edge two degrees to either the left or right of fixation. All words were presented for 200 ms and each interstimulus interval was 300 ms. A three second pause separated each trial.

A central fixation point remained on the screen throughout the entire experiment below the point where the words were presented. Participants were asked to minimize blinks, eye movements, and muscle activity while reading, and to maintain central fixation while words were presented laterally. They were instructed to read the sentences for comprehension while keeping in mind that they would be asked questions about what they had read at the conclusion of the experiment. The recording session began with a short set of practice sentences to acclimate the participants to the task situation. The main experimental session was divided into six blocks of sentences, with participants taking a short rest between each block.

An EOG calibration procedure was completed after the main experimental session. A capital letter X was presented in pseudo-random[5] order fifteen times[6] in each of the following locations: one, two, and four degrees to the left and right of fixation. This data was used to choose EOG artifact rejection thresholds (described in the EEG processing section).

After the recording session ended, participants completed a recognition test. A list of 240 words was selected such that for each participant, 80 of the words were unexpected endings from the experimental stimuli, 80 were expected endings, and 78[7] were unseen items (which were expected endings from other lists that a different set of participants would have seen). Half of the expected endings were from each visual field and half were from each type of sentence frame (every participant saw every unexpected word, because the same words were used in both constraint conditions, though as described above, unexpected critical words were not presented twice). Participants were asked to indicate all words that they remembered seeing as sentence-final words in the experiment.

Participants also completed a short set of neuropsychological measures, which included verbal fluency (category and letter), figural fluency (Ruff, 1988), reading span (Daneman & Carpenter, 1980), and author and magazine recognition questionnaires (Stanovich & West, 1989). These data were not included in the analyses presented here and are not reported.

EEG Recording and Processing

EEG was recorded from twenty-six geodesically arranged sites on the scalp using silver-silver chloride electrodes embedded in an Electro-cap. The sites are Midline Prefrontal (MiPf), Left and Right Medial Prefrontal (LMPf and RMPf), Left and Right Lateral Prefrontal (LLPf and RLPf), Left and Right Medial Frontal (LMFr and RMFr), Left and Right Mediolateral Frontal (LDFr and RDFr), Left and Right Lateral Frontal (LLFr and RLFr), Midline Central (MiCe), Left and Right Medial Central (LMCe and RMCe), Left and Right Mediolateral Central (LDCe and RDCe), Midline Parietal (MiPa), Left and Right Mediolateral Parietal (LDPa and RDPa), Left and Right Lateral Temporal (LLTe and RLTe), Midline Occipital (MiOc), Left and Right Medial Occipital (LMOc and RMOc), and Left and Right Lateral Occipital (LLOc and RLOc); the head icon in Figure 2 shows the arrangement. The position of the cap was determined by placing the Midline Prefrontal electrode (MiPf) at 10% of the nasion-inion distance from the nasion, the Midline Occipital (MiOc) electrode at approximately 10% of the distance from the inion, and the Midline Central (MiCe) electrode halfway between the mastoid processes. The

[5]As with the experimental stimuli, no more than three consecutive stimuli were presented in a visual field.

[6]The calibration procedure for three participants consisted of an X presented 30 times in each location, and three other participants did not complete the calibration procedure due to time constraints.

[7]Two of the items originally part of the unseen category were repeated stimuli; thus, they were not unseen for all intended lists, and were not scored.

electrodes were referenced online to the left mastoid and later referenced offline to the average of the left and right mastoids. Eye movements were monitored using a bipolar recording of EOG with electrodes placed on the outer canthus of each eye. Blinks were monitored with an electrode placed over the infraorbital ridge of the left eye, referenced to the left mastoid. Electrode impedances were kept below 4 k and signals were amplified with Sensorium amplifiers set at a bandpass of 0.02 to 100 Hz. EEG was sampled at 250 Hz and saved on a hard drive.

EEG records were examined and marked for EOG, EMG, or other artifactual contamination. Using data from the EOG calibration procedure described above, rejection algorithm thresholds corresponding to eye movements of one, two, and four degrees from fixation were determined for each participant. In the epoch consisting of the 100 ms before stimulus onset through 200 ms post-stimulus onset (corresponding to the duration of critical stimulus presentation plus a 100 ms baseline), individual trials containing eye movement activity that exceeded the average of the 1 and 2 degree thresholds were rejected to ensure that participants maintained fixation during presentation of lateralized stimuli for trials included in the ERP averages. After 200 ms, individual trials containing EOG activity exceeding the 4 degree threshold were rejected in order to prevent EOG activity from contaminating the ERP records. The effectiveness of this procedure was assessed by ensuring that for each condition of each participant, the average voltage recorded in the horizontal EOG channel (i.e. in the ERP for each condition) during time epochs of interest did not exceed the average voltage levels of the one- and two-degree eye movement calibration trials. Also, no effects of conditions within VFs were observed in the EOG channels when subjected to statistical analysis.

Artifactual trials containing eye blinks were corrected (see Dale, 1994 for the procedure) and added back into the EEG record for 27 of the 32 participants. The remaining artifactual trials (average 17.8% across conditions and subjects) were excluded from further analysis. This left an average of 28.98 trials per condition in each VF across subjects (minimum 20). There was a small but reliable tendency for ERPs for strongly constraining sentences to have more trials than those for weakly constraining sentences (29.3 versus 28.6 on average), but no other differences were found for conditions within or across VF of presentation.

ERPs were computed from 100 ms before the onset of critical words to 920 ms after. The data were rereferenced to the algebraic mean of the left and right mastoids, and averages of artifact-free ERPs were calculated for each type of critical word (SC-EE, WC-EE, SC-UE, WC-UE) after subtraction of the 100 millisecond pre-stimulus baseline. Measurements were taken after a digital bandpass filter of .2 to 20 Hz was applied.

Results

Behavioral (Post-test) Results

Participants correctly recognized an average of 40.5 of the 160 experimental words in the recognition test (25.3%) and false alarmed to an average of 7 of the 78 unseen words in the test (9%). They were thus able to discriminate between words they had and had not seen as sentence endings, indicating they were paying attention to the experimental stimuli (mean d' = .87).

To determine whether any effects of the experimental manipulations and visual field of presentation could be observed on memory for sentence endings, scores[8] were subjected to an analysis of variance (ANOVA) consisting of two levels of visual field (left and right), two levels of constraint (strong and weak), and two levels of expectancy (expected and unexpected). A main effect of Constraint [$F(1,31)=5.52$, $p=.0254$] was observed, modulated by a Constraint × Expectancy interaction [$F(1,31)=4.99$, $p=.0328$]. The interaction resulted because across the two levels of visual field, unexpected items in the two types of sentence contexts were remembered equally well (24.7% versus 25.3% for SC-UE and WC-UE endings respectively), but expected endings in weakly constraining contexts were remembered better than expected endings in strongly constraining contexts (28.7% versus 22.2% for WC-EE and SC-EE, respectively).

Overall, there was a numerical tendency for items presented to the RVF to be better remembered than items presented to the LVF [27% versus 23.4%, $F(1,31)=2.40$, $p=.1316$], but the patterns of performance were quite similar for the two VFs: unexpected endings were remembered equally well across levels of sentence constraint, while expected endings were remembered less well in strongly constraining contexts, indicated by the experimental effects above. What differed across VFs was the performance for unexpected items relative to expected ones: Expectancy interacted with VF [$F(1,31)=14.92$, $p=.0005$], such that for RVF presentation, unexpected endings (28.4%) were remembered better than expected endings (regardless of level of constraint, 23.6%), and for LVF presentation, unexpected items (21.6%) were remembered less well than expected items (regardless of level of constraint, 27.3%). The pattern for both VFs is shown in Figure 1.

The post-test results are similar to what Federmeier, Wlotko, De Ochoa-Dewald, and Kutas (in press) observed with the same experimental materials and a similar post-test, in overall discriminability of seen versus unseen items, as well as in finding that stronger sentential constraint leads to poorer memory for expected (and hence less distinctive) sentence completions. This virtually identical overall performance to that of the prior study suggests that participants were able to apprehend and integrate the laterally presented target words in a manner similar to that for central presentation. While there was not a large difference in overall performance for items presented to the two visual fields, unexpected items were remembered less well when presented to the LVF. It is possible that the RVF advantage for word recognition is mitigated when strongly expected, and hence more easily apprehended, stimuli are presented, and therefore an RVF advantage is observed only for unexpected items.

Event-related Potentials

Grand average ERPs to sentence-final words in each VF are shown in Figure 2. Early components in all conditions and hemifields include, at posterior sites, a positivity (P1) peaking between 100 and 150 ms (depending on VF and channel), a negativity (N1) peaking between 150 and 200 ms (depending on VF and channel), and a positivity (P2) peaking around 250 ms. As expected, these effects are strongly lateralized, being most prominent over posterior sites contralateral to VF of presentation. At frontal sites, all conditions include a negativity (N1) peaking around 100 ms and a positivity (P2) peaking at 230 ms. Early components are followed, most prominently for unexpected endings, by a broadly-distributed negativity (N400) between 300 and 500 ms and, in all conditions, by a posterior, lateralized negative-going effect (selection negativity) extending from about 300 ms to the end of the epoch. This morphology accords with all past ERP studies that have employed the VF technique.

Frontal P2—To examine effects on the frontal P2 component, mean amplitudes were measured in a 50 ms time window centered around its peak (205–255 ms) and subjected to an omnibus analysis of variance consisting of two levels of VF (left and right), two levels of constraint (strong and weak), two levels of expectancy (expected and unexpected), and 26 levels of electrode[9]. A significant main effect of Constraint [$F(1,31)=5.71$, $p=.0232$] was

[8]Because of the way the recognition test was constructed, the distribution of unexpected items across the two visual fields of presentation varied across lists (ranging from 15 to 24). Because of this, the proportions of items from each condition that were recognized were used as recognition scores. Also note that there is only one false alarm rate for the recognition test; thus, proportions recognized for each condition are used for the analysis, rather than d' or false alarm corrected scores.

modulated by a Constraint × VF interaction [F(1,31)=5.29, p=.0283]. This interaction resulted because words completing strongly constrained sentence contexts elicited a larger (more positive) P2 than did words completing weakly constrained contexts for RVF items [F(1,31) =7.92, p=.0084; Constraint × Electrode, F(25,775)=2.61, p=.0271, ε=.1902[10]] but not for LVF items [F(1,31)=.05, p=.8246; Constraint × Electrode, F(27,775)=.75, p=.5905, ε=.1868]. This pattern can be seen in Figure 3. The P2 analysis also elicited an Expectancy × Electrode interaction [F(25,775)=4.09, p=.0086, ε=.1395], which was the result of expected items being slightly more positive than unexpected items at medial frontal and central sites. This factor, and all other experimental factors, did not interact with VF of presentation.

N400—Mean amplitudes were measured across the 300–500 ms time window for all conditions over all channels. Values were submitted to an omnibus ANOVA as for the P2. An overall Constraint × Expectancy interaction was observed [F(1,31)=29.01, p<.0001; Constraint × Expectancy × Electrode, F(25,775)=5.34, p=.0001, ε=.2026], as was a main effect of Expectancy [F(1,31)=78.61, p<.0001] and an interaction between Expectancy and Visual Field [F(1,31)=11.43, p=.002]. The three way interaction between Constraint, Expectancy, and Visual Field was marginally significant [F(1,31)=3.46, p=.0722; Constraint × Expectancy × VF × Electrode, F(25,775)=1.79, p=.1181, ε=.1808]. Electrode also interacted with Constraint [F(25,775)=2.46, p=.0357, ε=.1933] and Expectancy [F(25,775)=20.08, p<.0001 ε=.1300].

To further examine the Constraint × Expectancy and Expectancy × VF interactions, as well as to assess planned comparisons for the conditions within each VF, pairwise comparisons were conducted using mean amplitudes from the 300–500 ms time window over all channels. Figure 4 shows the ERPs from the two VFs at both the left and right mediolateral central channels, which are representative of the N400 patterns for both RVF and LVF presentation. Also, the lateralization of sensory components (i.e. the N1) can be visualized at these channels. Figure 4 also includes a bar chart which displays mean amplitudes across all channels for the N400 time window.

RVF effects—As anticipated based on prior work, expected words presented to the RVF elicited smaller N400 responses than did unexpected words when these were embedded in strongly constraining sentence contexts [SC-EE versus SC-UE, F(1,31)=48.51, p<.0001], and this effect interacted with Electrode [F(25,775)=11.54, p<.0001, ε=.1756]. For weakly constraining contexts, the WC-EE condition was less negative than the WC-UE condition for RVF presentation [F(1,31)=33.22, p<.0001; interaction with Electrode, F(25,775)=7.81, p<.0001, ε=.1562], consistent with their cloze probabilities. However, when comparing the expected items from the two types of contexts for RVF presentation, there was only a marginal effect on the N400 response [SC-EE versus WC-EE, F(1,31)=3.30, p=.0789; Constraint × Electrode, F(25,775)=0.61, p=.6918, ε=.2076], indicating a lack of a cloze probability effect for RVF expected items. For RVF unexpected endings, N400s were less negative for these items in weakly compared to strongly constraining contexts [SC-UE versus WC-UE, F(1,31) =5.54, p=.0251], despite the equal cloze probability for the items in the two contexts.

LVF effects—As with RVF presentation, SC-EE items elicited a much smaller N400 than SC-UE items when presented to the LVF [F(1,31)=70.33, p<.0001; interaction with Electrode, F(25,775)=11.96, p<.0001, ε=.1826]. When assessing the effect of expectancy in weakly

[9]The P2 effect we observe is rather widespread in its distribution; thus, all channels are used in the analysis. The same pattern of results is obtained when using a more restricted set of medial frontal-central electrodes, where the P2 effect is visually largest.

[10]To compensate for violations of sphericity, comparisons with more than one degree of freedom for the numerator are reported with Huynh-Feldt corrected p-values, the original degrees of freedom, and the Epsilon value. Note that while interactions of experimental conditions with electrode will be reported when significant, they will be further analyzed and discussed only when of theoretical significance.

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constraining contexts, however, only a small, marginally significant N400 difference was observed for WC-EE and WC-UE items presented to the LVF [F(1,31)=3.49, p=.0712; interaction with Electrode, F(25,775)=1.12, p=.3516, ε=.1555]. For LVF expected endings, N400 amplitudes were greater in weakly than in strongly constraining contexts [SC-EE versus WC-EE, F(1,31)=37.17, p<.0001; interaction with Electrode, F(25,775)=8.69, p<.0001, ε=.1572], consistent with their cloze probabilities. For LVF unexpected endings, a similar difference between SC-UE and WC-UE items was observed compared to that of the RVF [F(1,31)=6.95, p=.0130]. Because of the lack of an expectancy effect for weakly constrained items presented to the LVF, facilitation for WC-EE items compared to SC-UE items presented to the LVF was assessed. LVF WC-EE items had significantly smaller N400s than LVF SC-UE items [F(1,31)=20.09, p=.0001].

Sizes of effects—To compare effect sizes across the two VFs of presentation, difference waves were formed from point-by-point subtractions of conditions of interest from one another. The size of the N400 effect in each case was measured in the 300–500 ms time window, and the comparison across VF of presentation was assessed via an ANOVA with two levels of VF and 26 levels of electrode. For strongly constraining contexts, the expectancy effect was not different for the two VFs [F(1,31)=1.05, p=.3128; interaction with Electrode, F(25,775)=.33, p=.8943, ε=.1986], but the expectancy effect for weakly constraining contexts was larger for RVF presentation compared to LVF presentation [F(1,31)=14.62, p=.0006; interaction with Electrode, F(25,775)=3.03, p=.0198, ε=.1776]. There was no difference across the two VFs for the constraint effect on unexpected items [F(1,31)=.04, p=.8407; interaction with Electrode, F(25,775)=.67, p=.6147, ε=.1469], but the constraint effect for expected items was much larger for LVF presentation [F(1,31)=7.20, p=.0116; interaction with Electrode, F(25,775)=2.86, p<.0258, ε=.1730].

In summary, effects of expectancy were observed in both VFs, with highly expected endings (those in strongly constrained sentences) eliciting smaller N400 responses than plausible endings that were unexpected in their contexts. However, the pattern of effects across constraint and expectancy revealed important differences between the two visual fields. Differences between expected and unexpected endings in weakly constraining sentences were observed only for RVF items, while differences between high and low cloze probability expected completions (in strongly versus weakly constraining contexts) were observed only for LVF items. Differences between equally unexpected (but lexically identical) items as a function of sentential constraint were seen for both RVF and LVF presentation.

Late effects—Because an effect of sentential constraint that began around 500–600 ms post-stimulus onset was observed for unexpected endings in Federmeier, Wlotko, De Ochoa-Dewald, & Kutas (in press), the late time window (mean amplitude in 600–900 ms window) was examined with an omnibus ANOVA as for the other time windows. A main effect of Expectancy [F(1,31)=12.40, p<.0014] and a main effect of VF [F(1,31)=4.74, p=.0372] were observed, as well as a Constraint × Electrode interaction [F(25,775)=3.52, p=.0096, ε=.1451], modulated by a Constraint × VF × Electrode interaction [F(25,775)=2.80, p=.0286, ε=.1596]. Strongly constrained completions tended to be more negative over frontal channels than weakly constrained completions, especially for LVF items. An Expectancy × Electrode interaction [F(25,775)=5.67, p=.0013, ε=.1192] was also observed, resulting from the fact that the main effect of expectancy (more negative for unexpected items) was most apparent over central-parietal channels and smallest over frontal channels.

The significant differences observed here likely represent activity of the late positive complex (LPC) effects often observed following the N400. However, no indication of a constraint effect similar to the one described in Federmeier, Wlotko, De Ochoa-Dewald, & Kutas (in press) was observed.

Discussion

The goal of this study was to further assess when and how each hemisphere makes use of message-level information provided by a sentence context. Prior ERP studies have shown that both hemispheres are broadly sensitive to basic manipulations of plausibility/expectancy (Federmeier & Kutas, 1999a; Coulson, Federmeier, Van Petten, & Kutas, 2005; Federmeier, Mai, & Kutas, 2005), manifested as larger N400 amplitudes to implausible or unexpected endings as compared with N400s to expected endings. However, such studies have also indicated that the two hemispheres use context information differently, as facilitation for unexpected endings related to a predicted completion is observed on N400 responses only with RVF/lh presentation (Federmeier & Kutas, 1999a), and as effects of expectancy on the amplitude of the P2, a component linked to higher-order visual processing, are also evident only for RVF/lh items (Federmeier & Kutas, 2002; Federmeier, Mai, & Kutas, 2005). Such patterns have been taken to suggest that only the LH actively uses context information to predict – that is, to prepare to process conceptual and perhaps even perceptual features of likely upcoming words. The RH, instead, has been hypothesized to adopt a more “integrative” approach to processing, in which the fit of a given word to its context is assessed in a more bottom-up, post hoc fashion. This framework predicts differences in each hemisphere’s sensitivity to expectancy (as indexed by cloze probability) and contextual constraint, factors that have not been systematically covaried in prior research.

To that end, the present study examined responses to expected and unexpected sentence completions in contexts that were either strongly or weakly constraining. Whereas constraint and cloze probability are inherently confounded for expected completions (because contextual constraint is defined by the cloze probability of the most expected ending), they can be unconfounded for endings that are not expected in the context. Here, unexpected endings were carefully controlled across the two constraint conditions: these words were identical lexical items and were matched for cloze probability. A prior study using these materials with centrally presented words uncovered distinct effects of cloze probability and constraint (Federmeier, Wlotko, De Ochoa-Dewald, & Kutas, in press). Consistent with numerous prior findings, N400 responses were graded by cloze probability, suggesting that this response primarily indexes the benefit of supportive contextual information for word processing, rather than reflecting any “cost” associated with a violation of expectancy in strongly constraining contexts or recovering from that violation. Of interest for the present study, then, was whether such contextual benefits accrue similarly for predictive-biased (i.e. LH) and integrative-biased (i.e. RH) processing strategies. In the Federmeier et al. (in press) study, effects of sentential constraint separate from cloze probability were not evident on the N400, but rather emerged later in the form of a sustained frontal positivity that was selectively enhanced for unexpected endings in strongly constraining sentence contexts. This effect was interpreted as indexing the additional processing that may be required to suppress and/or revise a prediction when unexpected (but plausible) information is encountered. Since only the LH is hypothesized to use context information predictively, such effects of constraint – i.e. differences in the processing of (cloze probability-matched) unexpected endings as a function of the level of expectancy that the context affords for the best completion (a completion which presumably could compete for activation with the presented unexpected item) – should be evident only for sentence completions presented to the RVF.

The results presented here replicated prior findings in showing that both hemispheres are sensitive to message-level context information, as manifested in N400 reductions to highly expected as compared with wholly unexpected endings. Replicating Federmeier, Mai, & Kutas (2005), N400 responses to strongly constrained expected completions (SC-EE) were smaller than those to weakly constrained unexpected completions (WC-UE) in both VFs, showing that both hemispheres could assess the basic fit of a word to the message-level meaning of the context in which it was embedded. Replicating Federmeier & Kutas (1999a) and Coulson, Federmeier, Van Petten, & Kutas (2005), the amount of facilitation for the expected relative to unexpected items in strongly constraining contexts (SC-EE versus SC-UE) was equivalent in the two VFs; thus, these data do not support an account which posits that the RH is wholly or partially insensitive to the message-level meaning of a sentence. However, the pattern of responses across all four conditions revealed differences in the nature of the facilitation that each hemisphere obtains from sentence context information. Surprisingly, neither VF showed the now well-replicated pattern of graded sensitivity to cloze probability seen under non-lateralized processing, including central presentation of these same sentences (Federmeier, Wlotko, De Ochoa-Dewald, & Kutas, in press), with N400 responses to items with low or moderate cloze probability (as in the WC-EE condition) intermediate between those to high cloze completions (SC-EE) and completions with cloze probability near zero (both UE conditions).

As in prior ERP work using VF presentation, effects of constraint emerged on the P2 component, limited to RVF/lh presentation. This is consistent with the hypothesis that the LH, but not the RH, uses context information to actively prepare to process upcoming words. We discuss each of these findings in turn, beginning with the temporally earliest P2 effect.

P2

Federmeier, Mai, and Kutas (2005) found that, with RVF but not LVF presentation, strongly constrained, expected endings elicited a larger (more positive-going) P2 than did weakly constrained, unexpected completions. They interpreted this difference as evidence that only the LH can use context information to predict the perceptual features of likely upcoming words, with a feature match engendering a P2 enhancement similar to that seen to targets in visual search studies (e.g. Luck & Hillyard, 1994). A similar difference was seen in the current study for the same comparison (SC-EE versus WC-UE); however, the additional comparisons afforded by the current design suggest a different interpretation of the P2 asymmetry. The P2 effect in the current experiment manifested as a main effect of constraint: strongly constrained sentence completions elicited larger P2s than weakly constrained completions for RVF presentation, regardless of expectancy. For items in strongly constrained contexts in particular, the P2 was identical for the expected and unexpected endings. Thus, it would appear that strongly constraining contexts induce a change in processing state for the LH, perhaps preparing the system in some way to apprehend what will likely be a very predictable stimulus. This state change did not seem to be affected by whether or not the predicted stimulus was then actually presented. This pattern supports the hypothesis that top-down expectations shape higher-level perceptual processing in the RVF/lh but not LVF/rh, consistent with the prediction/integration view. However, in this study, the P2 did not seem to index whether or not there was a match between the prediction and the presented item. This pattern contrasts with that seen for pictures in sentence contexts, in which the RVF/lh P2 response was more positive to expected than to unexpected items embedded in identical sentence contexts (Federmeier & Kutas, 2002). It is possible that the LH processing indexed by the P2 reflects a mix of both state-based effects, as reflected by increased positivity to strongly constrained targets, irrespective of actual fit, and match-based effects modulated by expectancy, which were observed in prior studies (and a suggestion of this possibility of a mix of effects is seen in the current data, with a numerical trend for the WC-EE condition to elicit larger P2 responses than the WC-UE condition). The nature of contextual effects may also differ for different types of stimuli, such as pictures and words (e.g. Federmeier & Kutas, 2001). For example, expected and unexpected pictures are less likely to share perceptual features than expected and unexpected words; thus, on the view that the processing indexed by the P2 is sensitive to perceptual feature matching, one might expect to find smaller effects of expectancy for words.

P2 effects have been reported in prior lateralized studies, but generally not with central presentation, and a P2 effect was not reported for the same stimuli in Federmeier, Wlotko, De Ochoa-Dewald, & Kutas (in press). Differences between the conditions were observed in the time window and scalp location of the P2 in that study; however, the pattern across conditions was the same as that observed on the N400. Thus, with central presentation, it can be difficult to differentiate P2 effects from effects resulting from the onset of the N400, especially when the scalp distribution of the two components can substantially overlap, as suggested by the broad distribution of the P2 observed in the present study. In lateralized studies, however, the P2 has been modulated differently for the two VFs, allowing identification of the component separately from the N400 (where the asymmetries observed or the patterns across conditions are not mirrored in the P2 effects).

N400: RVF/lh

N400 responses in the RVF/lh manifested a strong effect of expectancy, with reduced amplitude responses to the SC-EE and WC-EE conditions as compared with the SC-UE and WC-UE conditions. Strikingly, however, the difference between the SC-EE and WC-EE conditions, which had an average cloze probability difference of about 50%, was small and not statistically reliable. It seems that the LH predictive processing strategy may provide robust facilitation even under circumstances in which the context information leading to a given expectancy is relatively weak. In other words, when the LH selects a word (or words), it may do so with similar strength irrespective of the level of bottom-up support initially provided for that selection by the context.

The RVF/lh pattern, on its own, cannot distinguish between prediction and other types of processing mechanisms; indeed, in many cases the output of a predictive processor will look similar to that of other kinds of processing mechanisms, as all language comprehension models must explain basic findings such as strong facilitation for high cloze probability items. However, the results observed here are consistent with the evidence (including the P2 constraint effect in this study) that *does* suggest that the LH employs a predictive type of processing strategy, different from that of the RH. The current results would then suggest that prediction may tend to “override” cloze probability, which provides information only about the average strength and/or consistency of expectations engendered by the context.

Indeed, dissociations between cloze probability and N400 facilitation for RVF/lh processing were also seen in Federmeier & Kutas (1999a), where reduced N400s were observed for incongruous words when these were semantically related to the expected completion, as compared with the response to unrelated incongruous words, despite the similar (near-zero) cloze probabilities for these two ending types. A comparable pattern was seen in the responses to the unexpected completions in the present study, with smaller N400 responses to WC-UE than to SC-UE endings, despite the fact that these items were carefully matched for cloze probability. Although the endings were selected to be unrelated to the expected completion, it is possible that the wider range of plausible completions engendered by weakly constraining contexts provides more potential for overlap between the features of the expected ending(s) and those of the unexpected completions, resulting in some degree of facilitation. However, the same difference between SC-UE and WC-UE items was not observed for central presentation in Federmeier, Wlotko, De Ochoa-Dewald, & Kutas (in press), although the effect is present for LVF/rh presentation in this study (as discussed below). Thus, it is also possible that lateralization of the sentence completions makes the items more difficult to perceive and that this difficulty may interact with sentential constraint. Consistent with this idea, preliminary data indicate that older participants, who may use sentential context information differently from younger participants due to perceptual “noise” or timing differences in processing, also show a difference between SC-UE and WC-UE items for central presentation of these stimuli.

N400: LVF/rh

Whereas responses for RVF/lh items seemed to be dominated by expectancy, the pattern of response across the four conditions for the LVF/rh items revealed a striking interaction between expectancy and constraint. Facilitation was observed for the strongly constrained expected endings relative to unexpected items in the same sentence contexts, but there was no difference in the response to expected and unexpected endings when these were embedded in weakly constraining sentences, despite an average cloze probability difference of about 30%. Thus, facilitation for items initially processed by the RH seems limited to cases in which the context information provides a fairly strong base of support for the word/concept being processed. This finding may help to reconcile some of the differences between the pattern of results seen across prior ERP and behavioral studies; ERP work showing RH sensitivity to message-level context information has tended to use fairly strongly constraining contextual information (e.g. Coulson, Federmeier, Van Petten, & Kutas, 2005), whereas the behavioral work that has suggested a lack of RH sensitivity to such information has largely used stimuli that provide relatively weak contextual support (e.g. Chiarello, Liu, & Faust, 2001).

As with RVF/lh presentation, unexpected items in weakly constraining contexts elicited a smaller N400 compared to those items in strongly constraining contexts. Thus, the RH showed facilitation for WC-EE and WC-UE items compared with SC-UE items, though there was no differentiation between the WC-EE and WC-UE items. The overall pattern of results could be consistent with the idea that the RH is more flexible in its integration of unexpected but plausible items, particularly if the system is sensitive to overall patterns of activation (as opposed to just the activation level of any given word/concept). If, for example, the LH uses even weak contexts predictively, selection or facilitation for other (non-expected) competitors will be decreased. However, if the RH does not focus activation for one specific set of semantic features, a broader range of sentence completions may be more easily integrated into the context (perhaps by processes downstream from the N400).

N400: Overall pattern

The fact that the expected, graded N400 response to cloze probability was not obtained with stimulus presentation to either VF is quite remarkable and raises the intriguing possibility that the typical pattern actually reflects the joint influence of two different, lateralized processing mechanisms – neither of which is actually sensitive to cloze probability in a graded fashion. In particular, the moderate level of facilitation typically observed for low cloze probability completions could arise if these items are highly facilitated by one processor (the LH), but facilitated little or not at all by the other (the RH). Indeed, as can be seen in Figure 5, averaging the responses from the two VFs yields a response pattern very similar to that seen with central presentation of these same stimuli. Because this was the first visual half-field study to include plausible completions with several levels of cloze probability, further work manipulating cloze probability in a fine-grained manner will be needed to fully ascertain how the response functions of the two hemispheres are influenced by off-line expectancy and how the pattern observed with non-lateralized presentation relates to that seen from each VF individually.

Late frontal positivity

Another striking difference between the pattern of results seen with lateralized presentation in the present study as compared to that seen with central presentation of the same stimuli in Federmeier, Wlotko, De Ochoa-Dewald, & Kutas (in press) was the lack of a frontal positivity to unexpected endings embedded in strongly constraining sentence contexts. Federmeier et al. (in press) interpreted this positivity (similar to an effect recently reported in an abstract by DeLong and Kutas, 2006) as reflecting the need for inhibition and/or revision upon encountering an unexpected item in the face of a strongly predicted competitor. Because prior work has suggested that the LH, but not the RH, uses context information predictively, we expected to see this response only with RVF presentation. However, we did not observe this effect in either VF. This suggests that hemispheric cooperation may be necessary for such processes to emerge from the language processing system.

Conclusions

In sum, this study extends a recent line of ERP experiments showing that both hemispheres are sensitive to the message-level information provided by sentence contexts. However, the mechanisms by which sentence context affects word processing seem to be different in each, and these differences emerge at multiple levels of processing. In particular, the left hemisphere seems to make more use of top-down processing strategies to prepare for the processing of likely upcoming stimuli at both perceptual (P2) and semantic (N400) levels. This predictive approach makes the LH more sensitive to contextual constraint and seems to aid the processing of expected words that do not have strong contextual support. In contrast, the right hemisphere seems to adopt a more bottom-up approach, assessing the fit between a word actually presented and those that have come before. This processing strategy seems to afford less benefit to the processing of words that receive only weak contextual support but may allow for greater flexibility to integrate unexpected, but plausible, endings.

More generally, these data strongly suggest that normal language comprehension emerges from the joint operation of multiple mechanisms, arising not only from activity in classic left hemisphere language areas, but from a broader, bilateral network encompassing processes at several levels (e.g. Kaan & Swaab, 2002; Gernsbacher & Kaschak, 2003). In some cases, then, data patterns seen for normal language comprehension may reflect the summation of concurrent activity in multiple, distinct processors, none of which is individually sensitive to language variables in the manner suggested by the combined response. In other cases, hemispheric cooperation may afford processing strategies that neither hemisphere is capable of supporting alone. A complete understanding of the cognitive and neural mechanisms underlying normal language comprehension will thus require a further specification of not only the individual, but also the interactive, contributions of each cerebral hemisphere.

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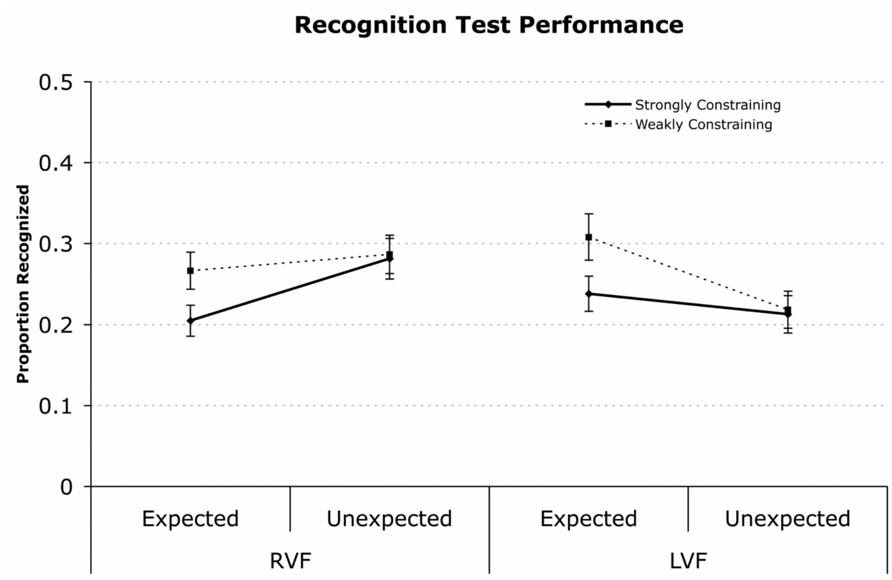

Figure 1.
Post-test recognition performance, displayed as proportion of items recognized from each experimental condition.

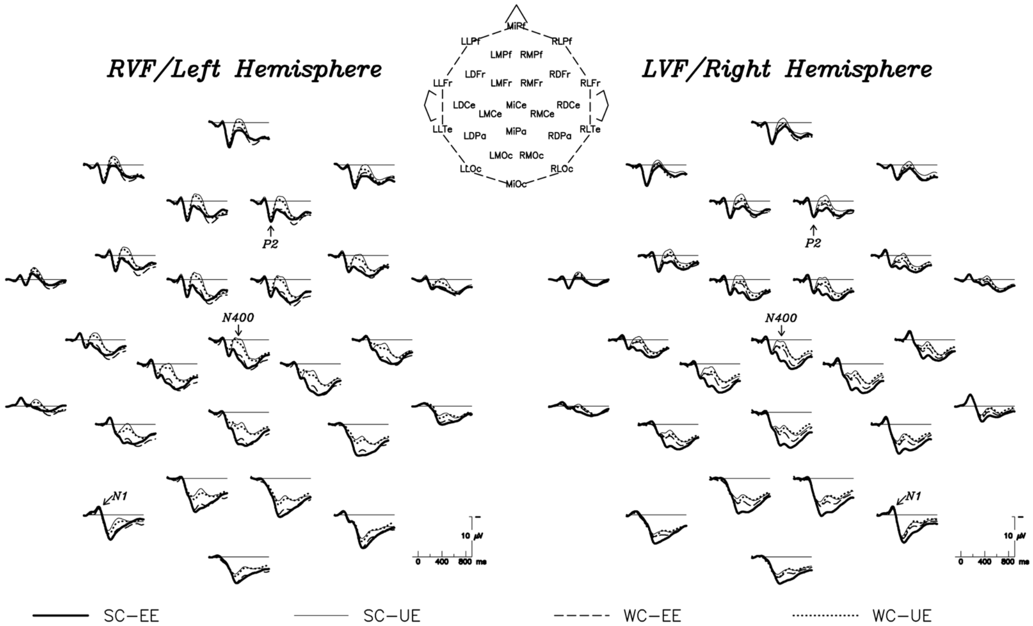

Figure 2.

Grand Average ERPs for all conditions at all scalp electrodes, for both RVF/lh and LVF/rh presentation. At center, the head icon (nose at top) indicates the approximate scalp position and the label of each electrode channel. Negative is plotted up in this and all subsequent figures.

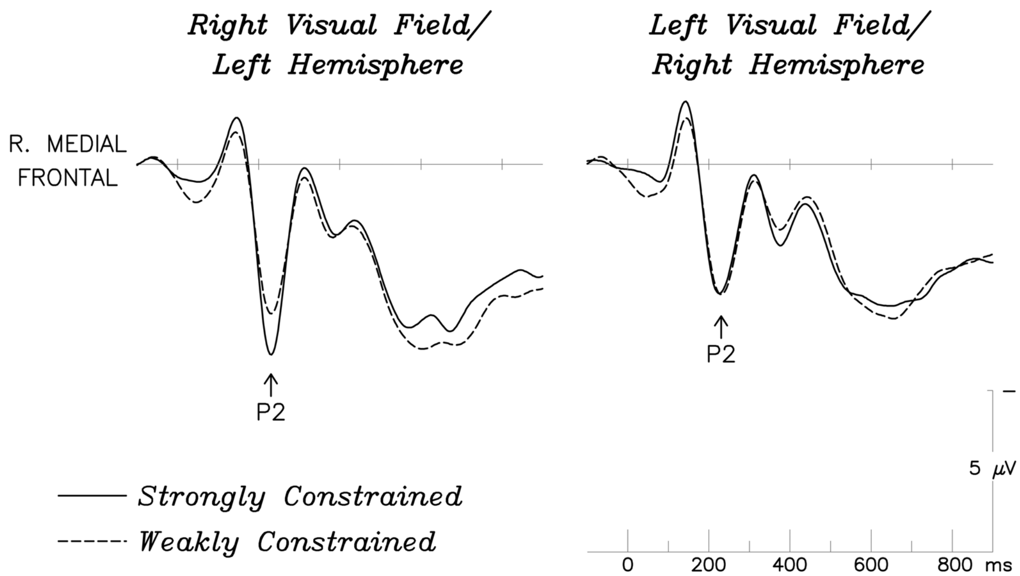

Figure 3.

P2 constraint effect (collapsed over expectancy) shown at the Right Medial Frontal Channel for RVF/lh and LVF/rh presentation.

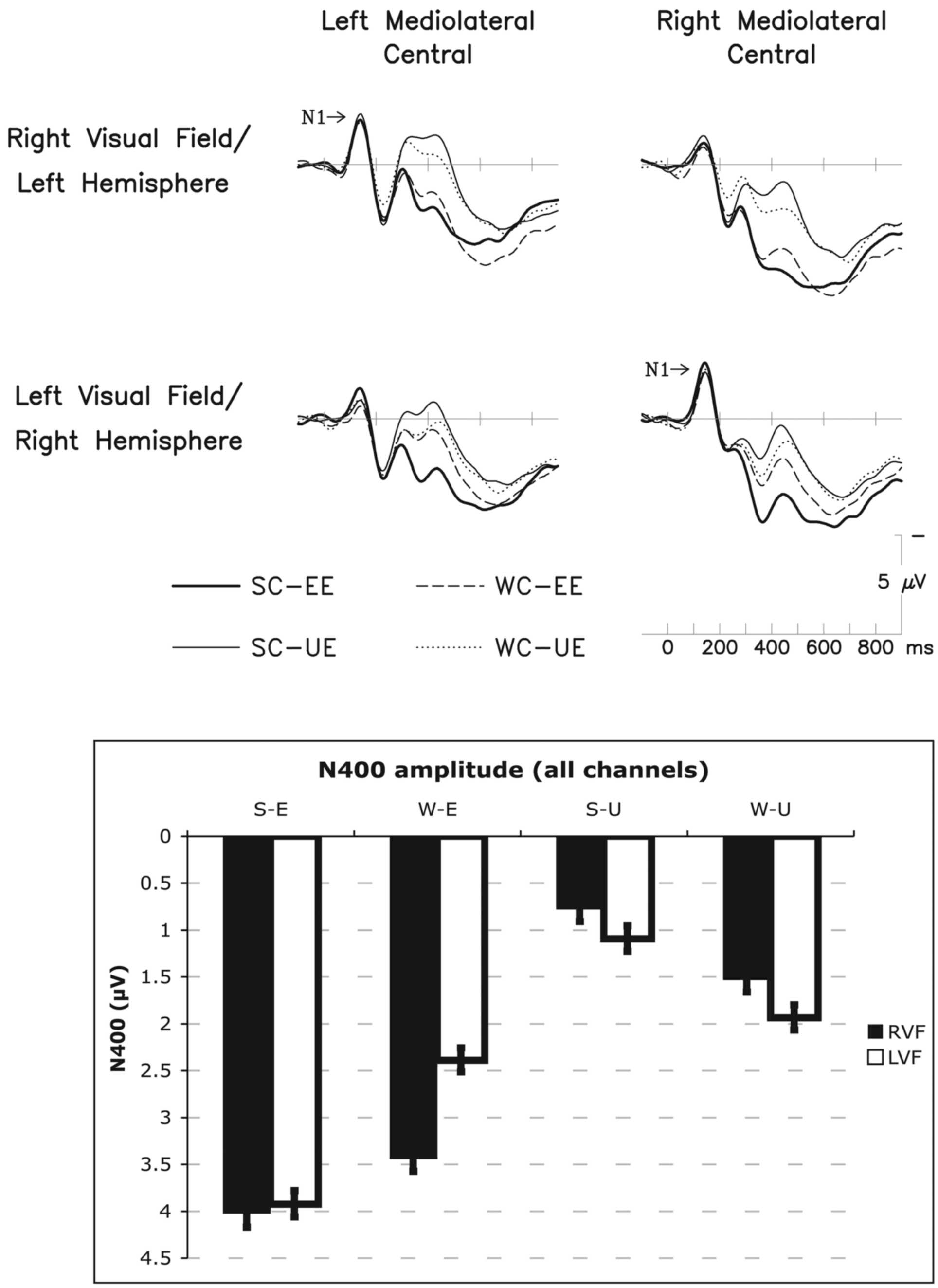

Figure 4.

Top Panel: All conditions for both RVF/lh and LVF/rh presentation, shown at the Left and Right Mediolateral Central channels. Lower Panel: Mean N400 amplitude in the 300–500 ms time window, averaged across all channels. Positive is plotted downward, analogous to ERP plots (a less negative value, and hence a lower bar, represents smaller N400s).

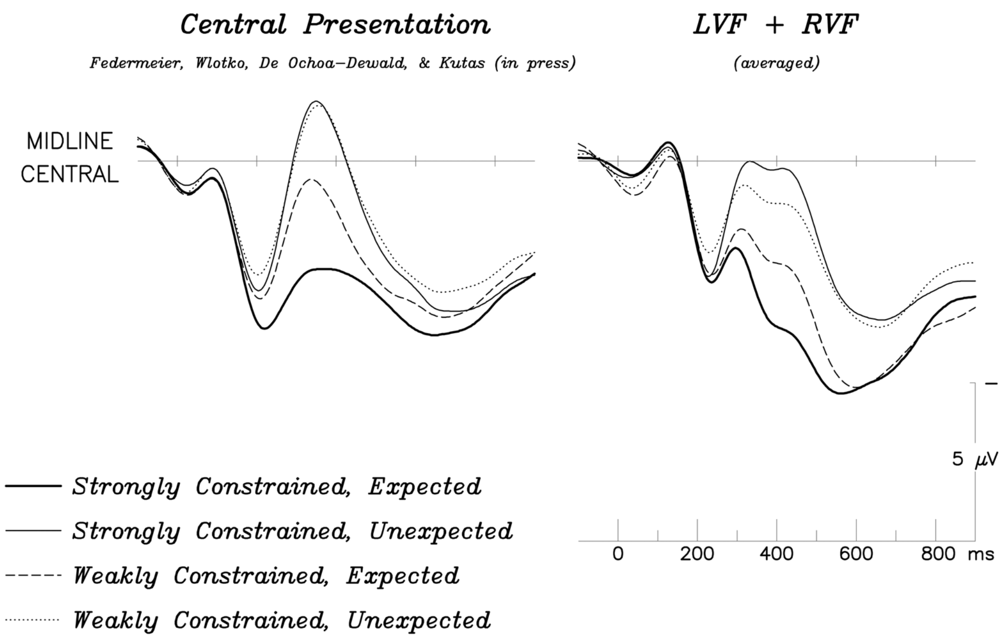

Figure 5.
Left: With central presentation, N400 amplitude is graded with cloze probability, as shown in numerous prior studies. Right: Although this pattern is not obtained with presentation to either VF, the graded pattern is approximated by averaging the ERP responses to LVF and RVF items, shown here at the Midline Central channel (i.e. Cz).

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Table 1

Examples of the stimuli (SC=Strongly Constraining, WC=Weakly Constraining).

	Sentence Frame	Expected	Unexpected
SC	He bought her a pearl necklace for her	birthday.	collection.
WC	He looked worried because he might have broken his	arm.	collection.
SC	The construction worker had developed very powerful arms from unloading bags of cement from the	truck.	dock.
WC	The county decided to tear down the gas station by the	park.	dock.
SC	Sam could not believe her story was	true.	published.
WC	I was impressed by how much he	knew.	published.
SC	The child was born with a rare	disease.	gift.
WC	Mary went into her room to look at her	clothes.	gift.
SC	He was cold most of the night and finally got up to get another	blanket.	log.
WC	He fell on the floor after tripping on the	crack.	log.

Table 2

Stimulus characteristics of the four sentence completion conditions. Means for First Completion Cloze (cloze probability for the first completion given in the norming; see text for details), “Next Best Cloze” (cloze probability for both additional completions given in the norming), Overall Cloze (sum of First Completion Cloze and “Next Best” Cloze), frequency, length, and ratings for concreteness, imagability, and familiarity are reported, with standard deviations in parentheses.

	Overall Cloze (%)	First Completion Cloze (%)	“Next Best” Cloze (%)	Frequency (wpm)	Length (letters)	Concreteness (100–700 scale)	Imagability (100–700 scale)	Familiarity (100–700 scale)
SC-EE	90.3 (7.61)	85.4 (8.55)	4.9 (5.25)	122 (175.5)	5 (1.3)	522 (105.7)	545 (86.3)	576 (39.2)
WC-EE	36.2 (11.37)	26.9 (8.35)	9.3 (5.25)	141 (309.2)	5 (1.7)	508 (101.7)	530 (88.7)	574 (39.5)
SC-UE	3.1 (3.78)	.6 (1.30)	2.6 (3.19)	74 (126.3)	6 (2.1)	508 (109.2)	531 (81.9)	558 (46.9)
WC-UE	3.1 (5.60)	1.5 (2.65)	1.6 (2.91)					