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Research Report

The divided visual world paradigm: Eye tracking reveals hemispheric asymmetries in lexical ambiguity resolution

Aaron M. Meyer[a,*], *Kara D. Federmeier*[a,b,c]

[a]*Department of Psychology, University of Illinois at Urbana-Champaign, USA*
[b]*Neuroscience Program, University of Illinois at Urbana-Champaign, USA*
[c]*Beckman Institute for Advanced Science and Technology, University of Illinois at Urbana-Champaign, USA*

ARTICLE INFO

Article history:
Accepted 14 May 2008
Available online 21 May 2008

Keywords:
Lexical ambiguity
Cerebral hemispheres
Context effect
Eye tracking

ABSTRACT

Eye tracking was combined with the visual half-field procedure to examine hemispheric asymmetries in meaning selection and revision. In two experiments, gaze was monitored as participants searched a four-word array for a target that was semantically related to a lateralized ambiguous or unambiguous prime. Primes were preceded by a related or unrelated centrally-presented context word. In Experiment 1, unambiguous primes were paired with concordant weakly-related context words and strongly-related targets that were similar in associative strength to discordant subordinate-related context words and dominant-related targets in the ambiguous condition. Context words and targets were reversed in Experiment 2. A parallel study involved the measurement of event-related potentials (ERPs; Meyer, A. M., and Federmeier, K. D., 2007. The effects of context, meaning frequency, and associative strength on semantic selection: distinct contributions from each cerebral hemisphere. Brain Res. 1183, 91–108). Similar to the ERP findings, gaze revealed context effects for both visual fields/hemispheres when subordinate-related targets were presented: initial gaze revealed meaning activation when an unrelated context was utilized, whereas later gaze also revealed activation in the discordant context, indicating that meaning revision had occurred. However, eye tracking and ERP measures diverged when dominant-related targets were presented: for both visual fields/hemispheres, initial gaze indicated the presence of meaning activation in the discordant context, and, for the right hemisphere, discordant context information actually facilitated gaze relative to unrelated context information. These findings are discussed with respect to the activeness of the task and hemispheric asymmetries in the flexible use of context information.

Most English words are ambiguous (Rodd et al., 2004), having either multiple unrelated meanings (homonymy) or multiple related senses (polysemy). For example, the homonym *bank* can refer to a financial institution or the edge of a river, and the polysemous word *lamb* can refer to food or a living animal. Lexical ambiguity has been the subject of much research over the past several decades; many studies (e.g., Duffy et al., 1988; Simpson, 1981; Swinney and Hakes, 1976; Tabossi, 1988; Vu et al., 1998) have presented homonyms in a biasing context in order to explore the possible effects of non-lexical sources of information on lexical access (e.g., the semantic context in a sentence like "The office walls were so thin that they could

* *Corresponding author*. Beckman Institute, University of Illinois, 405 N. Mathews Avenue, Urbana, IL 61801, USA.
E-mail address: meyeram@uiuc.edu (A.M. Meyer).

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doi:10.1016/j.brainres.2008.05.033

hear the *ring* …"; Onifer and Swinney, 1981). Several classes of models have developed out of this research: *exhaustive* models (Swinney, 1979), which argue that multiple meanings of an ambiguous word are automatically activated; *selective* models (Swinney and Hakes, 1976), which suggest that only the contextually-consistent meaning is initially activated; and *hybrid* models, which argue that context interacts with meaning frequency (e.g., Duffy et al., 1988; Tabossi, 1988). For example, the hybrid *reordered access model* developed by Duffy et al. postulates that the dominant (most frequent) meaning is activated first in a neutral context, but that context biased toward the subordinate (less frequent) meaning results in simultaneous activation of both meanings. Although exhaustive models prevailed for a time, the constraining effects of context are widely acknowledged today, with current disputes focusing on the potential interaction between meaning frequency and contextual constraint (see, e.g., Binder and Rayner, 1999; Kellas and Vu, 1999).

In recent years, studies of ambiguity resolution have increasingly focused on selection processes, rather than initial meaning access (see Gorfein, 2001). Such studies have used a variety of tasks (including naming, relatedness judgment, sentence verification, self-paced reading, and eye tracking) to probe activation for unselected meanings of an ambiguous word, subsequent to selection of the contextually-consistent meaning. Findings suggest that selection involves the inhibition of unselected meanings, which then results in difficulty accessing those meanings (Gernsbacher et al., 1990; Gernsbacher et al., 2001; Simpson and Kang, 1994; Simpson and Adamopoulos, 2001) or integrating them with discourse (Morris and Binder, 2001). In contrast to the interactive effects of meaning frequency and context on lexical access (e.g., Duffy et al., 1988), similar inhibition effects have been observed following dominant- and subordinate-biased contexts (Simpson and Kang, 1994; Gernsbacher et al., 2001; Morris and Binder, 2001).

As interest in the time course of meaning selection has increased, researchers have moved from the use of traditional behavioral measures, which provide information regarding the cognitive processing that occurs at a specific, discrete time point, toward methodologies such as event-related potentials (ERPs; Van Petten and Kutas, 1987) and eye tracking (Rayner and Duffy, 1986), which allow for continuous sampling of cognitive processing and provide multidimensional indices of processing. For example, the visual world paradigm (Cooper, 1974; Tanenhaus et al., 1995) has been combined with eye tracking in order to explore the time course of ambiguity resolution. In one such study, participants listened to neutral or subordinate-biased sentences containing an ambiguous word (e.g., "First, the man got ready quickly, but then he checked the *pen*…" or "First, the welder locked up carefully, but then he checked the *pen*…") while viewing an array of pictures that included a dominant referent (a writing instrument), a subordinate referent (an animal enclosure), and two unrelated distractors (Huettig and Altmann, 2007). At the onset of the ambiguous word in the subordinate-biased context, the probability of fixating the subordinate referent was greater than that for distractors, indicating that the context was successful in directing attention toward the "animal enclosure" concept. However, this did not prevent activation of the dominant meaning when the ambiguous word was processed. At the offset of the ambiguous word in both contexts, the probability of fixating each referent image was greater than that for the unrelated distractors, indicating that multiple meanings had been accessed. The findings of this study appear to be consistent with both exhaustive and hybrid models but inconsistent with selective models. However, it is possible that above-baseline fixation of the dominant referent in the subordinate-biased context reflects backward priming from the referent to the ambiguous word (Kiger and Glass, 1983; Van Petten and Kutas, 1987), or priming that originates when the referent is viewed prior to the presentation of the ambiguous word. In other words, although the referent image was intended to serve as a probe for activation of the dominant meaning, the dominant meaning may be activated as a result of the temporal proximity between the referent image and the ambiguous word. To rule out such an interpretation, it may be necessary to temporally separate the prime and target or use a complementary methodology such as ERPs.

Eye-tracking and ERPs have previously been utilized in parallel to obtain converging or complementary evidence regarding issues in language comprehension (e.g., Ledoux et al., 2007; Knoeferle et al., 2005, 2008). Because ERPs provide multiple, functionally-dissociable measures of word and sentence processing, they have proven useful for examining the nature and time course of meaning activation and revision. Two components that have played a particularly important role in studies of language processing are the N400 (Kutas and Hillyard, 1980) and the late positive complex, or LPC (e.g., Curran et al., 1993). The N400 is a negative-going potential that peaks around 400 ms after the onset of a meaningful stimulus. Its amplitude is reduced in the presence of supportive context information, such as a related word or a congruent sentence (see Kutas and Federmeier, 2000, for a review). Differences in N400 amplitude relative to an unrelated baseline have been used to examine the extent to which specific meanings of ambiguous words are activated or selected (e.g., Van Petten and Kutas, 1987). The LPC, a positive-going potential following the N400, has instead been linked to more explicit aspects of meaning selection and revision, such as the realization that a target word is related to an unselected meaning of a previously-presented ambiguous word (Swaab et al., 1998). Through these components, it has proven possible to dynamically track not only whether particular word meanings are active, but when and how that activation occurs. For example, some studies have found evidence that contextual information initially suppresses activation of the inconsistent meaning of an ambiguous word, as suggested by a lack of N400 facilitation to a target word related to that dispreferred meaning. More positive LPC responses to these targets, however, suggested that the suppressed meaning was eventually (re)activated (Swaab et al., 1998, 2003).

1. Hemispheric asymmetries in ambiguity resolution

In addition to the fact that the multiple meanings associated with a given lexical item may become active at different points in time, there are reasons to believe that meaning activation and selection may take place differentially in the two cerebral hemispheres (e.g., Jung-Beeman, 2005; Burgess and Simpson,