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Sensitivity to syntax in visual cortex

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Abstract

One of the most intriguing findings on language comprehension is that violations of syntactic predictions can affect event-related potentials as early as 120 ms, in the same time-window as early sensory processing. This effect, the so-called early left-anterior negativity (ELAN), has been argued to reflect word category access and initial syntactic structure building (Friederici, 2002). In two experiments, we used magnetoencephalography to investigate whether (a) rapid word category identification relies on overt category-marking closed-class morphemes and (b) whether violations of word category predictions affect modality-specific sensory responses. Participants read sentences containing violations of word category predictions. Unexpected items varied in whether or not their word category was marked by an overt function morpheme. In Experiment 1, the amplitude of the visual evoked M100 component was increased for unexpected items, but only when word category was overtly marked by a function morpheme. Dipole modeling localized the generator of this effect to the occipital cortex. Experiment 2 replicated the main results of Experiment 1 and eliminated two non-morphology-related explanations of the M100 contrast we observed between targets containing overt category-marking and targets that lacked such morphology. Our results show that during reading, syntactically relevant cues in the input can affect activity in occipital regions at around 125 ms, a finding that may shed new light on the remarkable rapidity of language processing.

Keywords

ELAN; MEG; Visual M100; Parsing; Syntax; Morphology

1. Introduction

Language is among the most complex of human cognitive systems, yet its processing is extremely automated and fast. Both behavioral and electrophysiological studies suggest that within 600 ms of a word's onset – whether presented auditorily or visually – its sensory properties have been analyzed, its syntactic and semantic features have been retrieved from memory, and it has been integrated into the preceding sentential context (e.g., DeLong, Urbach, & Kutas, 2005; Friederici, 2002; Friederici, Pfeifer, & Hahne, 1993; Kutas, Van Petten, & Kluender, 2006; Neville, Nicol, Barss, Forster, & Garrett, 1991; Salmelin, 2007; Tarkiainen, Helenius, Hansen, Cornelissen, & Salmelin, 1999). Of particular interest is a finding from electroencephalography (EEG) showing that syntactic operations can take effect as early as 120–160 ms post-stimulus onset, at which point the presence of an unpredicted word category elicits an early left-anterior negativity (ELAN) (Friederici et al., 1993; Neville et al., 1991).

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The rapidity of this response is surprising because the effect is cotemporaneous with early sensory processing (Bonte, Parviainen, Hytönen, & Salmelin, 2006; Di Russo, Martinez, Sereno, Pitzalis, & Hillyard, 2001; Hickok & Poeppel, 2007; Parviainen, Helenius, & Salmelin, 2005; Salmelin, 2007; Tarkiainen et al., 1999).

The ELAN refers to an enhanced negative-going wave generally found in left-anterior electrodes in response to word category violations. This response has been reported for a number of languages, including English (Lau, Stroud, Plesch, & Phillips, 2006; Neville et al., 1991), German (Friederici et al., 1993; Hahne, Schröger, & Friederici, 2002; Rossi, Gugler, Hahne, & Friederici, 2005), Spanish (Hinojosa, Martin-Loeches, Casado, Muñoz, & Rubia, 2003), and French (Isel, Hahne, Maess, & Friederici, 2007). For example, Neville et al. (1991) reported an ELAN peaking at around 125 ms post-stimulus onset for ungrammatically positioned prepositions like *about* in sentence (1b).

(1)

- **a.** The boys heard Joe's stories *about* Africa
- **b.** *The boys heard Joe's *about* stories Africa

In German, several studies have shown unexpected participles to generate an ELAN, for example when following the contracted preposition-determiner sequence *im* (2b), as opposed to after an inflected verb *wurde* ('was' 2a; taken from Friederici et al. (1993)).

(2)

- **a.** Das Baby wurde *ge*füttert

  The baby was fed
- **b.** *Das Baby wurde <u>im</u> *ge*füttert

  The baby was in the fed

In the present study we investigated the effects of word category violations using magnetoencephalography (MEG). In particular, we sought to address what exactly might explain the extremely short latency of these seemingly high-level syntactic effects.

1.1. Interpretations of the ELAN

Friederici (2002) proposes a model of the neurocognition of language that comprises a number of stages, each corresponding to a discretely defined electrophysiological correlate and brain area. Word category, morpho-syntax and semantics are autonomously, and not interactively, processed, and syntactic processing is initiated before semantic processing. In particular, the first stage of parsing a word in a sentence is argued to be word category access (in the anterior superior temporal gyrus) and then, on the basis of this information, local phrase-structure is built (in the inferior portion of BA 44). Friederici suggests these processes are performed within 200 ms of the word's onset (Friederici, 2002; Friederici, Wang, Herrmann, Maess, & Oertel, 2000). In this model, the ELAN is the electrophysiological correlate of this early syntactic processing: an enhanced ELAN is generated by an ungrammatical word category, which impedes normal initial structure building. The ELAN therefore reflects the impossibility of reconciling the word category of the target with its local syntactic environment.

While this interpretation is consistent with the conditions under which an ELAN has been elicited, it does not in itself shed any particular light on its early onset. Work by Lau et al. (2006) has, however, shown that anticipation plays a crucial role in rapid syntactic analysis. These authors compared the ELAN elicited by unexpected prepositions (similar to those tested by Neville et al., 1991) in two different syntactic contexts: in one case, (3a), the preposition violated a strong prediction for a noun, whereas in the other, (3b), the ungrammatical preposition did not violate a strong prediction, because of a possible ellipsis environment.

(3)

a. *Although the bridesmaid kissed Mary, she did not kiss Dana's *of* the bride

(−Ellipsis/Ungrammatical)

b. *Although Erica kissed Mary's mother, she did not kiss Dana's *of* the bride

(+ Ellipsis/Ungrammatical)

Consistent with the hypothesis that prediction is a crucial factor for the generation of the ELAN, Lau et al. (2006) obtained a greater early negativity to violations of strongly, as compared to weakly, predicted word categories. This, according to the authors, makes the rapidity of the ELAN less striking, as it suggests that at each word, the parser has already in some form anticipated (and thus pre-processed) its syntactic properties. However, this account still raises questions about what exactly is predicted, and how a mismatch with the prediction is detected.

In our research, we aimed to investigate the nature of the process by which the parser detects a word category mismatch, and in particular to shed light on the rapidity of this detection. To do so we tested the following two hypotheses in two experiments contrasting different types of word category mismatches in sentential contexts:

a. Rapid word category identification relies on overt category-marking closed-class morphemes;

b. Violations of word category predictions affect modality-specific sensory responses.

In the following two sections, we discuss and motivate these two hypotheses in detail.

1.2. Do early effects of word category violations depend on the presence of closed-class morphology?

The early latency of word category effects has been controversial as it implies that the syntactic category of any encountered lexical item can be checked within 150 ms. The rapidity of these responses would be more plausible if they were limited to a small set of highly frequent words or morphemes. More specifically, word category checking may be restricted to words containing closed-class morphemes that overtly mark word category.

Many behavioral studies have suggested that closed-class morphemes are processed differently from open-class items. In particular, Bradley (1983) has argued that the lexical retrieval of closed-class morphemes is faster than that of open-class items and that closed-class items do not exhibit frequency effects (although see e.g., Gordon & Caramazza, 1985; Segalowitz & Lane, 2000). There is also evidence that subjects are faster to reject non-words based upon closed-class items to which suffixes have been appended (e.g., *thanage*), than to equivalent open-class items (e.g., *thinage*) (Bradley, 1983; Matthei & Kean, 1989). In addition, eye-tracking studies have shown that while readers tend to fixate open-class words, they frequently skip function words (Carpenter & Just, 1983; Liversedge & Findlay, 2000; Reichle, Rayner, & Pollatsek, 2003). Thus the access of closed-class items appears to be extremely quick and automatic. Consequently, the rapidity of word category effects may in part be due to the rapid and automatic retrieval of frequent word category-marking function morphemes.

A possible connection between the ELAN and closed-class morphology has been noted before. In a 1999 paper, Hahne and Friederici observed that thus far the ELAN had only been generated by unexpected or ungrammatical target words containing highly frequent, closed-class morphemes (Hahne & Friederici, 1999). To the best of our knowledge, this fact still holds.

Several studies have found an ELAN for ungrammatical or unexpected verbal morphology in contexts where a noun or other word category was expected. ELAN responses for these types of word category violations have been found in German (Friederici, 2002; Friederici et al., 1993; Hahne & Friederici, 1999; Hahne et al., 2002; Oberecker, Friedrich, & Friederici, 2005), French (Isel et al., 2007), and Spanish (Hinojosa et al., 2003). In English, an early response has been observed following unexpected prepositions (Lau et al., 2006; Neville et al., 1991; see (1) above). However, in one study where word category was violated but the target item did not contain a closed-class morpheme, no ELAN was generated (Friederici & Meyer, 2004).

In sum, the access of closed-class items appears to be extremely quick and automatic. In view of this, the observation that early responses have only been reported for word category violations involving overt closed-class items suggests that their rapidity may at least in part be due to the rapid and automatic retrieval of frequent word category-marking function morphemes. Although previous research is compatible with this hypothesis, it has never been tested directly. To address it, we tested for the effects of three different types of word category violations within a single experiment. In one comparison, category was marked by a free closed-class morpheme. In the second case, the category-marking element was a bound closed-class morpheme. Finally, the third comparison involved an open-class target with no affixal material attached to it (see Section 2.2 for details).

1.3. Are sensory cortices sensitive to word category violations?

The temporal overlap between the ELAN and sensory responses to visual and auditory stimulation raises the question whether this seemingly high-level response is at least partly generated by enhanced activity in sensory cortices. If some part of it were due to a low-level sensory response, the rapid onset would be less puzzling. This hypothesis is particularly plausible if early responses to word category violations are indeed only obtained for overt closed-class word category markers, since these elements are perceptually salient. Thus we hypothesized that sensory cortices are tuned to recognize highly frequent, salient function morphemes that mark word category information, and that they show more activity when the input contains unexpected word category marking morphemes. Note that the hypothesis that early sensory responses are sensitive to word category violations does not rule out the existence of an additional left-anterior effect like the (E)LAN, i.e., sensory and left-anterior generators are not mutually exclusive.

In what follows, we review the extant literature on early effects of word category violations, asking whether current evidence is consistent with the hypothesis that early, seemingly syntactic, responses might, at least in part, be generated in sensory cortices.

1.3.1. Latency—As discussed above, the first response to word category violations is cotemporaneous with early sensory responses. Both take place in the first 200 ms post-stimulus onset. In the auditory modality, early sensory activity is reflected by the N1 in EEG and the auditory M100 in MEG, both peaking at around 100 ms. In the visual modality, sensory activity is measured by the P1/N1 complex in EEG (Di Russo et al., 2001; Luck, 2005) and the visual M100 in MEG, followed by the visual M170. The MEG M100 and the M170 have also been called “Type I” and “Type II” activity, respectively (Salmelin, 2007; Tarkiainen, Cornelissen, & Salmelin, 2002; Tarkiainen et al., 1999). Consistent with the timing of these various sensory components, the latency of the early responses to word category violations range from 125 ms (Neville et al., 1991) to 160 ms (Friederici et al., 1993, 2000).

However, in certain circumstances, responses to word category violations have also been reported to begin later than the 100–200 ms sensory time-window. In spoken stimuli for example, there is some evidence that prefixed words generate an ELAN, but suffixed words generate a later response (typically referred to as a LAN), at 300–500 ms (Friederici & Meyer, 2004). This, of course, is not surprising given that prefixes and suffixes become available at different time points in the spoken word. As Friederici (2001) discusses, the ELAN is obtained only after word category information has become available. Hence, an ELAN will be early for words containing prefixes, and later for words where the category information is contained in a suffix. Furthermore, some studies have indicated that visually presented suffixed words also yield a LAN as opposed to an early response, despite the immediate availability of the suffix in the visual modality. Importantly, though, most of these manipulations have involved inflection violations rather than phrase-structure violations (e.g., Barber & Carreiras, 2005; Morris & Holcomb, 2005; Rodríguez-Fornells, Clahsen, Lleo, Zaake, & Münte, 2001; Rossi et al., 2005), which arguably involve different processes. There is one study that reports a LAN instead of an ELAN for word category violations (Hagoort, Wassenaar, & Brown, 2003). However, in this study the word category violations were indirectly marked through an agreement morpheme (3rd person singular verbal morphology on an ambiguous root).

In sum, in the auditory modality, early responses to word category violations are consistently found in the same time period as sensory processing, i.e., within 200 ms after the word category information becomes available. In the visual modality, however, the corresponding generalization is somewhat less robust.

1.3.2. Localization—In Friederici's (2002) model, the ELAN is generated by sources in the left inferior frontal gyrus (IFG) and superior temporal gyrus (STG). These localizations are based on evidence from fMRI, lesion, and MEG studies.

In fMRI, Meyer, Friederici, and Von Cramon (2000) used auditorily presented stimuli involving a participial manipulation similar to the one already exemplified in (2) above. Ungrammatical, as compared to grammatical, stimuli resulted in a reliably enhanced BOLD signal in the anterior portion of the superior temporal gyrus. Importantly however, the BOLD response was also enhanced in both primary and secondary auditory cortex (including Heschl's gyrus and the planum temporale) – sensory cortices typically associated with speech processing and the generation of auditory evoked responses (Hickok & Poeppel, 2007; Näätänen, 1992). Enhanced activity in auditory cortices was also found in a second study, using similar stimuli, which replicated Meyer et al.'s results in primary and secondary auditory cortex (Friederici, Rüschemeyer, Hahne, & Fiebach, 2003), and the anterior superior temporal gyrus. Together these findings suggest that sensory cortices, as well as left-anterior temporal regions, are sensitive to word category violations. However, they do not address which regions are active during the ELAN time-window, given the low temporal resolution of fMRI.

In lesion studies, the absence of an ELAN in Broca's aphasics with damage to the left inferior frontal gyrus (IFG) (Friederici, Von Cramon, & Kotz, 1999) has been taken as evidence that early responses to word category violations are generated in the left IFG. However, the hypothesis that this area is part of a cortical network that generates the predictions for upcoming word categories is equally compatible with the data. In other words, if the left IFG is involved in generating word category predictions rather than checking whether the input matches them, then damage to this area would block the generation of predictions. Consequently, there would be no predictions for the input to violate and no ELAN would be observed.

Thus both fMRI and lesion studies underdetermine the neural generators of early responses to word category violations. Magnetoencephalography (MEG) offers the requisite temporal and spatial resolution to potentially address this question: brain activity can be monitored millisecond by millisecond and the current generators of the magnetic fields can be localized with relatively high accuracy (Hämäläinen, Hari, Ilmoniemi, Knuutila, & Lounasmaa, 1993). In an auditory MEG study, Friederici et al. (2000) presented subjects with grammatical and ungrammatical participles similar to example (2) above. A four-dipole model was fit to the ungrammatical data only, with sources in the left and right anterior portions of the superior temporal gyri and in fronto-lateral cortices bilaterally. From the model's relatively high goodness of fit, it was concluded that the ELAN is generated by these four sources. However, the modeling procedure used in this study makes this conclusion somewhat premature. To create each subject's source model, four dipoles were seeded in bilateral frontal and temporal locations. Each dipole's orientation and location were fit to the violation conditions' data within a 20 ms interval centered on the peak of the subject's ELAN response. Variation in location, however, was constrained to a sphere with a 10mm radius, centered on the initial seed point. Since this constraint *a priori* ensured localization of the ELAN close to the seeded locations, it is difficult to draw firm conclusions, despite the model's relatively high goodness of fit. Interestingly, for all subjects the dipole strength of the temporal source in the 20 ms time-window was higher than that of the frontal source. Given the greater proximity of the temporal (as opposed to frontal) dipole to auditory cortex, this is consistent with enhanced sensory activity, as predicted by the hypothesis that sensory cortices contribute to early effects of word category violations. Perhaps clearer evidence for the sensory hypothesis was obtained in an auditory MEG study by Gross et al. (1998), who reported enhanced and delayed activity in both the auditory cortex and left frontal cortex for word category violations, using Magnetic Field Tomography, a distributed source model. However, the authors did not expand on the possible implications of this finding.

The results of a recent EEG study, using visual stimuli, are also suggestive of the contribution of sensory cortices to the detection of word category violations. Specifically, Hagoort et al. (2003) reported a significant interaction of grammaticality by electrode site at 100–300 ms for Dutch word category violations. The interaction was due to enhanced activity in posterior electrodes (i.e., over the visual cortex), which in isolation however did not show a reliable modulation.

1.3.3. Further properties of the ELAN consistent with a sensory generator—If sensory cortices are sensitive to word category violations, the topography of the ELAN might plausibly resemble that of sensory responses. This prediction is supported by findings from Hahne et al. (2002), who reported that the topography of early responses to word category violations was statistically indistinguishable from responses to deviance in low-level auditory stimulation. In this study, word category violations of the type in (2) above were crossed with a manipulation of auditory expectancy, where deviants were presented from a different location from the rest of the sentence fragment. This physical manipulation was predicted to elicit an auditory mismatch negativity (MMN; Näätänen, 1992). The primary generators of the auditory MMN have been reported as the planum temporale (Liegeois-Chauvel, Musolino, Badier, Marquis, & Chauvel, 1994), and near-by regions around auditory cortex (Virtanen, Ahveninen, Ilmoniemi, Näätänen, & Pekkonen, 1998). In contrast, as pointed out above, in Friederici's model the ELAN is generated by two sources in the anterior left superior temporal gyrus, and in the inferior portion of BA 44. Instead of separate responses for the two manipulations, Hahne et al. (2002) found no topographical differences between the word category deviances and the physical deviances, consistent with the sensory hypothesis outlined above.

Similar results have also been obtained by Pulvermüller and colleagues with an oddball paradigm using linguistic stimuli only. Using MEG, Shtyrov, Pulvermüller, Näätänen, and Ilmoniemi (2003) found that hearing deviant syntactic violations (16.7% of the stimuli) interspersed with standard grammatical sequences (83.3% of the stimuli) resulted in a magnetic mismatch negativity (MMNm), the MEG response corresponding to the classical MMN (Näätänen, 1992). Minimum-norm estimation suggested the effect was generated in the left superior temporal lobe (although see Pulvermüller and Shtyrov (2003) for evidence from EEG for an additional frontal generator). Pulvermüller and Shtyrov (2006) argued that the syntactic

MMN is highly similar to the ELAN in terms of latency, topography, and laterality. Although these authors did not contrast linguistic and non-linguistic manipulations directly, this result in combination with Hahne et al.'s (2002) findings suggests that early responses to word category violations may be generated by the same sources that respond to low-level auditory deviance.

Finally, there is also evidence in the visual modality that early syntactic responses may be modulated by the same factors that affect sensory components. Gunter, Friederici, and Hahne (1999) demonstrated that no ELAN is observed in the visual modality when a target word is presented against a low contrast (dark grey) background. This result was interpreted to indicate that fast and automatic structure building is dependent upon good signal quality. However, this finding is equally consistent with the sensory hypothesis. In other words, low signal quality could hamper the sensory detection of a mismatch between word category expectations and properties of the visual (or auditory) input.

In sum, the ELAN literature at large is quite consistent with the hypothesis that sensory cortices are sensitive to word category violations. However, the picture is far from conclusive. fMRI provides no information regarding the timing of the effects in auditory cortex and EEG may yield null results regarding the topography of the ELAN vs. the MMN because of its low spatial resolution.

To address the sensory hypothesis we used MEG, which offers the same temporal accuracy as EEG but with enhanced spatial resolution. Further, we presented stimuli visually, as opposed to the auditory presentation used in the previous MEG studies reviewed above (Friederici et al., 2000; Gross et al., 1998). An obvious implication of the sensory hypothesis is that responses to word category violations should be modality dependent: one would expect modulation of activity in auditory cortex when stimuli are presented aurally and in visual cortex when stimuli are presented in the visual modality. We chose the visual modality since the visual cortex is further away from left-anterior regions than the auditory cortex. Thus detecting a sensory modulation not attributable to left-anterior generators should be easier in the visual than in the auditory modality. The next section reviews the visual evoked components relevant to our study.

1.4. Early visual evoked responses in MEG

Early stages of visual word recognition in MEG are primarily characterized by two response components. The first component is the co-called visual M100, also called "Type I activity" (Tarkiainen et al., 1999, 2002). This response is generated bilaterally in the occipital lobe, close to midline, at 100–150 ms, i.e., in a similar time-window as the ELAN. A detailed localization study using the Synthetic Aperture Magnetometry technique has suggested that the visual M100 has maximum intensity in the cuneus, lingual gyrus, and BA 17 (Itier, Herdman, George, Cheyne, & Taylor, 2006). Due to the close proximity of the bilateral generators, M100 activity is usually modeled by a single dipole, although bilateral two-dipole solutions are also possible (e.g., Pylkkänen, Llinas, & Murphy, 2006). The field distribution of the M100 typically shows a single posterior right-lateralized outgoing magnetic field and a left-lateralized posterior re-entering field (for examples, see Itier et al., 2006; Pylkkänen et al., 2006). The M100 is primarily sensitive to manipulation of low-level visual features, such as the noise and size of letter-strings and other similar stimuli, with no sensitivity to the content of the stimulus (Tarkiainen et al., 1999). An exception to this has been observed in the domain of face perception, where the visual M100 has been shown to be modulated by face categorization (Liu, Harris, & Kanwisher, 2002).

The second prominent response to visual stimulation is the M170 component, or "Type II activity" (Tarkiainen et al., 1999, 2002), peaking at 150–200 ms. fMRI evidence from manipulations similar to those affecting the M170 suggests that the M170 is generated in the left and right fusiform gyri (Cohen et al., 2000; Dehaene et al., 2004; Kanwisher, McDermott, & Chun, 1997; Tong, Nakayama, Vaughan, & Kanwisher, 1998). The left and right generators of the M170 appear to differ in functional specialization: the left generator has been reported as sensitive to the presence of letter-strings (Tarkiainen et al., 1999, 2002), whereas the right generator shows increased amplitudes for faces in comparison to various control categories (e.g., Kanwisher et al., 1997; Liu et al., 2002; Lueschow et al., 2004; Tarkiainen et al., 2002; although see Liu, Higuchi, Marantz, & Kanwisher, 2000, for a bilateral M170 modulation for face stimuli). In the fMRI literature, the left and right fusiform regions sensitive to letter-strings and faces have been dubbed the Visual Word Form Area (VWFA) and the Fusiform Face Area (FFA) respectively. In addition to showing sensitivity to the linguistic vs. non-linguistic nature of stimuli, the M170 has recently been reported as sensitive to morphological complexity, showing higher amplitudes for bimorphemic than for orthographically matched monomorphemic words (Zweig & Pylkkänen, 2008).

On the sensory hypothesis, both the M100 and the M170 components constitute candidates for an early visual effect of word category expectations. Given that the M170 has already been reported to be sensitive to linguistic factors, an M170 effect of category mismatch would perhaps be less surprising than an M100 modulation. However, the latency of the M100, which on average peaks at 130 ms, is in fact in better correspondence with ELAN latencies than the M170. In studies using English stimuli, the ELAN has peaked exactly around 130 ms (Neville et al., 1991; Yamada & Neville, 2007). The M100 and the ELAN are also sensitive to similar noise manipulations (Gunter et al., 1999; Tarkiainen et al., 2002).

It is of course also possible that the M100 and the M170 might both show sensitivity to word category violations. Such a result would in fact conform well with the fMRI finding that in the auditory modality, word category violations elicit an increased BOLD signal across all areas of the superior temporal gyrus.

2. Experiment 1

Two hypotheses were tested in Experiment 1

- **a.** Rapid word category identification relies on overt category-marking closed-class morphemes.
- **b.** Violations of word category predictions affect modality-specific sensory responses.

Participants read sentences word by word while their brain activity was monitored with MEG. Each sentence contained a target item whose word category was either expected or unexpected. To test hypothesis (a), the target varied in whether or not category was marked with a closed-class morpheme. Each target item was either a preposition (a free, closed-class morpheme), a regularly inflected participle (a category-marking closed-class morpheme bound to an open-class morpheme), or a bare nominal stem (a free, open-class morpheme).

To test hypothesis (b), the current generators of activity at the M100 and the M170 were estimated for each condition with multi-dipole modeling. Root-mean-square (RMS) analyses of sensor data were further used to assess whether the effects obtained in the source waves were also observable in sensor-space.

2.1. Methods

2.1.1. Participants—15 healthy right-handed subjects (7 male) participated. All had normal or corrected-to-normal vision and gave informed consent. All were students or employees at

New York University (ages 19–39). Two subjects were excluded for not showing typical M100 and M170 components in their across conditions grandaverage.

2.1.2. Materials—To test whether early effects of unexpected word category are limited to closed-class morphemes, we used three types of manipulation, shown in Table 1.

The first comparison used the exact materials of Neville et al.'s original ELAN study, where the target items were unpredicted prepositions, i.e., free closed-class morphemes (Neville et al., 1991). As a second contrast, we tested unexpected participles, which contained the bound closed-class morpheme *-ed*. This manipulation formed a close English approximation to the German stimuli presented in (2). One obvious difference is that in these German sentences the participial morpheme is a circumfix (***ge***-*STEM*-***t***), rather than a suffix. Note that both the German and the English manipulations involve unexpected rather than ungrammatical targets: in both languages a participial modifier can follow a determiner (so long as this modifier is followed by a noun). In German, the participle should carry a suffixed case marker in order to be grammatical in this context, but under auditory presentation the suffix has not become available yet at the point where the ELAN is recorded. Thus the ELAN generated by participles of the form ge-STEM-t has to be a response to the prefix rather than the lack of a case-marking suffix. Finally, we tested whether an early response would be dependent on closed-class morphological markers by including a third contrast containing unexpected bare stems which lacked any overt category-marking morphology.

Since we aimed to obtain very early differences between conditions, differences in the lexical material that immediately preceded the target item were of considerable importance. Lau et al. (2006) have pointed out that there may be a serious problem with the baseline of the prepositional manipulation, since the characteristics of the word presented just before the target vary dramatically between conditions (*stories* vs. *Joe's*). However, Lau et al. found an ELAN response even for prepositions whose baseline was controlled for. Note that our participle and bare stem conditions do not suffer from this possible confound, as they form a perfect cross-over between target (*report* and *reported*) and baseline (*was* and *was in the*). In other words, as shown in Table 1, the baselines of the expected participles were also the baselines of the unexpected bare stems, and similarly, the baselines of the unexpected participles were identical to the baselines of the expected bare stems. Consequently, effects which are inversed between participles and bare stems are unlikely to result from the intended manipulation.

Example sentences of each condition (6 in total) are presented in Table 1. 300 target sentences (60 per condition for participles and bare stems, 30 per condition for prepositions (replicating Neville et al., 1991) were intermixed with 240 filler sentences. All test sentences are listed in Appendix 1. Each subject saw all sentences, in a pseudorandom order.

To confirm that our manipulation in fact varied the predictability of word-category, an off-line cloze-probability test was carried out. Sixty subjects each read one of four different sets of 140 sentences; each set contained one quarter of the sentences used in the current study (45 sentences), divided such that no subject saw both members of a pair of sentences (e.g., *The discovery was* … and *The discovery was in the* …). The remaining sentences in each set consisted of fillers from a separate experiment. Sentences were presented up-to-and-including the pre-target word, and subjects were then asked to write a word, or a short phrase, which they felt completed the sentence. Cloze-probabilities were calculated in terms of the word category of the first word filled in by subjects for each sentence fragment. Note that our definition differs from the typical use of 'cloze-probability', which refers to the probability of a specific lexical item. The mean cloze probabilities of the target categories are given in Table 1. The cloze probabilities of the unexpected categories were uniformly at zero, or very close to zero. Thus, across all three manipulations, the probability of the target category was significantly greater

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(by at least two orders of magnitude) for the Expected than for the Unexpected condition (Prepositions: $t(58) = 4.1$, $p < 0.001$; Participles: $t(118) = 12$, $p < 0.001$; Bare Stems: $t(118) = 62.7$, $p < 0.001$). These results confirm for all conditions that unexpected word categories were in fact extremely unlikely continuations of the sentence fragments. For example, in the Unexpected Bare Stems condition, although *was* can be followed by a bare noun, as in *the man was president*, participants did not generate this type of sentence in the cloze-probability test.

2.1.3. Procedure—During the experiment, subjects lay down in a dimly lit, magnetically shielded room. The participants viewed the stimuli through fiberoptic goggles (Avotec, FL). Each trial began with a fixation point in the center of the screen. Participants initiated each trial by pressing a button. The sentences were presented word by word (300 ms on, 300 ms off), in non-proportional Courier font (font size = 90), and the end of each sentence was indicated with a question mark. At the question mark, participants were instructed to judge whether or not the sentence was well-formed by pressing a button with either the middle or the index finger of their left hand.

Data were collected using a 148-channel whole-head magnetometer (4-D Neuroimaging, Magnes WH 2500), sampling at 678 Hz in a band between 0.1 and 200 Hz. The entire recording session lasted approximately one hour.

2.1.4. Analysis—Prior to averaging, the MEG data were cleaned of artifacts and trials on which participants provided an incorrect well-formedness judgment. On average, this resulted in the exclusion of 18% of the data per subject (SD = 7%). Data were averaged by stimulus category over a 1300 ms epoch with a 300 ms pre-stimulus interval, time-locked to the appearance of the target word. Prior to analysis, the recordings were high and low-pass filtered at 1 and 40 Hz respectively.

2.1.4.1. Dipole modeling: In order to obtain a maximally complete characterization of the neural sources activated by our stimuli during the first 200 ms, the current generators of all prominent response components at 0–200 ms were estimated with a multiple-source model using BESA (Brain Electrical Source Analysis 5.1). Subjects typically showed two major peaks in this time-window, associated with the M100 and M170 field patterns (see Fig. 1 for grandaveraged sensor waveforms from all subjects). Thus we created two multiple-source solutions, aimed at characterizing all activity present at the M100 and M170 components. BESA minimum norm estimates (a distributed source model) were used to guide the hypothesis about how many sources were active at each component and data from all sensors were then used to estimate the discrete locations of these generators. In other words, we did not use sensors-of-interest but rather aimed to obtain a global characterization of all early activity. Thus although our hypothesis pertained to the early visual activities, our method was equally suited for identifying any other relatively focal early sources, such as potential left-anterior generators.

Dipole modeling is often performed using each individual's grandaveraged data across conditions (e.g., Pylkkänen et al., 2006), to ascertain that the models are based on data with a maximally high signal-to-noise ratio. This procedure, however, was less than ideal for our data: Although it should give an accurate characterization of sensory activity – and thus allow us to address our main hypothesis – it risks missing non-sensory ELAN sources that may not be active across all conditions. Therefore we aimed to model activity using data from the individual conditions. This was successful for the M100 component, but less so for the M170, whose bilateral sources can be difficult to distinguish with this type of multi-dipole modeling (cf., Zweig & Pylkkänen, 2008). To enhance signal-to-noise ratio, we instead modeled the activity at the M170 using the combined data from the Expected and Unexpected conditions for each word category (resulting in three M170 models per subject: one for the Prepositions grandaverage, one for the Participles grandaverage, and one for the Bare Stems grandaverage). This model was then applied to the Expected and Unexpected conditions.

Only models that were consistent with both the magnetic field maps and the minimum norm estimates were accepted for analysis. This resulted in the inclusion of 11 subjects in the analysis of the M100 time-window. In the M170 time-window, 9 subjects' dipole models were accepted for the participles and the bare stems, but only 6 subjects' for the prepositions. The average source locations of all M100 and M170 dipoles are shown in Figs. 2 and 3 respectively.

Our multi-dipole modeling did not yield any consistent source clusters apart from the M100 and the M170 generators. In other words, although other dipoles were present in many subjects' models, their locations did not exhibit any observable generalization across subjects. Thus statistical analysis was only possible on the M100 and M170 dipoles. M100 and M170 peaks were first identified for each condition using across-subjects grandaveraged source waveforms. After this, an interval of interest, 15 ms around the peak, was defined for each condition. Dipole strength was calculated and averaged across this interval per subject and condition. These values were then entered into a 2 (Expectedness: Expected vs. Unexpected) by 3 (Word Category: Preposition vs. Participle vs. Bare Stem) within-subjects ANOVA. Separate ANOVA's were performed for the M100 and M170 components. Planned comparisons tested for the effects of expectedness for each target word category.

2.1.4.2. RMS analysis: A root-mean-square analysis of sensor data was used as a second analysis to further assess the robustness of the findings from the multi-dipole modeling analysis. This also allowed us to test whether left-anterior effects might be obtained in sensor data. This analysis was performed over 5 equally sized regions of interest (ROI's, see Figs. 4 and 5), each containing approximately 18 sensors. To test for visual M100 effects, we examined two posterior ROI's, which captured the field pattern of the M100 component (the right-hemisphere posterior ROI captured the outgoing magnetic field produced by the M100 generator, the left-hemisphere posterior ROI captured the re-entering field). To investigate possible activity in left temporal and frontal areas, the remaining left-hemisphere sensors were also examined. They were divided into three ROI's in order to differentiate between more posterior and anterior sources. The regions and sensors within them were held constant across subjects to ensure a consistent analysis.

RMS waveform analysis followed the same procedure used in the source wave analysis, described above. To analyze activity in each ROI, the averaged root-mean-square value of the sensor activity in the ROI was first calculated for each subject in each condition. For each condition, the grandaveraged RMS wave of all subjects was then examined to identify peak activity. This revealed a consistent and prominent peak in the M100 time-window (100–150 ms). Our RMS analysis focused on this activity. Activity was averaged across a 15 ms window around this peak, per condition, per subject and per ROI, and then entered into a 2 (Expectedness: Expected vs. Unexpected) by 3 (Word Category: Preposition vs. Participle vs. Bare Stem) within-subjects ANOVA.

For the most frontal ROI, no clear peak activity in the time-window of interest was identified. In this case, we also averaged each subject's RMS data, for each condition, over the window between 100 ms and 150 ms. This was then also entered into a 2 (Expectedness: Expected vs. Unexpected) by 3 (Word Category: Preposition vs. Participle vs. Bare Stem) within-subjects ANOVA, in the same way as for the other measure.

2.2. Results

2.2.1. Behavioral data—Overall accuracy was very high; 96% of sentences were correctly classified in the well-formedness judgment task.

2.2.2. MEG data—Fig. 1 visualizes the across participants (*n* = 13) grandaveraged MEG signals for each of the six conditions. The magnetic field patterns associated with sensor activity during the first peak (indicated by the dashed line) showed a typical M100 distribution in all conditions. Visual inspection of this peak revealed that its amplitude increased for unexpected items containing a closed-class morpheme (participles and prepositions), as compared to the expected items. However, there appeared to be no change in M100 amplitude for unexpected items without a closed-class morpheme (the bare stems). The second peak, around 170 ms, represents the M170 activity. Note that this peak was less consistent across conditions for these 13 subjects. The preposition conditions in particular did not show a clear peak.

2.2.3. Dipole results

2.2.3.1. The M100 time-window: ***Consistency in the multi-dipole models:*** Dipole solutions for the eleven subjects included in the analysis contained a typical posterior M100 dipole in all conditions (Tarkiainen et al., 1999). Each subject also required other dipoles to be included in their solutions in order for the M100 dipole to localize accurately. There was no consistent pattern in the location/direction of these additional dipoles, and no reliable difference between conditions with regard to the number of additional dipoles. Average goodness of fit for the multi-dipole models was very high, greater than 90% in every condition (overall mean 92.5%, SD = 6.0), and did not reliably vary between conditions.

To test whether conditions differed in M100 dipole location or orientation, we ran 2 (Expectedness: Expected vs. Unexpected) by 3 (Word Category: Preposition vs. Participle vs. Bare Stem) within-subjects ANOVA's for the *x*, *y* and *z* location and orientation measures (on a Cartesian coordinate system). These analyses revealed no reliable main effects or interactions, except for a reliable interaction between word category and expectedness on location along the *x*-axis ($F(2,20) = 3.81$, $p = 0.04$). However, these differences were not significant when the effect of expectedness was analyzed separately per word category.

Effects of expectedness at the M100: The averaged waveforms of M100 dipole strength over time are shown in Fig. 2. M100 peak amplitudes were entered into a 2 (Expectedness: Expected vs. Unexpected) by 3 (Word Category: Preposition vs. Participle vs. Bare Stem) within-subjects ANOVA. This revealed no main effect of word category ($F(2,20) = 1.62$, $p = 0.22$), a marginal main effect of expectedness ($F(1,10) = 4.65$, $p = 0.056$), and a reliable interaction between word category and expectedness ($F(2,20) = 4.22$, $p = 0.030$).

Planned comparisons revealed that, for the preposition and participle conditions, unexpected items generated a reliable increase in M100 amplitude (Prepositions: $t(10) = 2.45$, $p = 0.034$. Participles: $t(10) = 2.46$, $p = 0.033$). However, there was no reliable effect for the bare stem conditions ($t(10) = 1.03$, $p = 0.33$). Thus these results support both the sensory hypothesis as well as the hypothesis that early effects of category violations are limited to closed-class morphemes.

2.2.3.2. The M170 time-window: ***Consistency in the multi-dipole models:*** For the bare stems and the participles, the dipole models of 9 subjects included two (bilateral) dipoles whose location, orientation, and latency was typical for the M170 component (Tarkiainen et al., 1999). For the prepositions, this was the case for only 6 subjects.

Eight subjects' models required additional, non-M170-like, dipoles to be included in the solutions (2 dipoles on average, SD = 1.2, maximum: 4 additional dipoles for 2 subjects). Again, there was no consistent pattern in the location/direction of these dipoles. Average goodness of fit for the multi-dipole models was high, greater than 90% for the participle and bare stem conditions, and greater than 85% for the preposition conditions (overall mean 92.3%, SD = 7.1), and did not vary reliably between conditions.

Because activity was modeled on the basis of the combined expected and unexpected data for each word category, and because the number of subjects included in the analysis varied across word categories, we did not run statistical analyses on the locations and orientations of the M170 dipoles. However, visual inspection of the dipoles in Fig. 3 suggests a high consistency in both location and orientation.

Effects of expectedness at the M170: The averaged waveforms of M170 dipole strength over time are shown in Fig. 3. Because the M170 is generated by a pair of bilateral sources, average source-waveform activity centered around the M170 peaks was entered into a 2 (Hemisphere: Left vs. Right) by 2 (Expectedness: Expected vs. Unexpected) within-subjects ANOVA for the prepositions, and a 2 (Hemisphere: Left vs. Right) by 2 (Expectedness: Expected vs. Unexpected) by 2 (Word Category: Participle vs. Bare Stem) within-subjects ANOVA for the participles and bare stems.

As can be seen in Fig. 3, M170 amplitudes appeared larger for unexpected than for expected prepositions, but this effect was not reliable: the prepositions showed no main effects and no interactions. The participles and bare stems also showed no main effects, but they did exhibit a reliable hemisphere by word category interaction ($F(1,8) = 6.37$, $p = 0.036$), as well as a reliable expectedness by word category interaction ($F(1,8) = 14.68$, $p = 0.005$).

To explore these interactions, we ran follow-up 2 (Hemisphere: Left vs. Right) by 2 (Expectedness: Expected vs. Unexpected) within-subjects ANOVAs separated by word category. This showed no effects for the bare stem comparisons. For the participles, there was a marginal main effect of hemisphere ($F(1,8) = 5.12$, $p = 0.054$), with the left hemisphere M170 dipole showing more activity than the right hemisphere M170 dipole. There was no main effect of expectedness, nor did expectedness interact with hemisphere. A 2 (Word Category: Participle vs. Bare Stem) by 2 (Expectedness: Expected vs. Unexpected) within-subjects ANOVA by hemisphere showed no effects for the right hemisphere M170 source. For the left hemisphere source, there were no main effects, but there was an interaction between word category and expectedness ($F(1,8) = 6.60$, $p = 0.033$), suggesting that the unexpected participles yielded a higher M170 amplitude than the expected participles, while the reverse was true for the bare stem conditions. However, post-hoc *t*-tests revealed no reliable difference by expectedness for either the participles ($t(8) = 1.06$, $p = 0.322$), or the bare stems ($t(8) = 1.66$, $p = 0.136$).

2.2.3.3. Anterior sources?: In addition to the M100 and M170 generators, we would have expected to capture any consistent left-anterior sources clusters, at least in the unexpected conditions, if these stimuli were associated with a left-anterior effect. However, there was no consistent grouping of dipoles in anterior regions of the left-hemisphere.

This could indicate that there were no left-anterior discrete sources. However, it may also be because the sensory components dominate our time-window of interest. Especially the visual M100 is usually reflected by a very strong magnetic field pattern covering most of the sensors. Since we did not perform dipole analyses based on sensors of interest but rather let the dipole locations and orientations vary freely, a weaker left-anterior field may have been masked by the M100. To further test for left-anterior effects, and to confirm the posterior effects, we carried out an RMS analysis of posterior and left-anterior ROI's.

2.2.4. RMS results

2.2.4.1. Posterior octants: To capture the ingoing and out-going field maxima of the visual M100, we first collapsed the RMSs of the two most posterior regions of interest (Fig. 4A). Surprisingly, there was no significant main effect of expectedness or word category, nor a reliable interaction between the two.

Given that the M100 is bilaterally generated, we then tested for potential effects of laterality by analyzing the two posterior ROIs separately (Fig. 4B and C). This analysis did reveal a significant main effect of expectedness in the left posterior ROI ($F(1,12) = 5.19$, $p = 0.042$), showing increased amplitudes for the expected items. No significant main effect of word category ($F(2,24) = 1.46$, $p = 0.25$) and no significant interaction between expectedness and word category ($F(2,24) = 0.65$, $p = 0.53$) were obtained. However, planned comparisons revealed that the main effect of expectedness on peak amplitude was driven by those conditions containing overt closed-class morphemes. In other words, reliable increases in amplitude were found for the preposition condition ($t(12) = 2.31$, $p = 0.04$) and the participle condition ($t(12) = 2.18$, $p = 0.049$), but not for the bare stem condition ($t(12) = 0.47$, $p = 0.65$).

In contrast, the right posterior ROI (Fig. 4C) displayed no effect for any of the manipulations, nor an interaction. Planned comparisons also revealed no reliable effects of expectedness for any word category. However, the participles did show a marginal effect of expectedness, but this was due to an increase in activation in the expected condition ($t(12) = -2.09$, $p = .059$).

In summary, analyses of the posterior ROIs revealed a left-lateralized effect of expectedness at the visual M100 peak. In the planned comparisons, this effect was limited to the preposition and participle contrasts, i.e., to targets containing either a free or a bound overt closed-class category-marking morpheme. This pattern of findings is consistent with the dipole-analysis – the mean dipole locations across conditions were medial, but slightly left-lateralized.

2.2.4.2. Anterior octants: To assess the possible contribution of additional left-anterior generators to the effects of expectedness, we analyzed the remaining three left lateralized regions of interest in the same manner as above.

In the medial-posterior ROI (Fig. 5A), clearly over-lapping with the M100 field distribution, peak amplitude in the time-window of interest showed a marginal main effect of expectedness ($F(1,12) = 3.89$, $p = 0.072$), but no main effect of word category or reliable interaction between the two. Planned comparisons revealed a significant effect of expectedness for the preposition condition ($t(12) = 2.57$, $p = 0.025$), but no other effects.

In the medial-anterior ROI (Fig. 5B), capturing only the very edges of the M100 distribution, peak amplitude in the 100–150 time-window no longer showed any significant main effects or interactions. Again, planned comparisons revealed an effect of expectedness for the preposition condition ($t(12) = 2.32$, $p = 0.039$) but no other effects.

The most anterior ROI (Fig. 5C) was the most crucial for any potential left-anterior effects: while for the other ROIs examined so far, the modulation found for the preposition conditions could be due to spill-over from a posterior M100 effect, a posterior generator alone would be unlikely to explain an effect in this ROI. Thus an effect in this ROI would strongly suggest an additional left-anterior generator. However, analysis of this ROI's peaks in the 100–150 time-window showed no reliable main effects of expectedness or word category, and no reliable interaction between the two. In addition, planned comparisons revealed no significant differences between the conditions. The analysis of this ROI was complicated by the low amplitude of the responses, which impeded detection of peaks. To ensure our result was not an artifact of this, we also performed an identical ANOVA for the mean amplitude of the 100–150 ms interval, as explained in Section 2.2.4. This revealed a significant main effect of word category ($F(2,24) = 6.73$, $p = 0.005$), participles showing a higher amplitude than the other word categories overall, but no other effects.

2.2.5. Summary of results—The peak amplitude of the visual M100, a neuromagnetic sensory response to visual stimulation, was modulated by the expectedness of the target word category, but only when the target was overtly marked for word category by a closed-class morpheme. This effect of expectedness was found in both the M100 dipole and RMS analyses. The peak amplitude of the subsequent M170 component demonstrated no effects of expectedness in any of the conditions. There was a marginal effect of hemisphere for the participles, showing increased activity for the left as compared to the right M170 dipole.

Neither the dipole nor the sensor analysis showed evidence for anterior generators.

2.3. Discussion

Experiment 1 investigated two hypotheses about the generators and generating conditions of early neural responses to unexpected word category violations in sentential contexts. Using magnetoencephalography, we tested whether early syntactic responses depend on the presence of category-marking closed-class morphemes in unexpected target words and whether these early responses are at least partly generated by enhanced activity in sensory cortices. Consistent with both hypotheses, we found the peak amplitude of the visual M100 response to be modulated by expectedness but only when the target word contained overt category-marking functional morphology.

Multi-dipole modeling suggested a posterior generator for this effect, and did not reveal further left-anterior sources in any conditions. RMS analyses of regions of interest also revealed a posterior effect, although this effect was left lateralized. No effect was found in the most anterior region of interest. Further, no reliable modulation of the M100 was found for the morphologically unmarked bare stems in any ROI.

The visual M170 response, a slightly later component that has been associated with the VWFA, did not show any effects of expectedness for any of the word categories. Thus in this experiment, we found no evidence suggesting that the M170 participates in the post-M100 computation of category violations. However, due to the relative difficulty in modeling the M170, this conclusion must remain tentative. For example, in the preposition manipulation, there was in fact a clear numerical M170 difference between the expected and unexpected conditions, but this effect was not reliable, potentially because of the small number of subjects for which a clear bilateral M170 source could be modeled.

Although our data offer a rather strong confirmation of the sensory hypothesis, the evidence from this experiment for the crucial role of closed-class morphology is somewhat more tentative. Below, we outline four alternative explanations for the lack of an M100 effect for the bare stems. Two of these are challenged by extant data in the literature; the other two are tested in Experiment 2.

Given that the M100 reflects a response to visual features, one might hypothesize that any unexpected perceivable indicator of category information would generate an M100 effect. In English, it is hard to imagine what such an indicator might look like, but evidence against this type of account exists for German, where nouns and no other word classes are capitalized. The examples in (4) illustrate stimuli used by Friederici and Meyer (2004) in an EEG study that was designed to compare word category and argument structure violations in German. In German, subordinate clauses have SOV word order when introduced by a complementizer such as *dass* (4a), but SVO order when *dass* is absent, as in (4c). In the ungrammatical (4b), the noun *Ärger* occurs where an inflected verb is expected.

(4)

a. Er meinte dass Lisa *Ärger* verursacht

'He mentioned that Lisa <u>trouble</u> causes'

b. *Er meinte auch Lisa *Ärger* verursacht

lit: ‘He mentioned also Lisa trouble causes’

c. Er meinte auch Lisa verursacht *Ärger*

(grammatical version of 4b)

In these stimuli, the target word contained no closed-class morpheme indicating word category. However, the materials were presented visually and thus the capitalization of *Ärger* was an overt cue to its nominal category. The manipulation (4a vs. 4b) failed to generate an ELAN and instead yielded a later left-anterior negativity (LAN), at 300–500 ms. These results are consistent with an interpretation where early responses are sensitive to the *linguistic* dimension of closed vs. open-class, and inconsistent with an account where the M100 is driven by any physically perceivable category-marking.

Another possible explanation for our results might be that the M100 effect reflects a response to an unexpected length of the target word. For example, it could be the case that when one expects a noun, such an expectation includes a form-based estimate in terms of how much visual space the next word may occupy. A participle would then exceed this expected amount of visual input (since our participial targets all contained an *-ed* string added onto the stem), thereby generating an enhanced visual response. Conversely, in the case of unexpected prepositions, the amount of visual stimulation would be less than expected. Indeed, it has been shown that the M100 is sensitive to stimulus size (Tarkiainen et al., 1999). Under this type of an account, one would not need to attribute any linguistic sensitivity to sensory cortices. However, it is unlikely that our M100 effect for the participles was carried by the fact that all participles contained two letters more than their bare stem counterparts. Our stimuli included bare stems from one to three syllables, ranging between three and nine letters in length. Compared to the bare stems, some participles were in fact shorter. In addition, we saw no main effects of word category in our analysis of the M100 dipole’s strength, or our RMS analysis of posterior regions of interest, suggesting the magnitude of potential length differences between words was not sufficient to reliably modulate the M100.

There are, however, two factors in Experiment 1 which partially confound the conclusion that the null result for the bare stems was due to the lack of closed-class morphology. First, unlike the participles and prepositions, the word category of the bare stems was ambiguous between noun and verb. Second, the expectations violated by the unexpected participles and the unexpected prepositions were considerably stronger than the expectations violated by the unexpected bare stems (see cloze-probabilities in Table 1). Experiment 2 tested whether either of these two factors was responsible for our null results for the bare stems.

3. Experiment 2

3.1. Introduction

Experiment 2 was designed to assess whether the bare stems of Experiment 1 failed to show an M100 modulation because of their lack of a CCM, their category ambiguity or because of the lesser contrast in prediction strength between the expected and unexpected conditions.

As already observed above, in Experiment 1 all bare stems were ambiguous for word category (nominal/verbal). It is possible that this ambiguity, rather than the lack of closed-class morphology, resulted in the absence of an M100 effect. To test whether this may have confounded the results of Experiment 1, Experiment 2 included unambiguously nominal stems like ‘tree’, in addition to the ambiguous stems tested in Experiment 1 (e.g., ‘report’):

(5)

a. The owl was in the TREE

b. *The owl was TREE

In addition, the unexpected bare stem condition in Experiment 1 violated a weaker prediction for a specific word category than the unexpected participle condition. Recall that Lau et al. (2006) found that the ELAN is sensitive to the strength of a violated prediction (see example 3). The M100 modulation may thus be dependent upon violating a particularly strong prediction, and the bare stem condition in Experiment 1 may not have met this criterion. For the sentence fragment preceding the target word in the unexpected bare stem condition (e.g., *The discovery was*…), the cloze-probability of a participle was only 29% and there was no strong prediction for any other category either. Thus the unexpected bare stems contrasted with the unexpected participle condition (e.g., *The discovery was in the **reported***), where the cloze-probability of a noun was 91%. This discrepancy raises the question whether the relatively low prediction strength in the unexpected bare stem condition may have caused the lack of M100 modulation.

To investigate this, we created a very strong prediction for a participle by inserting an adverb into the stimuli of Experiment 1 (e.g., *The discovery was solemnly **report***). As discussed in Experiment 1, it is important to control for possible effects that may be due to the baseline of a target word rather than the intended manipulation. In Experiment 1, we solved this problem by making sure that in each stimulus the baseline for an expected word (e.g., …*<u>was</u> reported*) was also the baseline for an unexpected item in another condition (e.g., …*<u>was</u> report*) and vice versa (e.g., …*in <u>the</u> report*/…*in <u>the</u> reported*). To ensure that a similar baseline cross-over held for the conditions in Experiment 2, we also inserted an adjective in the expected bare stem/noun conditions (e.g., *The discovery was in the solemn* report (ed); see Section 3.2.2 for details). In addition to these conditions, all other conditions of Experiment 1, except the prepositions, were also included in Experiment 2.

In summary, in Experiment 2 we added two additional factors to the design of Experiment 1, namely category ambiguity and prediction strength, in order to investigate whether M100 effects are limited to close-class morphemes or modulated by these other factors.

3.2. Methods

3.2.1. Participants—12 healthy right-handed subjects (3 male) participated. All had normal or corrected-to-normal vision and gave informed consent. All were students or employees at New York University (ages 19–42).

3.2.2. Materials—Our materials consisted of three types of manipulations. First we tested unexpected participles containing the bound closed-class morpheme *–ed*, exactly as in Experiment 1, with the exception of a few items that were replaced because they did not lend themselves to the addition of an adjective or adverb (see below). Second, we included a bare stem manipulation as in Experiment 1. Again, as in Experiment 1, the only difference between the participle conditions and the bare stem conditions was the presence of the *–ed* morpheme. Finally, we included sentences that contained unambiguous nouns (items defined as nouns by the COBUILD corpus, and which COBUILD listed as either not having a verbal form, or whose verbal form's COBUILD frequency was below 750 and rarer by at least two orders of magnitude than the noun form). These unambiguous nouns were open-class, but were not productively used as any other word category. This condition allowed us to test whether the presence of closed-class morphology is indeed a prerequisite for the M100 effect, or whether this effect is also obtained for unexpected open-class morphemes that are category unambiguous.

To investigate whether the absence of an M100 effect for the bare stems in Experiment 1 was caused by a lack of a strong category prediction, prediction strength was varied across word category, including in the participle manipulation, by inserting either an adjective or a manner adverb. As pointed out above, the intention of inserting this additional material was to create a very strong prediction for a participle after sentence fragments such as *the discovery was solemnly*. … The full design (6 conditions total) is shown in Table 2. 60 sentences were presented in each condition (720 sentences overall, see Appendix 2 for full list).

3.2.2.1. Cloze-probability: To confirm that the different conditions manipulated predictions for the target word-category, an off-line cloze-probability test was carried out, as in Experiment 1 (see Section 2.2.2). Cloze-probabilities were calculated in terms of the word category of the first word filled in by subjects for each sentence fragment. Results are given in Table 2.

As in Experiment 1, the probability of the word category of the target word was significantly greater for the Expected than for the Unexpected conditions across all three manipulations. Importantly, for each Word Category, there was a significant effect of Prediction Strength on cloze-probability: A participle was significantly more often filled in after an adverb than after a auxiliary ($t(118) = 14.13$, $p < 0.001$), and a noun was more often filled in after an adjective than after a determiner (Bare Stems: $t(118) = 3.17$, $p = 0.002$; Nouns $t(118) = 5.16$, $p < 0.001$). Notice however that the percentage point difference between the likelihood of a participle after an adverb vs. after an auxiliary was much greater (27% vs. 79%) than the difference between the likelihood of a bare stem after an adjective vs. after a determiner (86% vs. 90%); this interaction between our prediction strength manipulation and condition was reliable ($F(1,236) = 150.3$, $p < 0.001$). Our manipulation therefore succeeded in increasing the strength of the violated prediction in the Unexpected Bare Stem and the Unambiguous Noun manipulations.

3.2.3. Procedure—During the experiment, subjects sat in a dimly lit, magnetically sealed chamber. The participants viewed the stimuli on a screen approximately 17 inches from their head. Each trial began with a fixation point in the center of the screen. Participants initiated each trial by pressing a button. The sentences were presented word by word (300 ms on, 300 ms off), in non-proportional Courier font (font size = 90), and the end of each sentence was indicated with a question mark. At the question mark, participants were instructed to judge whether the sentence was well-formed or not by pressing a button with either the middle or the index finger of their left hand. The entire recording session lasted approximately 75 min.

Data were collected using a whole-head 275-channel gradiometer (CTF, Vancouver Canada) system sampling at 600 Hz in a band between 0.1 and 200 Hz. Since Experiments 1 and 2 used different MEG machines, our study also serves to address to what extent the results of Experiment 1 replicate with a different machine.

3.2.4. Analysis—Prior to averaging, the MEG data were cleaned of artifacts. On average, this resulted in the exclusion of less than 10% of the data per subject. Data were averaged by stimulus category over a 900 ms epoch including a 300 ms pre-stimulus interval, time-locked to the appearance of the target word. Prior to analysis, the recordings were high and low-pass filtered at 1 and 40 Hz respectively.

M100 activity was modeled for each condition and each subject separately, following the procedure outlined for Experiment 1, in Section 2.2.4.

3.3. Results

3.3.1. Behavioral data—Overall accuracy in the grammaticality judgment task was again very high, averaging at 94%.

3.3.2. M100 dipole results

3.3.2.1. M100 multi-dipole models: For 5 of the 12 subjects, the M100 activity could be modeled by a single dipole in all conditions. All other subjects required at least one additional dipole. The mean number of dipoles for all subjects was 1.4; there were no reliable differences in the number of dipoles between conditions. As in Experiment 1, there was also no consistent pattern with respect to expectedness or word category for either the number or location of the additional non-M100 dipoles. The mean goodness of fit for the dipole solutions was 89.5%. (SD = 5.9%). Fig. 6 shows the average waveform (solid line = expected/dotted line = unexpected) and average dipole for each condition (blue = expected/red = unexpected), as well as the individually modeled dipoles (grey).

To investigate possible consistent variation in dipole location and orientation across conditions, the *x*, *y*, and *z* locations and orientations of the individual M100 dipoles per condition were entered into a series of 2 (Expectedness: Expected vs. Unexpected) by 2 (Prediction Strength: Weak vs. Strong) by 3 (Word Category: Participle vs. Bare Stem vs. Unambiguous Noun) within-subjects ANOVAs.

For dipole location, an interaction was observed between word category and expectedness along the anterior –posterior axis (*y*-location) ($F(2,22) = 5.278$, $p = 0.021$). For the participles the generators of the M100 for unexpected participles were significantly more anterior (−.676) than for the expected participles (−.725) overall ($F(1,11) = 11.328$, $p = 0.006$). In the unambiguous noun comparison, in contrast, the M100 dipoles for unexpected conditions were significantly more posterior (−.678 mm) than for expected conditions (−.652 mm) overall ($F(1,11) = 5.737$, $p = 0.036$). However, as can be seen in Fig. 6, these location differences were extremely slight, smaller than the resolution of MEG (0.04 mm for the participles and 0.02 mm for the unambiguous nouns), and do not warrant any strong conclusions.

Dipole orientation vectors also demonstrated a very slight (less than .04) but reliable main effect of expectedness on the *y*-coordinate ($F(1,11) = 5.527$, $p = 0.038$; Expected: −.223; Unexpected: −.186). No further effects on dipole orientation or location were found.

3.3.2.2. Effects of expectedness at the M100: Following the same procedure as in Experiment 1, amplitudes of the M100 component over a 15 ms interval (9 time samples) centered around the component's peak (indicated with dotted lines in Fig. 6) for each condition were entered into several within-subjects ANOVAs. A 2 (Expectedness: Expected vs. Unexpected) by 2 (Prediction Strength: Weak vs. Strong) by 3 (Word Category: Participle vs. Bare Stem vs. Unambiguous Noun) within-subjects ANOVA revealed a significant main effect of expectedness ($F(1,11) = 4.93$, $p = 0.048$) as well as a reliable interaction between expectedness and word category ($F(2,22) = 5.08$, $p = 0.028$). Follow-up 2 (Expectedness: Expected vs. Unexpected) by 2 (Prediction Strength: Weak vs. Strong) ANOVAs separated by word category were carried out to clarify this interaction.

First, the participle comparisons revealed a main effect of expectedness ($F(1,11) = 8.82$, $p = 0.013$): unexpected participles yielded higher M100 amplitude than the expected participles overall. There was no main effect of prediction strength ($F(1,11) = 2.13$, $p = 0.17$), nor was there an interaction between expectedness and prediction strength ($F(1,11) = 0.51$, $p = 0.49$). In other words, the expectedness effect was not modulated by prediction strength.

In contrast to the participle conditions, the bare stems manipulations showed no main effect of expectedness ($F(1,11) = 0.002$, $p = 0.97$), but there was a marginal main effect of prediction strength ($F(1,11) = 4.29$, $p = 0.063$), which did not interact with expectedness ($F(1,11) = 0.002$, $p = 0.96$). Participants showed higher amplitudes for contexts that set up strong predictions, irrespective of whether this prediction was violated or satisfied. The unambiguous nouns showed a similar pattern as the bare stems (Expectedness: $F(1,11) = 0.22$, $p = 0.65$; Prediction Strength: $F(1,11) = 13.66$, $p = 0.004$; Expectedness × Prediction Strength: $F(1,11) = 0.099$, $p = 0.76$). Thus, as in Experiment 1, expectedness only modulated the M100 generated by words containing closed-class morphemes.

Finally, the overall ANOVA including all conditions and word categories revealed a main effect of prediction strength ($F(1,11) = 14.72$, $p = 0.003$), which did not interact with expectedness ($F(1,11) = 0.216$, $p = 0.651$), or word category ($F(2,22) = 0.65$, $p = 0.889$): participants displayed increased M100 amplitudes to targets appearing in strongly predictive contexts, irrespective of word category or whether the expectation was violated. That targets satisfying a strong prediction and targets violating a strong prediction should both be associated with the same M100 amplitude increase is quite surprising and certainly does not follow from any of the hypotheses we tested in this work. This effect was robust though and thus merits further investigation.

3.4. Discussion

Experiment 1 demonstrated that the amplitude of the visual M100 is modulated by the presence of an unexpected word category, but only when the target item contains a closed-class category-marking morpheme. To assess whether the closed/open-class distinction was in fact the critical factor, Experiment 2 tested two alternative explanations of this effect, one based on category ambiguity and the other on prediction strength. Specifically, we tested whether we would obtain an M100 effect for category unambiguous nouns which lack closed-class category-marking morphology and violate a strong prediction for a participle.

Our results clearly support the hypothesis that closed-class morphology is indeed the crucial factor. Category disambiguation and the increase in prediction strength did not result in an M100 effect for the category unambiguous nouns. Bare stems also failed to show an effect, as in Experiment 1. The only word category showing an M100 effect of expectedness was the participles, i.e., the items containing closed-class category-marking morphology.

Surprisingly, we obtained a main effect of prediction strength – both strongly expected and unexpected items showed increased M100 amplitudes as compared to the weak prediction conditions. In other words, overall higher M100 amplitudes were found for participle, bare stem and noun targets after adverbs and adjectives than after a determiner or copula. Thus prediction strength does affect the M100, although perhaps in a somewhat complicated way.

4. General discussion

In this research we aimed to elucidate why the human brain seems to react to certain types of syntactic violations at the same speed as it generates primary sensory responses. Specifically, when the parser's word category expectations mismatch with the actual input, the brain seems to detect the mismatch within 130–150 ms (Friederici, 2002; Friederici et al., 1993; Hahne & Friederici, 1999; Neville et al., 1991). We tested two hypotheses which, if true, would render this intriguing finding somewhat less surprising. First, we hypothesized that these early effects are limited to words whose category is marked by an overt closed-class category-marking morpheme. For such words, word category can be identified without any deep semantic analysis. Second, we hypothesized that during this time window sensory cortices might be able to check category predictions, in particular when category is marked by an overt function morpheme, whose form the sensory cortices might be tuned to detect. If the early effects of category mismatch were, in fact, at least partly sensory responses, then their occurrence in the same time-window with sensory responses would obviously be expected.

The results of two MEG experiments supported both hypotheses. In Experiment 1, we found an effect of expectedness on the visual M100 response, but only when the unexpected item contained a category-marking closed-class morpheme. Experiment 2 replicated this finding and further showed that the lack of an M100 effect for the monomorphemic open-class stems in Experiment 1 was not due to their category ambiguity nor to their weakly predictive contexts.

The current work is the first to demonstrate that early visual responses to word forms can be influenced by prior syntactic context. Our results underdetermine whether left-anterior regions, such as those previously proposed to generate the ELAN, also participate in the early detection of word category violations. In the current data sets, we found no evidence for this, but from the null result we are obviously unable to draw any firm conclusions. Our study used a different technique from the vast majority of the ELAN literature. Furthermore, the failure to find a left-anterior effect may be due to our rate of presentation (300 ms on, 300 ms off); it has previously been hypothesized that early left-anterior effects are only found under very fast visual presentation (Kotz & Friederici, 2003). Ultimately, simultaneous EEG and MEG recordings should contribute to a more complete picture regarding these early stages of syntactic processing.

What mechanism might underlie the ability of visual cortex to respond to syntactic mismatches? This question can be broken down to two subparts: what types of predictions are visual regions sensitive to and what are the computations by which the incoming stimulus is evaluated with respect to the predictions? As regards the range of syntactic phenomena that might elicit early sensory effects, the extant EEG literature suggests that word category mismatches are the main generator of very early violation effects, and our results are obviously consistent with this. As discussed in the Introduction, agreement violations, for example, have primarily generated later ERP effects. However, there are some recent studies where very early Mismatch Negativities have been obtained for local agreement violations, at the same latency and with a similar scalp distribution as word category violations (see Hasting and Kotz, 2008, for a review). Thus whether there really is something special about word category predictions, as opposed to other types of predictions about the upcoming word, remains an open empirical question in need of additional studies. Further, where in the brain predictions are generated and whether multiple regions are involved – potentially differentiated by type of prediction – remain interesting questions for future research.

As regards the mechanisms by which sensory cortices evaluate predictions, one possibility is that predictions about upcoming word categories include form-based estimates (cf., Tanenhaus & Hare, 2007), which are then checked against perceptually salient elements in the input that signal word category, i.e., closed-class morphemes. Under this hypothesis, the primary role of visual cortex would be to match very specific instructions regarding the visual form of upcoming elements. A mismatch is only detected if there is a strong visual indicator in the input that does not match the prediction, e.g., a frequent closed-class morpheme.

However, although some type of top-down process seems perhaps the most plausible, on the basis of the current data we cannot reject the possibility that the visual cortex actually contains some type of representation of closed-class category-marking morphemes. On this account, the generating regions of the M100 would be a type of Visual Word Form Area, but dedicated to closed-class category-marking morphemes. Such a finding would obviously be extremely striking, but our data set raises it as a real possibility for future research.

Regarding the nature of the information that triggers the visual M100 effect, there is at least one viable hypothesis in addition to the closed/open-class distinction that might be relevant to our results, namely the typical orthographic properties of different word categories. A recent study by Farmer and colleagues revealed for open-class items that certain phoneme combinations are more canonically associated with nominal stems whereas others occur more frequently in verbal stems (Farmer, Christiansen, & Monaghan, 2006). This canonicity affects processing time: in unambiguous sentential contexts, more ‘verby’ verb forms are processed faster than verbs that share phonological properties with nouns, and vice versa for ‘nouny’ nouns. Recent research by Hauk and colleagues has, in fact, already demonstrated that orthographic typicality modulates event-related potentials at only 100 ms (Hauk et al., 2006). The combination of this research and our results raise the possibility that early visual responses may be sensitive to this canonicity, an interesting hypothesis to contrast in future studies with the more categorical account that appeals to the closed/open-class distinction.

5. Conclusion

In the current studies, salient indices of word category (i.e., closed-class category-marking morphemes) generated an enhanced sensory response when presented in an unexpected syntactic context. This finding suggests that syntactically relevant cues affect processing in sensory cortices after only 125 ms. Although the exact nature of this response and its relation to high-level syntactic processing require further investigation, the finding that sensory areas show sensitivity to these cues in any way is a striking one, and potentially a key element for understanding how language processing can be so remarkably fast.

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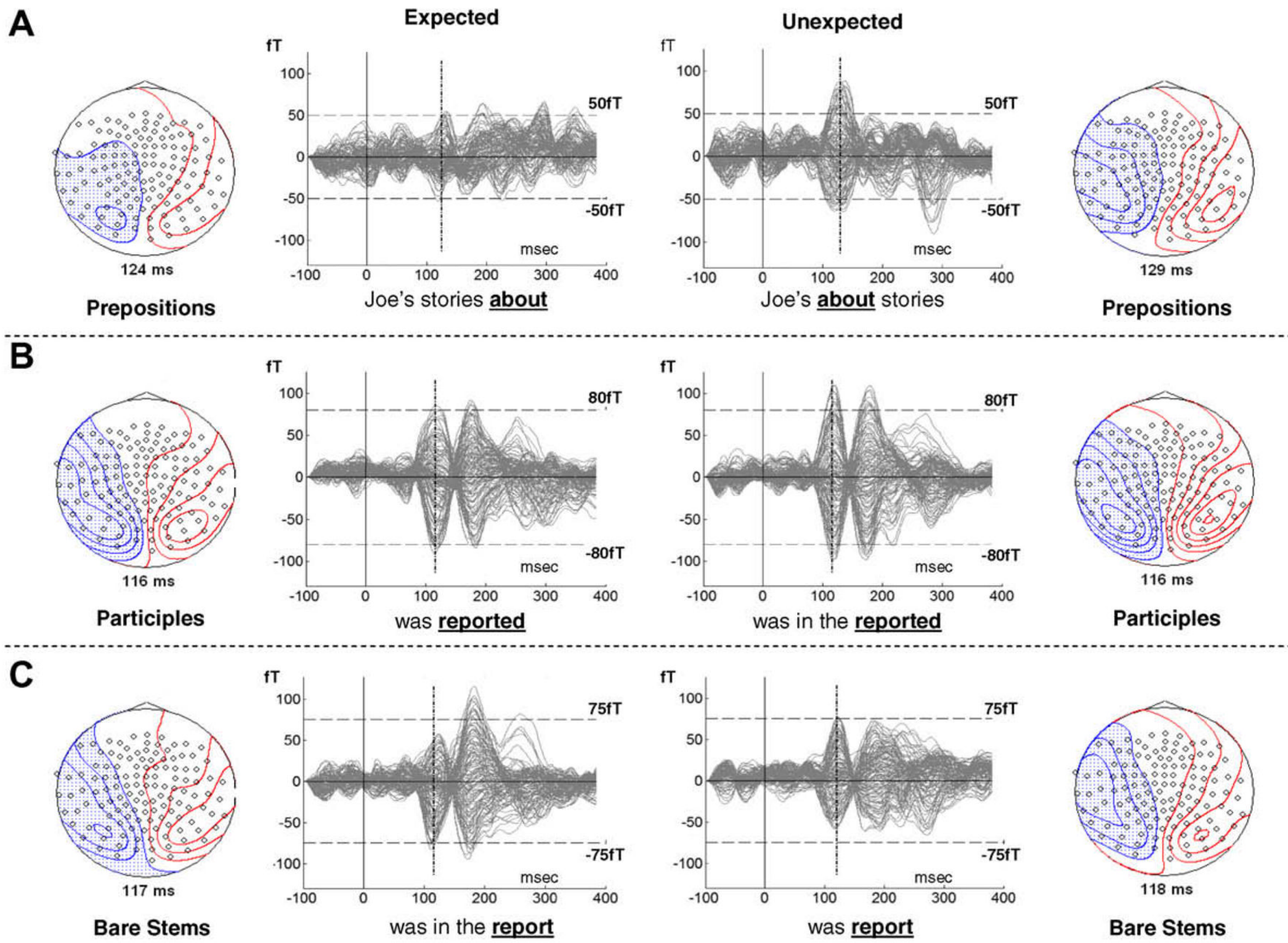

Fig. 1.

Grandaveraged waveforms and field distributions (n = 13) for each condition. All sensors are shown. In the waveforms, the cursor is pointed at the largest peak within 100–150 ms. The gradient maps on the left and right depict the magnetic field patterns associated with these peaks (10fT/line). In each case, the field pattern is a canonical M100 pattern. Both the waveforms and the field maps suggest an effect of expectedness at the visual M100 for unexpected prepositions and participles, but not for the bare stems.

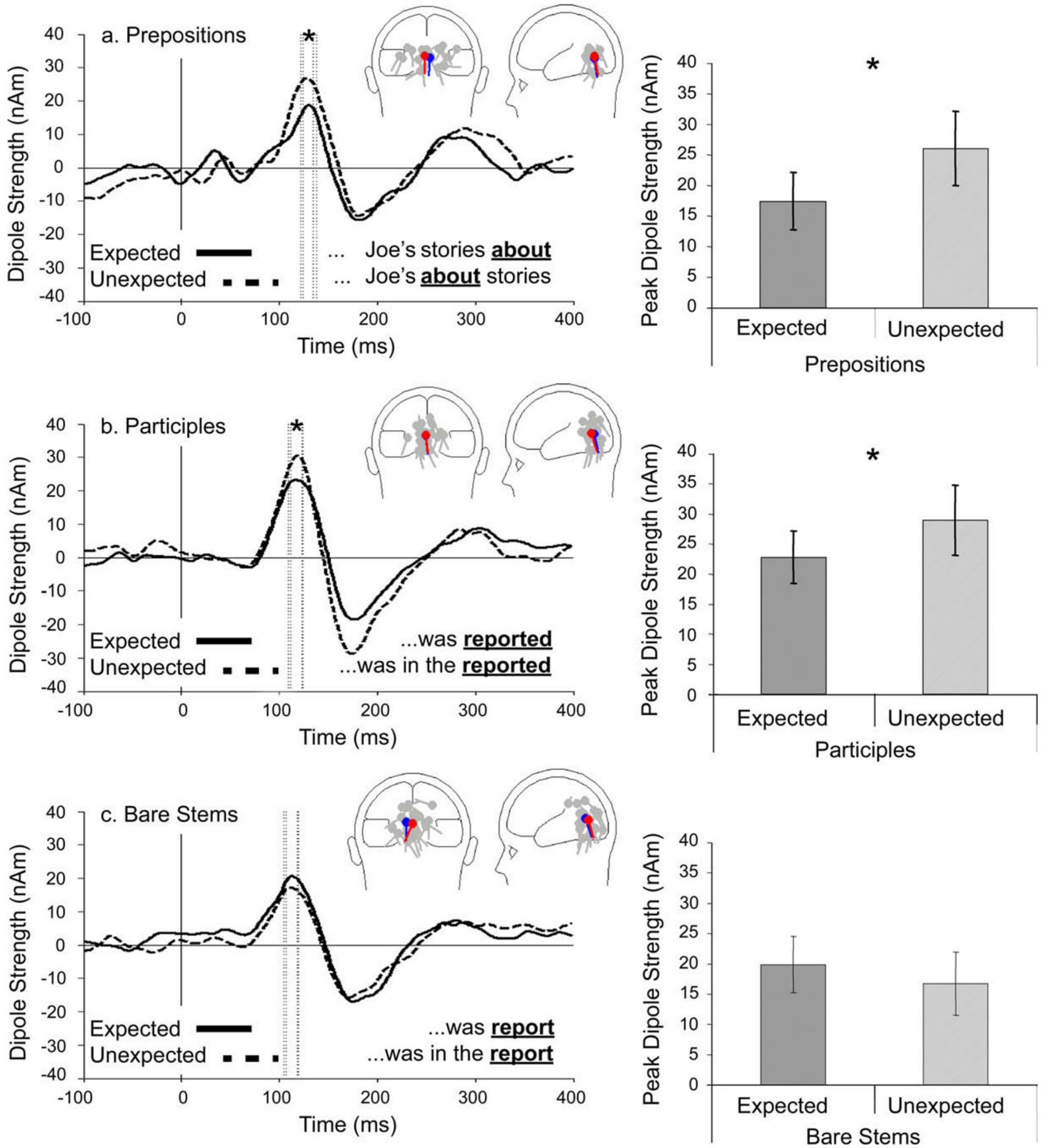

Fig. 2.
Grandaveraged waveforms for the M100 dipole sources per comparison (*n* = 11) and mean amplitudes in nAm for the 15 ms intervals centered around the M100 peaks (the time-window between the dotted lines in the waveform graphs). Mean dipole locations and orientations (blue = expected/red = unexpected) as well as the dipoles from the individual participants (grey) are plotted for each category. Results reveal effects of expectedness on M100 amplitude, but only for the Prepositions and Participles (* = $p < .05$). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

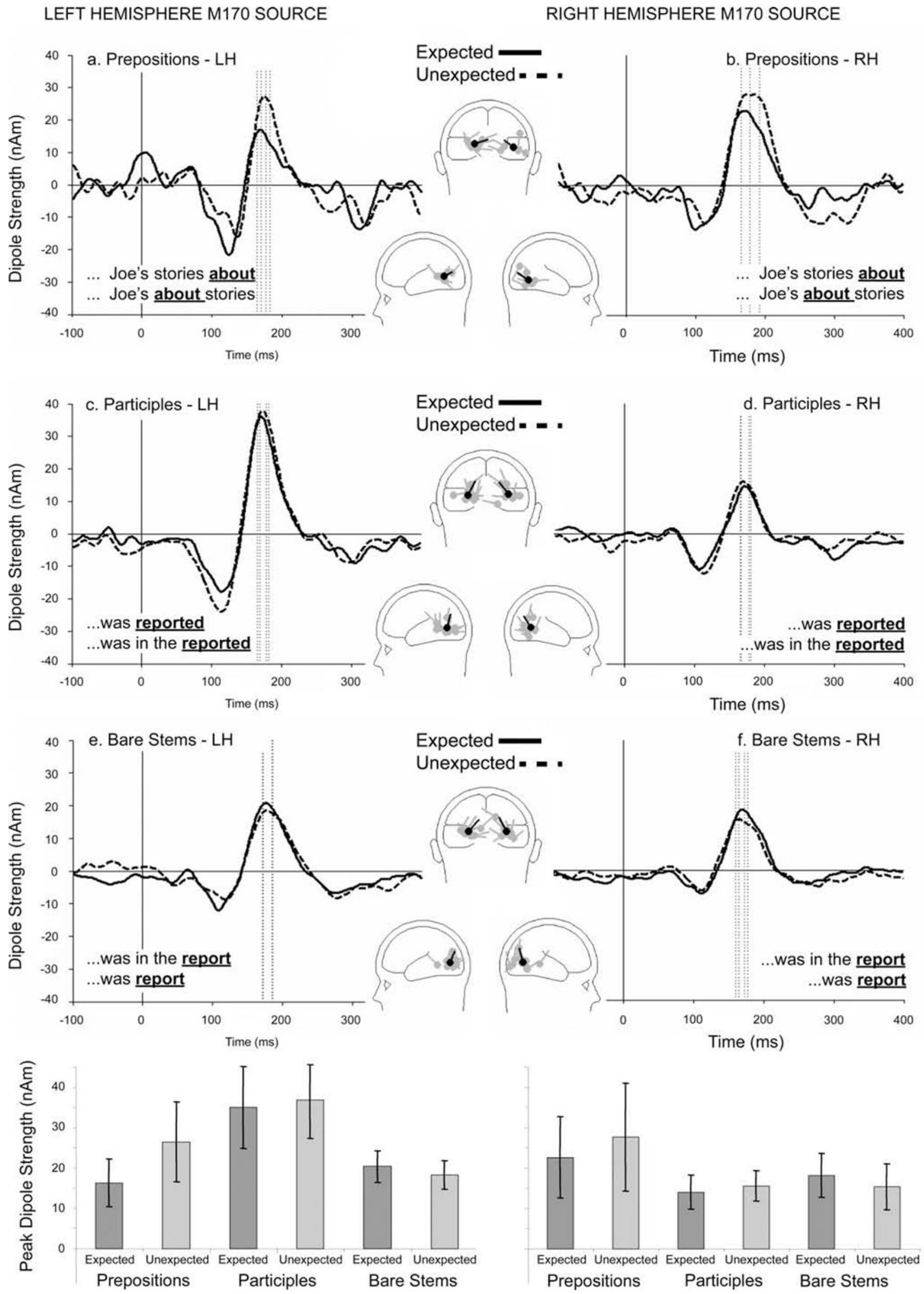

Fig. 3.

Grandaveraged waveforms for the left and right M170 dipole sources per condition and mean amplitudes in nAm for the 15 ms intervals centered around the left and right M170 peaks (the time-window between the dotted lines in the waveform graphs). Mean dipole locations and orientations (black) as well as the dipoles from the individual participants (grey) are plotted in the center for each word category. Results reveal no effects of expectedness on M170 amplitude.

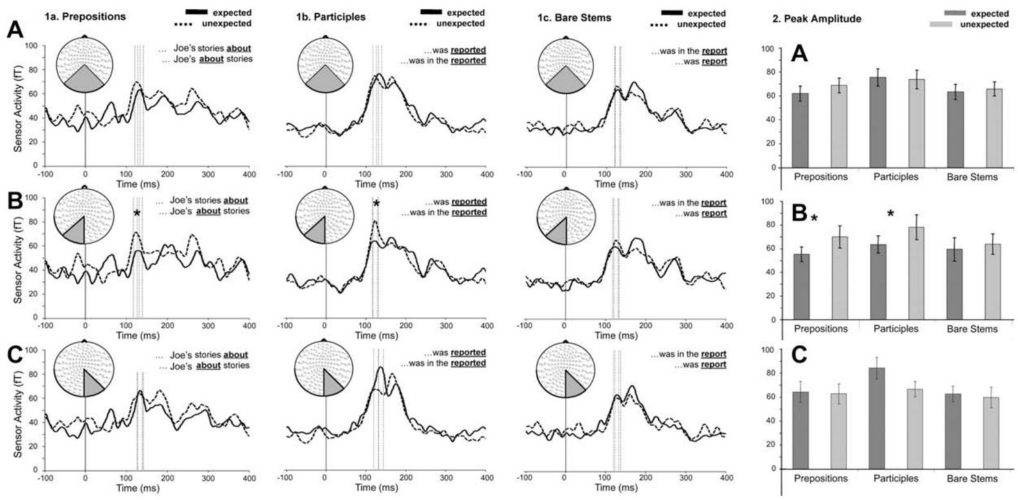

Fig. 4.

Left to right: Grandaveraged RMS's per condition and mean amplitudes in fT for the 15 ms intervals of interest (indicated by the dotted lines in the RMS waveform graphs). *The three regions of interest* (*ROIs*), *top to bottom*: The two posterior octants combined (A), the left posterior octant (B), and the right posterior octant (C). ROIs are highlighted in sensor space. Results reveal reliably enhanced activity for the unexpected conditions in the left posterior ROI only (* = $p < .05$; $n = 13$).

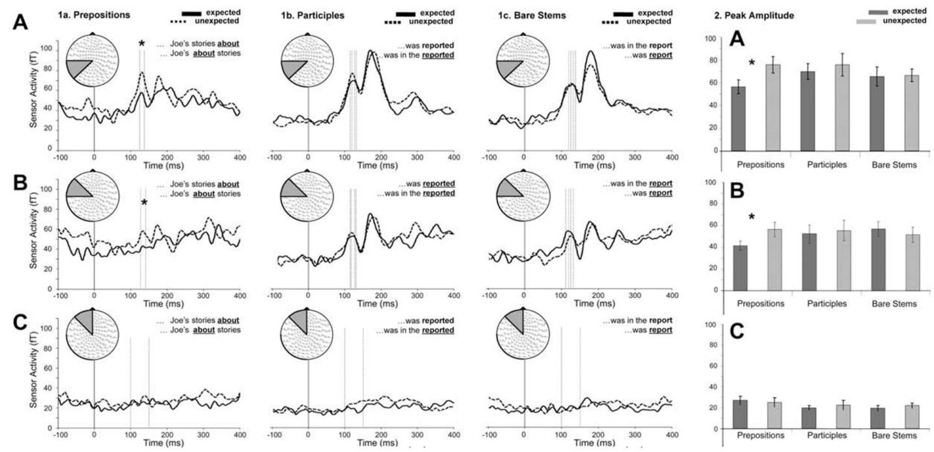

Fig. 5.

Left to right: Grandaveraged RMS's per condition and mean amplitudes in fT for the 15 ms intervals of interest (indicated by the dotted lines in the RMS waveform graphs). *Three regions of interest* (*ROIs*), *top to bottom*: the left medial-posterior (A), left medial-anterior (B), and left-anterior octant (C). ROIs are highlighted in sensor space.

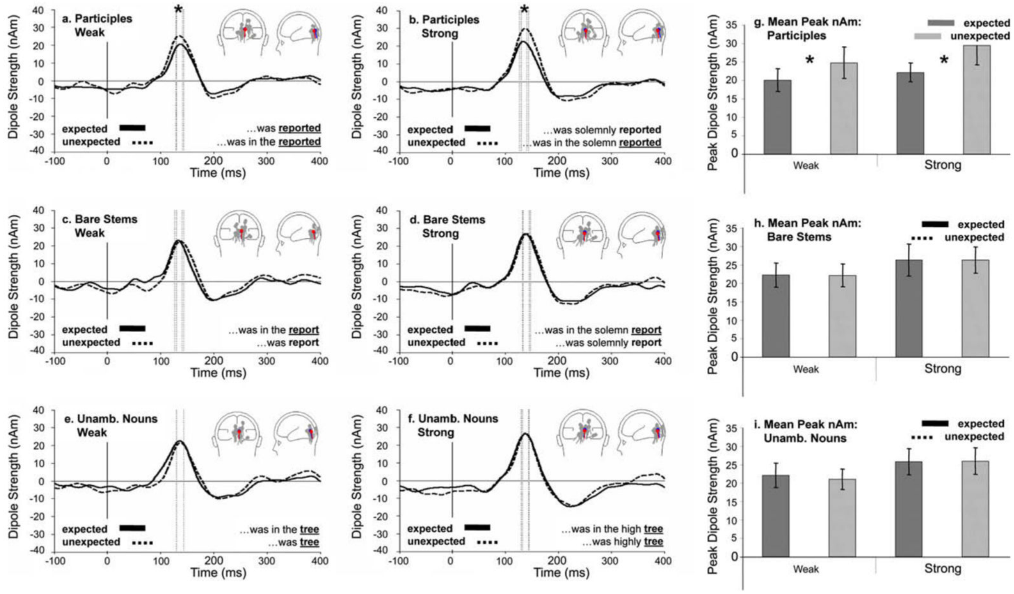

Fig. 6.

Grandaveraged waveforms for the M100 dipole sources per comparison (n = 12) and mean amplitudes in nAm for the 15 ms intervals centered around the M100 peaks (time-window between dotted lines in graphs). Mean dipole locations and orientations (blue = expected/red = unexpected) as well as the dipoles from the individual participants per condition (grey) are plotted.

Table 1

Examples of the experimental stimuli of Experiment 1. 300 target sentences (60 per condition for Participles and Bare stems, 30 per condition for Prepositions) were intermixed with 240 filler sentences. See Appendix 1 for a complete list of the target sentences. Cloze-probabilities reflect the proportion of the word category of interest filled in during an off-line sentence completion task (see text): cloze-probabilities for unexpected targets were at or close to zero.

Condition	**Expected**		**Unexpected**		**Nature of the violation**
	Example sentence	**Cloze-P**	**Example sentence**	**Cloze-P**	
Preposition	The boys heard Joe's stories ***about*** Africa	0.44	The boys heard Joe's ***about*** stories Africa	0	**Presence** of an unpredicted **free** closed-class morpheme
Participle	The discovery was ***reported***	0.29	The discovery was in the ***reported***	0.002	**Presence** of an unpredicted **bound** closed-class morpheme
Bare stem	The discovery was in the ***report***	0.91	The discovery was ***report***	0.002	**Absence** of a necessary **bound** closed-class morpheme

Table 2

Examples of the experimental stimuli of Experiment 2 (60 per condition). See Appendix 2 for a complete list of the test sentences. Cloze-probabilities reflect the proportion of the word category of interest filled in during an off-line sentence completion task (see text). For the unexpected conditions, cloze-probabilities are also given for the violated word category expectation (i.e., participles for the unexpected bare stems and the unexpected unambiguous nouns, and nouns for the unexpected participles).

Condition			**Expected**		**Unexpected**		
Word Category	**Category Ambiguity**	**Prediction Level**	**Example sentence**	**Cloze-P**	**Example sentence**	**Cloze-P**	
Participle	Unambiguous	Weak	The discovery was ***reported***	0.27	The discovery was in the ***reported***	Part: 0	Noun: 0.86
		Strong	The discovery was solemnly ***reported***	0.79	The discovery was in the solemn ***reported***	Part: 0	Noun: 0.90
Bare stem	Ambiguous	Weak	The discovery was in the ***report***	0.86	The discovery was ***report***	Noun: 0	Part: 0.27
		Strong	The discovery was in the solemn ***report***	0.90	The discovery was solemnly ***report***	Noun: 0	Part: 0.79
Noun	Unambiguous	Weak	The owl was in the ***tree***	0.79	The owl was ***tree***	Noun: 0	Part: 0.23
		Strong	The owl was in the high ***tree***	0.89	The owl was highly ***tree***	Noun: 0	Part: 0.59

Appendix 1

Experiment 1 stimuli

Prepositional targets

Expected

1 The girl resented Tom's comments about her looks.

2 The reviewer despises Richard's films about murder.

3 The police discovered Bob's pictures of the suspect.

4 The child enjoys Terry's cartoons about animals.

5 Most people enjoy Jim's stories about the past.

6 The boys heard Joe's stories about Africa.

7 The boys saw Ted's films about America.

8 The children enjoyed Ed's stories about the farm.

9 The crowd shouted Marx's slogans about peace.

10 The editor published Harry's report about drugs.

11 The firm needed Mike's ideas about marketing.

12 The judge read Chuck's article about crime.

13 The lady sold Mary's portrait of her father.

14 The man admired Don's sketch of the landscape.

15 The man bought Larry's painting of the ocean.

16 The man read Peter's report of the case.

17 The network broadcast Kevin's lecture about planets.

18 The newspaper printed John's picture of the accident.

19 The people disliked Fred's jokes about the Queen.

20 The police circulated Ruth's sketch of the thief.

21 The police received Sam's note about the ransom.

22 The professor praised Alan's poem about the moon.

23 The scientist criticized Max's proof of the theorem.

24 The students discussed Frank's speech about migrants.

25 The students enjoyed Bill's review of the play.

26 The students sang Lisa's songs about freedom.

27 The visitors accepted Gary's advice about the money.

28 The widow asked Fred's advice about taxes.

29 The women ignored John's complaints about the noise.

30 The parents saw Jean's pictures of her friends.

Unexpected

1 The girl resented Tom's about comments her looks.

2 The reviewer despises Richard's about films murder.

3 The police discovered Bob's of pictures the suspect.

4 The child enjoys Terry's about cartoons animals.

5 Most people enjoy Jim's about stories the past.

6 The boys heard Joe's about stories Africa.

7 The boys saw Ted's about films America.

8 The children enjoyed Ed's about stories the farm.

9	The crowd shouted Marx's about slogans peace.
10	The editor published Harry's about report drugs.
11	The firm needed Mike's about ideas marketing.
12	The judge read Chuck's about article crime.
13	The lady sold Mary's of portrait her father.
14	The man admired Don's of sketch the landscape.
15	The man bought Larry's of painting the ocean.
16	The man read Peter's of report the case.
17	The network broadcast Kevin's about lecture planets.
18	The newspaper printed John's of picture the accident.
19	The people disliked Fred's about jokes the Queen.
20	The police circulated Ruth's of sketch the thief.
21	The police received Sam's about note the ransom.
22	The professor praised Alan's about poem the moon.
23	The scientist criticized Max's of proof the theorem.
24	The students discussed Frank's about speech migrants.
25	The students enjoyed Bill's of review the play.
26	The students sang Lisa's about songs freedom.
27	The visitors accepted Gary's about advice the money.
28	The widow asked Fred's about advice taxes.
29	The women ignored John's about complaints the noise.
30	The parents saw Jean's of pictures her friends.

Participial targets

Expected	
1	The coat was quilted.
2	The discovery was reported.
3	The passenger was seated.
4	The picture was shaded.
5	The man was rescued.
6	His brain was scanned.
7	Her hair was styled.
8	The boxes were shipped.
9	The books were ordered.
10	The criminal was stoned.
11	The car was stopped.
12	The parcel was mailed.
13	The plants were studied.
14	The students were tested.
15	The problem was documented.
16	The prisoner was tracked.
17	The mouse was trapped.
18	The clothes were washed.
19	The novel was reviewed.
20	The excursion was planned.

21 The routes were mapped.

22 The appointments were scheduled.

23 The points were scored.

24 The problem was noted.

25 The shirt was painted.

26 The song was recorded.

27 The plants were watered.

28 The picture was framed.

29 The meal was microwaved.

30 The string was knotted.

31 The entrance was blockaded.

32 The flowers were bunched.

33 The team was coached.

34 The bicycles were claimed.

35 The robber was cornered.

36 The couch was stored.

37 The amendment was debated.

38 The songs were debuted.

39 The terms were demanded.

40 The chapel was designed.

41 The girl was dressed.

42 The story was ended.

43 The pictures were exhibited.

44 The field was farmed.

45 The park was fenced.

46 The information was faxed.

47 The elephant was filmed.

48 The horseshoe was forged.

49 The virus was emailed.

50 The steak was grilled.

51 The kids were grouped.

52 The tourists were guided.

53 The pan was heated.

54 The actor was interviewed.

55 The apartment was leased.

56 His qualities were listed.

57 The clothes were modeled.

58 The student was lectured.

59 The horse was harnessed.

60 The play was staged.

Unexpected

1 The coat was on the quilted.

2 The discovery was in the reported.

3 The passenger was in the seated.

4	The picture was in the shaded.
5	The man was at the rescued.
6	His brain was on the scanned.
7	Her hair was in a styled.
8	The boxes were on the shipped.
9	The books were in the ordered.
10	The criminal was on a stoned.
11	The car was at a stopped.
12	The parcel was in the mailed.
13	The plants were in the studied.
14	The students were in a tested.
15	The problem was in the documented.
16	The prisoner was on the tracked.
17	The mouse was in the trapped.
18	The clothes were in the washed.
19	The novel was in the reviewed.
20	The excursion was in the planned.
21	The routes were on the mapped.
22	The appointments were on the scheduled.
23	The points were in the scored.
24	The problem was on the noted.
25	The shirt was in the painted.
26	The song was on the recorded.
27	The plants were in the watered.
28	The picture was in the framed.
29	The meal was in the microwaved.
30	The string was in a knotted.
31	The entrance was behind the blockaded.
32	The flowers were in a bunched.
33	The team was behind the coached.
34	The bicycles were in the claimed.
35	The robber was around the cornered.
36	The couch was in the stored.
37	The amendment was in the debated.
38	The songs were in her debuted.
39	The terms were in the demanded.
40	The chapel was in the designed.
41	The girl was in the dressed.
42	The story was at the ended.
43	The pictures were in the exhibited.
44	The field was by the farmed.
45	The park was inside the fenced.
46	The information was in the faxed.
47	The elephant was in the filmed.
48	The horseshoe was in the forged.

49	The virus was in the emailed.
50	The steak was on the grilled.
51	The kids were in a grouped.
52	The tourists were with the guided.
53	The pan was on the heated.
54	The actor was in an interviewed.
55	The apartment was on a leased.
56	His qualities were on the listed.
57	The clothes were on the modeled.
58	The student was in the lectured.
59	The horse was in a harnessed.
60	The play was on the staged.

Bare stem targets

Expected

1	The coat was on the quilt.
2	The discovery was in the report.
3	The passenger was in the seat.
4	The picture was in the shade.
5	The man was at the rescue.
6	His brain was on the scan.
7	Her hair was in a style.
8	The boxes were on the ship.
9	The books were in the order.
10	The criminal was on a stone.
11	The car was at a stop.
12	The parcel was in the mail.
13	The plants were in the study.
14	The students were in a test.
15	The problem was in the document.
16	The prisoner was on the track.
17	The mouse was in the trap.
18	The clothes were in the wash.
19	The novel was in the review.
20	The excursion was in the plan.
21	The routes were on the map.
22	The appointments were on the schedule.
23	The points were in the score.
24	The problem was on the note.
25	The shirt was in the paint.
26	The song was on the record.
27	The plants were in the water.
28	The picture was in the frame.
29	The meal was in the microwave.
30	The string was in a knot.

31 The entrance was behind the blockade.

32 The flowers were in a bunch.

33 The team was behind the coach.

34 The bicycles were in the claim.

35 The robber was around the corner.

36 The couch was in the store.

37 The amendment was in the debate.

38 The songs were in her debut.

39 The terms were in the demand.

40 The chapel was in the design.

41 The girl was in the dress.

42 The story was at the end.

43 The pictures were in the exhibit.

44 The field was by the farm.

45 The park was inside the fence.

46 The information was in the fax.

47 The elephant was in the film.

48 The horseshoe was in the forge.

49 The virus was in the email.

50 The steak was on the grill.

51 The kids were in a group.

52 The tourists were with the guide.

53 The pan was on the heat.

54 The actor was in an interview.

55 The apartment was on a lease.

56 His qualities were on the list.

57 The clothes were on the model.

58 The student was in the lecture.

59 The horse was in a harness.

60 The play was on the stage.

Unexpected

1 The coat was quilt.

2 The discovery was report.

3 The passenger was seat.

4 The picture was shade.

5 The man was rescue.

6 His brain was scan.

7 Her hair was style.

8 The boxes were ship.

9 The books were order.

10 The criminal was stone.

11 The car was stop.

12 The parcel was mail.

13 The plants were study.

14 The students were test.

15 The problem was document.

16 The prisoner was track.

17 The mouse was trap.

18 The clothes were wash.

19 The novel was review.

20 The excursion was plan.

21 The routes were map.

22 The appointments were schedule.

23 The points were score.

24 The problem was note.

25 The shirt was paint.

26 The song was record.

27 The plants were water.

28 The picture was frame.

29 The meal was microwave.

30 The string was knot.

31 The entrance was blockade.

32 The flowers were bunch.

33 The team was coach.

34 The bicycles were claim.

35 The robber was corner.

36 The couch was store.

37 The amendment was debate.

38 The songs were debut.

39 The terms were demand.

40 The chapel was design.

41 The girl was dress.

42 The story was end.

43 The pictures were exhibit.

44 The field was farm.

45 The park was fence.

46 The information was fax.

47 The elephant was film.

48 The horseshoe was forge.

49 The virus was email.

50 The steak was grill.

51 The kids were group.

52 The tourists were guide.

53 The pan was heat.

54 The actor was interview.

55 The apartment was lease.

56 His qualities were list.

57 The clothes were model.

58 The student was lecture.

59	The horse was harness.
60	The play was stage.

Appendix 2

Experiment 2 stimuli

Participle Targets
Weak Prediction Level
Expected
1. The elephant was filmed.
2. The coat was quilted.
3. The terrace was shaded.
4. The hair was styled.
5. The books were ordered.
6. The rubbish was dumped.
7. The problem was documented.
8. The routes were mapped.
9. The appointments were scheduled.
10. The problem was noted.
11. The cactus was watered.
12. The picture was framed.
13. The flowers were bunched.
14. The team was coached.
15. The amendment was debated.
16. The chapel was designed.
17. The girl was dressed.
18. The story was ended.
19. The pictures were exhibited.
20. The information was faxed.
21. The plants were potted.
22. The kids were grouped.
23. The actor was interviewed.
24. The apartment was leased.
25. Everyone’s qualities were listed.
26. The clothes were modeled.
27. The student was lectured.
28. The horse was harnessed.
29. The play was staged.
30. The king was throned.
31. The papers were filed.
32. The glasses were packed.
33. The discovery was reported.
34. The passenger was seated.
35. The man was rescued.
36. The brain was scanned.
37. The boxes were shipped.
38. The car was stopped.
39. The plants were studied.

40. The students were tested.
41. The prisoner was tracked.
42. The mouse was trapped.
43. The clothes were washed.
44. The novel was reviewed.
45. The excursion was planned.
46. The shirt was painted.
47. The song was recorded.
48. The meal was microwaved.
49. The string was knotted.
50. The entrance was blockaded.
51. The items were claimed.
52. The robber was cornered.
53. The couch was stored.
54. The songs were debuted.
55. The terms were demanded.
56. The field was farmed.
57. The park was fenced.
58. The virus was emailed.
59. The steak was grilled.
60. The tourists were guided.

Weak Prediction Level

Unexpected

61. The elephant was in the filmed.
62. The coat was on the quilted.
63. The terrace was in the shaded.
64. The hair was in a styled.
65. The books were in the ordered.
66. The rubbish was in the dumped.
67. The problem was in the documented.
68. The routes were on the mapped.
69. The appointments were on the scheduled.
70. The problem was on the noted.
71. The cactus was in the watered.
72. The picture was in the framed.
73. The flowers were in the bunched.
74. The team was behind the coached.
75. The amendment was in a debated.
76. The chapel was in the designed.
77. The girl was in the dressed.
78. The story was at an ended.
79. The pictures were in the exhibited.
80. The information was in the faxed.
81. The plants were in the potted.

82. The kids were in the grouped.
83. The actor was in an interviewed.
84. The apartment was on a leased.
85. Everyone's qualities were on the listed.
86. The clothes were on the modeled.
87. The student was in a lectured.
88. The horse was in a harnessed.
89. The play was on a staged.
90. The king was on the throned.
91. The papers were in the filed.
92. The glasses were in the packed.
93. The discovery was in the reported.
94. The passenger was in the seated.
95. The man was at the rescued.
96. The brain was on the scanned.
97. The boxes were on the shipped.
98. The car was at a stopped.
99. The plants were in the studied.
100. The students were in a tested.
101. The prisoner was on the tracked.
102. The mouse was in the trapped.
103. The clothes were in the washed.
104. The novel was in the reviewed.
105. The excursion was in the planned.
106. The shirt was in the painted.
107. The song was on the recorded.
108. The meal was in the microwaved.
109. The string was in a knotted.
110. The entrance was behind the blockaded.
111. The items were in the claimed.
112. The robber was in the cornered.
113. The couch was in the stored.
114. The songs were in the debuted.
115. The terms were in the demanded.
116. The field was by the farmed.
117. The park was inside the fenced.
118. The virus was in the emailed.
119. The steak was on the grilled.
120. The tourists were with the guided.

Strong Prediction Level

Expected

121. The elephant was silently filmed.
122. The coat was finely quilted.
123. The terrace was continuously shaded.

124. The hair was elaborately styled.
125. The books were regularly ordered.
126. The rubbish was locally dumped.
127. The problem was eloquently documented.
128. The routes were incorrectly mapped.
129. The appointments were inaccurately scheduled.
130. The problem was politely noted.
131. The cactus was sparsely watered.
132. The picture was tastelessly framed.
133. The flowers were carelessly bunched.
134. The team was excellently coached.
135. The amendment was carefully debated.
136. The chapel was carefully designed.
137. The girl was wrongly dressed.
138. The story was swiftly ended.
139. The pictures were masterfully exhibited.
140. The information was rashly faxed.
141. The plants were incorrectly potted.
142. The kids were smartly grouped.
143. The actor was cleverly interviewed.
144. The apartment was dishonestly leased.
145. Everyone’s qualities were systematically listed.
146. The clothes were capably modeled.
147. The student was proficiently lectured.
148. The horse was loosely harnessed.
149. The play was sparsely staged.
150. The king was royally throned.
151. The papers were neatly filed.
152. The glasses were expensively packed.
153. The discovery was solemnly reported.
154. The passenger was safely seated.
155. The man was heroically rescued.
156. The brain was accurately scanned.
157. The boxes were properly shipped.
158. The car was abruptly stopped.
159. The plants were objectively studied.
160. The students were rigorously tested.
161. The prisoner was correctly tracked.
162. The mouse was ingeniously trapped.
163. The clothes were quickly washed.
164. The novel was honestly reviewed.
165. The excursion was stupidly planned.
166. The shirt was brightly painted.
167. The song was comically recorded.
168. The meal was badly microwaved.

169. The string was tightly knotted.
170. The entrance was firmly blockaded.
171. The items were verbally claimed.
172. The robber was quietly cornered.
173. The couch was cheaply stored.
174. The songs were proudly debuted.
175. The terms were anxiously demanded.
176. The field was organically farmed.
177. The park was securely fenced.
178. The virus was anonymously emailed.
179. The steak was excellently grilled.
180. The tourists were excitedly guided.

Strong Prediction Level

Unexpected

181. The elephant was in the silent filmed.
182. The coat was on the fine quilted.
183. The terrace was in the continuous shaded.
184. The hair was in an elaborate styled.
185. The books were in the regular ordered.
186. The rubbish was in the local dumped.
187. The problem was in the eloquent documented.
188. The routes were on the incorrect mapped.
189. The appointments were on the inaccurate scheduled.
190. The problem was on the polite noted.
191. The cactus was in the sparse watered.
192. The picture was in the tasteless framed.
193. The flowers were in the careless bunched.
194. The team was behind the excellent coached.
195. The amendment was in a careful debated.
196. The chapel was in the careful designed.
197. The girl was in the wrong dressed.
198. The story was at a swift ended.
199. The pictures were in the masterful exhibited.
200. The information was in the rash faxed.
201. The plants were in the incorrect potted.
202. The kids were in the smart grouped.
203. The actor was in a clever interviewed.
204. The apartment was on a dishonest leased.
205. Everyone’s qualities were on the systematic listed.
206. The clothes were on the capable modeled.
207. The student was in a proficient lectured.
208. The horse was in a loose harnessed.
209. The play was on a sparse staged.
210. The king was on the royal throned.

211. The papers were in the neat filed.
212. The glasses were in the expensive packed.
213. The discovery was in the solemn reported.
214. The passenger was in the safe seated.
215. The man was at the heroic rescued.
216. The brain was on the accurate scanned.
217. The boxes were on the proper shipped.
218. The car was at an abrupt stopped.
219. The plants were in the objective studied.
220. The students were in a rigorous tested.
221. The prisoner was on the correct tracked.
222. The mouse was in the ingenious trapped.
223. The clothes were in the quick washed.
224. The novel was in the honest reviewed.
225. The excursion was in the stupid planned.
226. The shirt was in the bright painted.
227. The song was on the comical recorded.
228. The meal was in the bad microwaved.
229. The string was in a tight knotted.
230. The entrance was behind the firm blockaded.
231. The items were in the verbal claimed.
232. The robber was in the quiet cornered.
233. The couch was in the cheap stored.
234. The songs were in the proud debuted.
235. The terms were in the anxious demanded.
236. The field was by the organic farmed.
237. The park was inside the secure fenced.
238. The virus was in the anonymous emailed.
239. The steak was on the excellent grilled.
240. The tourists were with the excited guided.

Bare Stem Targets

Weak Prediction Level

Expected

241. The elephant was in the film.
242. The coat was on the quilt.
243. The terrace was in the shade.
244. The hair was in a style.
245. The books were in the order.
246. The rubbish was in the dump.
247. The problem was in the document.
248. The routes were on the map.
249. The appointments were on the schedule.
250. The problem was on the note.
251. The cactus was in the water.

252. The picture was in the frame.
253. The flowers were in the bunch.
254. The team was behind the coach.
255. The amendment was in a debate.
256. The chapel was in the design.
257. The girl was in the dress.
258. The story was at an end.
259. The pictures were in the exhibit.
260. The information was in the fax.
261. The plants were in the pot.
262. The kids were in the group.
263. The actor was in an interview.
264. The apartment was on a lease.
265. Everyone's qualities were on the list.
266. The clothes were on the model.
267. The student was in a lecture.
268. The horse was in a harness.
269. The play was on a stage.
270. The king was on the throne.
271. The papers were in the file.
272. The glasses were in the pack.
273. The discovery was in the report.
274. The passenger was in the seat.
275. The man was at the rescue.
276. The brain was on the scan.
277. The boxes were on the ship.
278. The car was at a stop.
279. The plants were in the study.
280. The students were in a test.
281. The prisoner was on the track.
282. The mouse was in the trap.
283. The clothes were in the wash.
284. The novel was in the review.
285. The excursion was in the plan.
286. The shirt was in the paint.
287. The song was on the record.
288. The meal was in the microwave.
289. The string was in a knot.
290. The entrance was behind the blockade.
291. The items were in the claim.
292. The robber was in the corner.
293. The couch was in the store.
294. The songs were in the debut.
295. The terms were in the demand.
296. The field was by the farm.

297. The park was inside the fence.
298. The virus was in the email.
299. The steak was on the grill.
300. The tourists were with the guide.

Weak Prediction Level

Unexpected

301. The elephant was film.
302. The coat was quilt.
303. The terrace was shade.
304. The hair was style.
305. The books were order.
306. The rubbish was dump.
307. The problem was document.
308. The routes were map.
309. The appointments were schedule.
310. The problem was note.
311. The cactus was water.
312. The picture was frame.
313. The flowers were bunch.
314. The team was coach.
315. The amendment was debate.
316. The chapel was design.
317. The girl was dress.
318. The story was end.
319. The pictures were exhibit.
320. The information was fax.
321. The plants were pot.
322. The kids were group.
323. The actor was interview.
324. The apartment was lease.
325. Everyone’s qualities were list.
326. The clothes were model.
327. The student was lecture.
328. The horse was harness.
329. The play was stage.
330. The king was throne.
331. The papers were file.
332. The glasses were pack.
333. The discovery was report.
334. The passenger was seat.
335. The man was rescue.
336. The brain was scan.
337. The boxes were ship.
338. The car was stop.

339. The plants were study.
340. The students were test.
341. The prisoner was track.
342. The mouse was trap.
343. The clothes were wash.
344. The novel was review.
345. The excursion was plan.
346. The shirt was paint.
347. The song was record.
348. The meal was microwave.
349. The string was knot.
350. The entrance was blockade.
351. The items were claim.
352. The robber was corner.
353. The couch was store.
354. The songs were debut.
355. The terms were demand.
356. The field was farm.
357. The park was fence.
358. The virus was email.
359. The steak was grill.
360. The tourists were guide.

Strong Prediction Level

Expected

361. The elephant was in the silent film.
362. The coat was on the fine quilt.
363. The terrace was in the continuous shade.
364. The hair was in an elaborate style.
365. The books were in the regular order.
366. The rubbish was in the local dump.
367. The problem was in the eloquent document.
368. The routes were on the incorrect map.
369. The appointments were on the inaccurate schedule.
370. The problem was on the polite note.
371. The cactus was in the sparse water.
372. The picture was in the tasteless frame.
373. The flowers were in the careless bunch.
374. The team was behind the excellent coach.
375. The amendment was in a careful debate.
376. The chapel was in the careful design.
377. The girl was in the wrong dress.
378. The story was at a swift end.
379. The pictures were in the masterful exhibit.
380. The information was in the rash fax.

381. The plants were in the incorrect pot.
382. The kids were in the smart group.
383. The actor was in a clever interview.
384. The apartment was on a dishonest lease.
385. Everyone's qualities were on the systematic list.
386. The clothes were on the capable model.
387. The student was in a proficient lecture.
388. The horse was in a loose harness.
389. The play was on a sparse stage.
390. The king was on the royal throne.
391. The papers were in the neat file.
392. The glasses were in the expensive pack.
393. The discovery was in the solemn report.
394. The passenger was in the safe seat.
395. The man was at the heroic rescue.
396. The brain was on the accurate scan.
397. The boxes were on the proper ship.
398. The car was at an abrupt stop.
399. The plants were in the objective study.
400. The students were in a rigorous test.
401. The prisoner was on the correct track.
402. The mouse was in the ingenious trap.
403. The clothes were in the quick wash.
404. The novel was in the honest review.
405. The excursion was in the stupid plan.
406. The shirt was in the bright paint.
407. The song was on the comical record.
408. The meal was in the bad microwave.
409. The string was in a tight knot.
410. The entrance was behind the firm blockade.
411. The items were in the verbal claim.
412. The robber was in the quiet corner.
413. The couch was in the cheap store.
414. The songs were in the proud debut.
415. The terms were in the anxious demand.
416. The field was by the organic farm.
417. The park was inside the secure fence.
418. The virus was in the anonymous email.
419. The steak was on the excellent grill.
420. The tourists were with the excited guide.

Strong Prediction Level

Unexpected

421. The elephant was silently film.
422. The coat was finely quilt.

423. The terrace was continuously shade.
424. The hair was elaborately style.
425. The books were regularly order.
426. The rubbish was locally dump.
427. The problem was eloquently document.
428. The routes were incorrectly map.
429. The appointments were inaccurately schedule.
430. The problem was politely note.
431. The cactus was sparsely water.
432. The picture was tastelessly frame.
433. The flowers were carelessly bunch.
434. The team was excellently coach.
435. The amendment was carefully debate.
436. The chapel was carefully design.
437. The girl was wrongly dress.
438. The story was swiftly end.
439. The pictures were masterfully exhibit.
440. The information was rashly fax.
441. The plants were incorrectly pot.
442. The kids were smartly group.
443. The actor was cleverly interview.
444. The apartment was dishonestly lease.
445. Everyone’s qualities were systematically list.
446. The clothes were capably model.
447. The student was proficiently lecture.
448. The horse was loosely harness.
449. The play was sparsely stage.
450. The king was royally throne.
451. The papers were neatly file.
452. The glasses were expensively pack.
453. The discovery was solemnly report.
454. The passenger was safely seat.
455. The man was heroically rescue.
456. The brain was accurately scan.
457. The boxes were properly ship.
458. The car was abruptly stop.
459. The plants were objectively study.
460. The students were rigorously test.
461. The prisoner was correctly track.
462. The mouse was ingeniously trap.
463. The clothes were quickly wash.
464. The novel was honestly review.
465. The excursion was stupidly plan.
466. The shirt was brightly paint.
467. The song was comically record.

468. The meal was badly microwave.
469. The string was tightly knot.
470. The entrance was firmly blockade.
471. The items were verbally claim.
472. The robber was quietly corner.
473. The couch was cheaply store.
474. The songs were proudly debut.
475. The terms were anxiously demand.
476. The field was organically farm.
477. The park was securely fence.
478. The virus was anonymously email.
479. The steak was excellently grill.
480. The tourists were excitedly guide.

Unambiguous Noun Targets

Weak Prediction Level

Expected

481. The towel was in the sun.
482. The view was from the office.
483. The team was in a league.
484. The order was for the thing.
485. The silence was for a minute.
486. The payment was for the chairman.
487. The car was in the street.
488. The view was of the hill.
489. The bird was behind the window.
490. The owl was in the tree.
491. The ship was in the sea.
492. The protest was against the crisis.
493. The basket was for the fruit.
494. The building was in the city.
495. The promotion was for the spokesman.
496. The meeting was about an idea.
497. The toaster was in the sale.
498. The taxes were for the situation.
499. The boy was in a hotel.
500. The tree was on a property.
501. The shirt was for the son.
502. The bird was on the animal.
503. The water was for the mile.
504. The cheer was for the theatre.
505. The bid was for the dollar.
506. The equipment was for the army.
507. The memory was of the crime.
508. The monster was in the story.

509. The film was about the affair.
510. The plan was for a weekend.
511. The document was about a fact.
512. The gift was for the queen.
513. The criminal was in the area.
514. The song was on the album.
515. The altar was in the church.
516. The house was on the road.
517. The computer was for the secretary.
518. The mother was with the baby.
519. The boot was on the foot.
520. The abuse was for the loss.
521. The photo was of a husband.
522. The advertisement was for a job.
523. The present was for the family.
524. The appointment was for the Sunday.
525. The application was for a college.
526. The shop was in a community.
527. The form was with the agency.
528. The experience was for a moment.
529. The pill was for a body.
530. The conversation was about the goal.
531. The punishment was for the boy.
532. The bill was for a cent.
533. The mud was on the ball.
534. The dress was for the wife.
535. The fence was for the cow.
536. The grief was about the daughter.
537. The resort was on the island.
538. The method was in the example.
539. The word was in a language.
540. The check was for the course.

Weak Prediction Level

Unexpected

541. The towel was sun.
542. The view was office.
543. The team was league.
544. The order was thing.
545. The silence was minute.
546. The payment was chairman.
547. The car was street.
548. The view was hill.
549. The bird was window.
550. The owl was tree.

551. The ship was sea.
552. The protest was crisis.
553. The basket was fruit.
554. The building was city.
555. The promotion was spokesman.
556. The meeting was idea.
557. The toaster was sale.
558. The taxes were situation.
559. The boy was hotel.
560. The tree was property.
561. The shirt was son.
562. The bird was animal.
563. The water was mile.
564. The cheer was theatre.
565. The bid was dollar.
566. The equipment was army.
567. The memory was crime.
568. The monster was story.
569. The film was affair.
570. The plan was weekend.
571. The document was fact.
572. The gift was queen.
573. The criminal was area.
574. The song was album.
575. The altar was church.
576. The house was road.
577. The computer was secretary.
578. The mother was baby.
579. The boot was foot.
580. The abuse was loss.
581. The photo was husband.
582. The advertisement was job.
583. The present was family.
584. The appointment was Sunday.
585. The application was college.
586. The shop was community.
587. The form was agency.
588. The experience was moment.
589. The pill was body.
590. The conversation was goal.
591. The punishment was boy.
592. The bill was cent.
593. The mud was ball.
594. The dress was wife.
595. The fence was cow.

596. The grief was daughter.
597. The resort was island.
598. The method was example.
599. The word was language.
600. The check was course.

Strong Prediction Level

Expected

601. The towel was in the blazing sun.
602. The view was from the amazing office.
603. The team was in an awful league.
604. The order was for the beautiful thing.
605. The silence was for a brief minute.
606. The payment was for the brilliant chairman.
607. The car was in the broad street.
608. The view was of the charming hill.
609. The bird was behind the clean window.
610. The owl was in the high tree.
611. The ship was in the dangerous sea.
612. The protest was against the deep crisis.
613. The basket was for the delicious fruit.
614. The building was in the enormous city.
615. The promotion was for the excellent spokesman.
616. The meeting was about an exciting idea.
617. The toaster was in the exhaustive sale.
618. The taxes were for the expensive situation.
619. The boy was in an extravagant hotel.
620. The tree was on a famous property.
621. The shirt was for the fashionable son.
622. The bird was on the ferocious animal.
623. The water was for the final mile.
624. The cheer was for the great theatre.
625. The bid was for the historical dollar.
626. The equipment was for the hopeless army.
627. The memory was of the horrible crime.
628. The monster was in the horrid story.
629. The film was about the incredible affair.
630. The plan was for an intense weekend.
631. The document was about an interesting fact.
632. The gift was for the kind queen.
633. The criminal was in the local area.
634. The song was on the loud album.
635. The altar was in the magnificent church.
636. The house was on the narrow road.
637. The computer was for the new secretary.

638. The mother was with the noisy baby.
639. The boot was on the painful foot.
640. The abuse was for the pathetic loss.
641. The photo was of a peculiar husband.
642. The advertisement was for a permanent job.
643. The present was for the poor family.
644. The appointment was for the previous Sunday.
645. The application was for a reasonable college.
646. The shop was in a rural community.
647. The form was with the secret agency.
648. The experience was for a short moment.
649. The pill was for a sick body.
650. The conversation was about the significant goal.
651. The punishment was for the sinful boy.
652. The bill was for a single cent.
653. The mud was on the strange ball.
654. The dress was for the stunning wife.
655. The fence was for the stupid cow.
656. The grief was about the terrible daughter.
657. The resort was on the tropical island.
658. The method was in the ultimate example.
659. The word was in an unusual language.
660. The check was for the useful course.

Strong Prediction Level

Unexpected

661. The towel was blazingly sun.
662. The view was amazingly office.
663. The team was awfully league.
664. The order was beautifully thing.
665. The silence was briefly minute.
666. The payment was brilliantly chairman.
667. The car was broadly street.
668. The view was charmingly hill.
669. The bird was cleanly window.
670. The owl was highly tree.
671. The ship was dangerously sea.
672. The protest was deeply crisis.
673. The basket was deliciously fruit.
674. The building was enormously city.
675. The promotion was excellently spokesman.
676. The meeting was excitingly idea.
677. The toaster was exhaustively sale.
678. The taxes were expensively situation.
679. The boy was extravagantly hotel.

NIH-PA Author Manuscript

NIH-PA Author Manuscript

680. The tree was famously property.
681. The shirt was fashionably son.
682. The bird was ferociously animal.
683. The water was finally mile.
684. The cheer was greatly theatre.
685. The bid was historically dollar.
686. The equipment was hopelessly army.
687. The memory was horribly crime.
688. The monster was horridly story.
689. The film was incredibly affair.
690. The plan was intensely weekend.
691. The document was interestingly fact.
692. The gift was kindly queen.
693. The criminal was locally area.
694. The song was loudly album.
695. The altar was magnificently church.
696. The house was narrowly road.
697. The computer was newly secretary.
698. The mother was noisily baby.
699. The boot was painfully foot.
700. The abuse was pathetically loss.
701. The photo was peculiarly husband.
702. The advertisement was permanently job.
703. The present was poorly family.
704. The appointment was previously Sunday.
705. The application was reasonably college.
706. The shop was rurally community.
707. The form was secretly agency.
708. The experience was shortly moment.
709. The pill was sickly body.
710. The conversation was significantly goal.
711. The punishment was sinfully boy.
712. The bill was singly cent.
713. The mud was strangely ball.
714. The dress was stunningly wife.
715. The fence was stupidly cow.
716. The grief was terribly daughter.
717. The resort was tropically island.
718. The method was ultimately example.
719. The word was unusually language.
720. The check was usefully course.