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Hemispheric sensitivities to lexical and contextual information: Evidence from lexical ambiguity resolution

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Abstract

The present study examined the manner in which both hemispheres utilize prior semantic context and relative meaning frequency during the processing of homographs. Participants read sentences biased toward the dominant or the subordinate meaning of their final homograph, or unbiased neutral sentences, and performed a lexical decision task on lateralized targets presented 250 ms after the onset of the sentence-final ambiguous prime. Targets were either related to the dominant or the subordinate meaning of the preceding homograph, or unrelated to it. Performance asymmetry was found in the absence of a biasing context: dominant-related targets were exclusively facilitated in the RVF/LH, whereas both dominant- and subordinate-related targets were facilitated in the LVF/RH. Performance symmetry was found in the presence of a biasing context: dominant-related targets were exclusively activated in dominant-biasing contexts, whereas both dominant- and subordinate-related targets were facilitated in subordinate-biasing contexts. The implications of the results for both general and hemispheric models of word processing are discussed.

Keywords: Cerebral hemispheres; Lexical ambiguity; Word frequency; Sentence context; Priming; Visual field

1. Introduction

Understanding written words during sentence comprehension requires readers to rapidly access and integrate different sources of information from long-term memory, including lexical knowledge related to the word itself and contextual knowledge related to the sentential context in which the word is embedded. This process is complicated by the fact that many words have more then one distinct meaning and thus part of the comprehension process entails a selection of one of those meanings. Ample evidence from behavioral research (e.g., Duffy, Morris, & Rayner, 1988; Peleg, Giora, & Fein, 2001; Peleg, Giora, & Fein, 2004; Titone, 1998) indicates that this selection process is governed by lexical factors (for example, relative meaning frequency), and by contextual factors (for example, prior semantic information). However, despite decades of intensive research, effects on ambiguity resolution are still controversial and not fully fleshed out (for an overview, see Simpson, 1984; Simpson, 1994; Small, Cottrell, & Tanenhaus, 1988).

On the one hand, two-stage models argue that all meanings of an ambiguous word are initially activated regardless of either frequency or contextual bias. According to this view, contextually inappropriate meanings are discarded only at a later, post-lexical, selection stage (Onifer & Swinney, 1981; Swinney, 1979). On the other hand, direct-access models suggest that a strong biasing context can selectively activate the contextually appropriate meaning of an ambiguous word, regardless of relative meaning frequency (e.g., Martin, Vu, Kellas, & Metcalf, 1999; Vu, Kellas, & Paul, 1998). Between these two extremes, hybrid models such as “The Reordered Model” (Duffy et al., 1988) or “The Graded Salience Hypothesis” (Giora, 1997; Giora, 1999; Giora, 2003; Peleg et al., 2001, 2004) suggest that both contextual and lexical factors influence meaning activation immediately and independently of each other. According

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to these models, context can facilitate the activation of a contextually appropriate meaning, but it cannot inhibit dominant or salient inappropriate meanings. Thus, when context is biased toward the less salient, subordinate meaning of an ambiguous word, both meanings (the contextually appropriate subordinate meaning and the contextually inappropriate dominant meaning) are initially activated.

Importantly, recent neuropsychological studies have shown that lexical processing in general and ambiguity resolution in particular, require the intact functioning of *both* cerebral hemispheres (e.g., Grindrod & Baum, 2003). Moreover, converging data from split-brain (e.g., Iacoboni & Zaidel, 1996; Zaidel, 1987; Zaidel, 1990; Zaidel, 1998), focal lesion studies (e.g., Copland, Chenery, & Murdoch, 2002; Swaab, Brown, & Hagoort, 1998; Tompkins & Lehman, 1998), and neurologically intact subjects (e.g., Beeman & Chiarello, 1998; Beeman et al., 1994; Chiarello, 1988; Chiarello, 1998; Federmeier & Kutas, 1999) demonstrate that whereas both hemispheres participate in word processing, they do so in qualitatively different ways. Specifically, several studies have shown that the two hemispheres differ in the way in which lexical and contextual sources of information are applied to the processing of words (e.g., Burgess & Simpson, 1988; Coney & Evans, 2000; Faust & Chiarello, 1998; Faust & Gernsbacher, 1996; Titone, 1998). Thus, models of ambiguity resolution should be refined and extended so as to include these differential contributions of the two hemispheres.

A widespread experimental method for assessing hemispheric contributions to language comprehension in general and ambiguity resolution in particular is the divided visual-field (DVF) priming paradigm: this technique takes advantage of the fact that stimuli presented in the left side of the visual field are initially processed exclusively by the right hemisphere and vice versa. Although information presented in this manner can be later transmitted to both hemisphere, the interpretation of DVF paradigms rests on the assumption that responses to stimuli presented briefly to one visual field reflect mainly the processing of that stimulus by the contralateral hemisphere, so that responses to targets in the right visual field (RVF) reflect left hemisphere (LH) processes and responses to targets in the left visual field (LVF) reflect processes in the right hemisphere (RH) (for theoretical and electrophysiological support for this assumption, see Banich, 2003; Berardi & Fiorentini, 1997; Coulson, Federmeier, Van Petten, & Kutas, 2005).

Research using the DVF priming technique, has led to the conclusion that the hemispheres differ significantly in the way they deal with lexical factors such as relative meaning salience or frequency. Beeman (1993, 1998) proposed that during word processing, a different range of meanings or semantic associates is activated in each hemisphere: narrow, focused meanings are activated in the LH, while weak and diffuse activation occurs in the RH. This proposal, known as the "Fine/Coarse Coding Model", is based on evidence from studies showing that semantic priming effects of remotely related words are obtained in the RH but not in the LH (e.g., Beeman et al., 1994; Chiarello, Burgess, Richards, & Pollock, 1990). For example, in a study conducted by Beeman et al. (1994), two types of semantic priming were used: a prime word (*scissors*) closely related to the target (*cut*) and summation priming from three words (*cry–foot–glass*), each distantly related to the same target (*cut*). The results indicated that the direct primes were more effective for RVF/LH targets, while the summation primes were more effective for LVF/RH targets. The authors concluded that the LH strongly activates a small number of semantic fields of closely related meanings, whereas the RH weakly activates large loosely related semantic fields that also include distantly associated meanings.

Similarly, ambiguity resolution studies using the DVF paradigm, have shown that less salient, subordinate or figurative meanings are more likely to be maintained in the RH (e.g., Anaki, Faust, & Kravetz, 1998; Burgess & Simpson, 1988). For example, in a seminal study by Burgess and Simpson (1988), subjects read ambiguous word primes (e.g., *bank*) and performed lexical decision on target words that were either related to the dominant meaning (*money*) or the subordinate, less frequent meaning (*river*). The ambiguous primes were presented in central vision, followed by a target word projected to the left (LVF/RH) or right (RVF/LH) visual fields. Targets were presented either 35 or 750 ms after the onset of the prime (SOA). Results indicate that at the short delay, the LH activated immediately and exhaustively all of the meanings (both dominant and subordinate) of a semantically ambiguous word. However in longer SOAs (750 ms), only the dominant meaning was actively maintained. In contrast, the RH has access only to the more frequent interpretation in the immediate condition, and "exhaustive" availability of both meanings at the longer temporal delay. On the basis of these results, Burgess and Simpson suggested that the LH accesses all of the meanings of an ambiguous word very quickly and then suppresses the less frequent meaning. The RH, on the other hand, activates both meanings more slowly and maintains these meanings.

It is thus generally agreed that relative meaning frequency has differential implications for word processing in the hemispheres: the LH quickly focuses on a single dominant interpretation, whereas the RH activates and maintains a wider range of interpretations including distantly related, subordinate, figurative or nonconventional meanings (e.g., Anaki et al., 1998; Beeman et al., 1994; Chiarello et al., 1990). Indeed, consistent with this proposal, neurological studies have shown that subordinate, less salient, figurative, or connotative meanings are much less accessible when the RH is dysfunctional (e.g., Brownell, Simpson, Birhle, Potter, & Gardner, 1990; Schmitzer, Strauss, & DeMarco, 1997; Stemmer, Giroux, & Joanette, 1994; Weylman, Brownell, Roman, & Gardner, 1989).

Conclusions regarding hemispheric sensitivities to contextual information, however, have been less monolithic. Several DVF studies using sentences as primes, have suggested that RH processing is less sensitive to sentence-level context (e.g., Faust, 1998; Faust & Kravetz, 1998) and therefore maintains alternate meanings regardless of their contextual appropriateness (e.g., Faust & Chiarello, 1998; Faust & Gernsbacher, 1996). For example, Faust and Gernsbacher (1996) have shown that sentential information can be used to suppress contextually inappropriate meanings in the LH but not in the RH. In that study, experimental stimuli were constructed so that each sentence ended in an equibiased homograph (a word with similarly likely interpretations) such as *spade* or an unambiguous control word such as *shovel* ('He dug with the *spade/shovel*'), followed by a target word related to the contextually inappropriate meaning of the homograph (*ace*). Sentence primes were presented centrally one word at a time. Target words were presented laterally either after a short (100 ms) or after a long (1000 ms) delay. Subjects were asked to judge whether the target was related to the overall meaning of the sentence. Results indicated that at the short SOA, targets presented after ambiguous words were harder to reject relative to those presented after unambiguous words in both visual fields. However, at the long SOA, interference from the contextually inappropriate meaning was only observed in the LVF/RH presentation. These results were taken to indicate that while contextually inappropriate meanings are initially activated in both hemispheres, it is only the LH that can use sentential context in order to suppress contextually incompatible meanings.

Similar results were reported by Faust and Chiarello (1998). They presented subjects with sentences biased toward the dominant or subordinate meaning of a final polarized homograph (a word that has highly dominant meanings and also subordinate ones, such as *second*). Subjects then performed lexical decision on lateralized target words, presented 900 ms after the onset of the final ambiguous prime. Targets were either related to the dominant meaning (*time*) or the subordinate meaning (*number*), or were unrelated words (*sound*). Results revealed that in the RVF/LH, priming was restricted to targets related to the contextually compatible meaning. In contrast, in the LVF/RH, related targets were primed regardless of context. This again suggests that during ambiguity resolution, the RH is less sensitive than the LH to contextual information.

In contrast, other researchers have suggested that the RH is highly sensitive to contextual information. For example, neurological studies show that an intact RH is needed for drawing and revising inferences (Beeman, 1993; Brownell, Potter, Birhle, & Gardner, 1986), extracting the main points from a given discourse context (Gardner, Brownell, Wapner, & Michelow, 1983), or for integrating the elements of a story into a coherent narrative (Wapner, Hamby, & Gardner, 1981). Moreover, the unique ability of the RH to extract the more global or wider, connotative meaning of words (Beeman, 1998) can be taken to reflect not only broader semantic activations in the RH, but also the ability to use contextual information during language comprehension.

In addition, if both stages of ambiguity resolution (initial activation of multiple meanings and then the selection of the contextually appropriate meaning) are carried out in the LH, as suggested by the DVF studies reported above, then this hemisphere should be sufficient for successful resolution (at least in cases where reanalysis is not required). However, studies of focally brain damaged patients show that despite an intact LH, patients with RH damage perform worse than controls on ambiguity resolution (e.g., Grindrod & Baum, 2003). This should suggest a more active role for the RH in ambiguity resolution than simply activating and maintaining alternative meanings with no consideration of either lexical or contextual factors.

Indeed, two DVF studies that examined the joint effects of frequency and sentential context on ambiguity resolution report effects of these factors in *both* hemispheres. First, Coney and Evans (2000) presented subjects with sentences biased toward the dominant or the subordinate meaning of a final polarized homograph. Subjects then performed lexical decisions on lateralized target words, presented either 40 or 750 ms after the onset of the final ambiguous prime. Targets were related either to the contextually appropriate or inappropriate meaning. Here hemispheric differences were apparent at the short SOA: in the RVF/LH, targets related to the dominant meaning of the homographs were exclusively facilitated, whereas in the LVF/RH, targets related to both meanings were facilitated. Interestingly, however, at the longer SOA, biasing sentences exerted equivalent effects upon the retrieval of meaning in the left and right visual fields. Dominant meanings were activated in both dominant- and subordinate-biasing context, whereas subordinate meanings were activated only when context supported the subordinate meaning.

Moreover, Titone (1998) has demonstrated that in some cases the RH can even be more sensitive to sentential information than the LH. Using a cross modal priming paradigm with a 0 ms inter-stimulus interval (ISI) between auditory ambiguous primes (*ball*) and visual targets (*round/dance*), Titone showed that both lexical and contextual factors influenced meaning activation in both visual fields. In an unbiased context (*They really liked the ball*), both hemispheres primed only the dominant meaning (*round*). When the context was strongly biased toward the subordinate meaning (*Because it featured a great orchestra, they really liked the ball*) both hemispheres primed both subordinate and dominant meanings of the primes (*round* and *dance*). Interestingly, when the context was weakly biased towards the subordinate meaning (*Because it lasted the entire night, they really liked the ball*), the LH primed the dominant meaning (*round*) as if the sentence was unbiased, while the RH selectively activated the subordinate meaning (*dance*). In agreement with the ‘‘fine/coarse coding model’’, Titone concluded that only the RH is sensitive to contexts that emphasize peripheral semantic features (*night–ball*) and that both hemispheres are sensitive to sentence contexts that emphasize central semantic features (*orchestra–ball*). These findings are also consistent with ERP studies showing that context-sensitivity characterizes both hemispheres (e.g., Coulson et al., 2005; Federmeier & Kutas, 1999).

In sum, the contribution of each hemisphere to ambiguity resolution is presently unclear. Specifically, RH sensitivity to contextual information is still debated. Some researchers have proposed that RH involvement in ambiguity resolution may simply result from bottom-up lexical processes, in which a broader range of meanings is activated and maintained regardless of context (e.g., Faust & Chiarello, 1998; Faust & Gernsbacher, 1996). This may be potentially useful in situations where an initial understanding must be revised (e.g., Kacinik & Chiarello, 2007). In contrast, other researchers have proposed greater RH involvement in higher-level, contextual processes (e.g., Brownell et al., 1986) and several DVF studies have shown large sentential context effects on both visual fields (e.g., Coulson et al., 2005; Federmeier & Kutas, 1999; Titone, 1998). According to these studies, both hemispheres exploit contextual information to determine the meaning of words, albeit in a qualitatively different and complementary way. Given these conflicting evidence in the literature, the present study attempts to further explore the effects of prior semantic context and meaning predominance on the processing of homographs in the two cerebral hemispheres.

The ambiguity studies reported above usually focused on either very short or very long SOAs. Thus, their conclusions pertain to either the very initial stage of lexical access, where frequency effects may be stronger and/or both factors may not fully exert their influence at that early point, or to the very late stages of meaning access, where context can overcome highly frequent inappropriate meanings, so that frequency effects are no longer evident. The present study examines the joint effects of meaning frequency and sentential context at a point in time (250 SOA) that is consistent with general reading times (approximately 200–250 ms per word). This temporal stage may be more revealing and relevant to the joint contribution of the two hemispheres during normal reading. In addition, for the first time in a single DVF study, we compare the effects of three different sentential contexts: unbiased (ambiguous sentence: *He went to the bank*), biased toward the dominant meaning (*The businessman entered the bank*) and biased toward the subordinate meaning (*The fisherman sat on the bank*). This design, together with the manipulation of the relatedness of target words presented laterally to each visual field (e.g., money, river, or book), allows us to measure the effects of frequency and context using two different baselines: within each sentence context, we can compare, as have other studies, the response times to related (e.g., *river*) and unrelated (e.g., *book*) targets. In addition, pure sentential priming can be assessed by comparing response times to the same prime-target pairs (bank–river) presented after biased (*The fisherman sat on the...*) compared to unbiased (*He went to the...*) contexts.

Finally, it is important to note that this study was conducted in Hebrew which is highly suitable for this particular study. First, in Hebrew letters represent mostly consonants, and vowels can optionally be superimposed on consonants as diacritical marks. Since the vowel marks are usually omitted, readers frequently encounter words with more than one possible interpretation. In addition, the right to left reading direction in Hebrew eliminates the possibility (raised by Western languages such as English) of accounting for VF differences in terms of reading habits.

Based on previous studies, two major claims are investigated: first, if the LH activates a relatively small semantic field, including only closely related meanings, while the RH diffusely activates a much broader range of related meanings, including more distant associates (e.g., Beeman et al., 1994), then only dominant, more frequent meanings will be activated in the RVF/LH, whereas all meanings related to an ambiguous word (dominant and subordinate) will be activated in the LVF/RH. Second, if the LH is sensitive to contextual information, while the RH activates and maintains alternative meanings irrespective of contextual information (e.g., Faust & Chiarello, 1998; Faust & Gernsbacher, 1996), then only contextually compatible meanings will be activated in the RVF/LH, whereas both compatible and incompatible meanings will be activated in the LVF/RH.

2. Methods

2.1. Participants

Thirty six undergraduate students (18 males), aged 19–28 participated in the study. All subjects were healthy, right handed, native speakers of Hebrew with normal or corrected-to-normal vision.

2.2. Stimuli

The experimental materials consisted of 112 noun–noun polarized Hebrew homographs (both homophonic and heterophonic)[1] selected on the basis of the following pretests: (1) A booklet containing homographs and their paraphrased meanings was presented to 50 subjects, who were instructed to circle the most frequent sense. The dominant meaning of a homograph was defined as the meaning chosen by at least 65% of subjects. (2) The validity of this selection was then tested by asking 50 different subjects to write the first association that came to their minds when reading

[1] The different phonological status of the homographs did not interact with lexical and contextual factors in this study, and therefore the data were pooled across these categories in the results presented here.

the homographs. Only those homographs whose frequency judgment coincided with the additional test were used in the experiment. Overall, the selected homograph corpus was polarized with the dominant meaning being chosen with a mean of 84%.

For each homograph, two target words were selected: one related to the dominant meaning and the other to the subordinate meaning. To avoid the development of strategies by subjects, two unrelated targets were also constructed for each homograph by randomly re-pairing related primes and targets. To insure similar semantic relatedness in the case of related targets, and to establish that unrelated target words were indeed unrelated, 36 different subjects were instructed to rate the degree to which each target is associatively related to the compatible meaning of the homograph on a 5-point scale (where 5 represented a very strong association and 1 represented a very weak association). In this pretest, presentation of word pairs was counterbalanced by using 4 stimulus lists, each of which contained homograph-dominant pairs, homograph-subordinate pairs, and homograph-unrelated pairs. Thus, the same homograph primes appeared in each of the lists, each time paired with a different target word (two related and two unrelated). The means of these association ratings were 4.4 for the dominant meanings and 4.35 for the subordinate meanings and no reliable difference was found between them (all ps > .3). The mean for unrelated pairs was 1.9 (related pairs were always rated significantly higher than unrelated pairs). Dominant and subordinate targets were also compared in terms of length (number of letters). The means were 4.22 and 4.25, respectively, and did not differ ($p > .7$). Given the lack of frequency norms in Hebrew, we asked 36 additional subjects to perform a simple lexical decision task on all of the target words. The mean times for dominant and subordinate targets were 697 and 691, respectively. Latencies from this pretest revealed no reliable differences among the targets ($p > .7$).

Finally, for each homograph, three sentence contexts were constructed, each preceding the final homograph: an unbiased (i.e., ambiguous) context, one biased toward the dominant meaning, and another biased toward the subordinate meaning. To ensure similar degree of contextual bias, the relatedness of the sentential context and its final homograph was rated by 36 new subjects on a 5-point scale ranging from very related (5) to very unrelated (1). Presentation of contexts and primes were counterbalanced by creating three stimulus lists which contained homograph-dominant contexts, homograph-subordinate contexts, and homograph-unbiased contexts. Thus, the same homograph primes appeared in each of the lists, each time embedded in a different sentential context. The means of these relatedness ratings were 4.62 for the dominant-biased context; 4.32 for the subordinate-biased context; and 3.15 for the unbiased context. An analysis of variance revealed no significant difference between dominant- and subordinate-biased contexts ($p > .2$). Biased contexts were rated significantly higher then unbiased contexts (all ps < .001). Translated examples of the stimuli are shown in Table 1.

2.3. Apparatus

Stimulus presentation and responses were controlled and recorded by a Dell GX-260 PC P4-1800-14H. An adjustable chin-rest kept subjects at a fixed viewing distance from the computer screen (57 cm). Stimuli, constructed from characters presented in Ariel font (size 20), were colored white and displayed on a gray colored screen.

2.4. Experimental design and procedures

The experiment used a 3 (context type: biased toward the dominant or the subordinate meaning or unbiased) × 2 (Target Dominance: dominant or subordinate) × 2 (Target Relatedness: related or unrelated) × 2 (target location: LVF or RVF) within subjects design. There were 2688 experimental permutations for the target words (112 homographs × 3 types of sentential context × 2 target words × 2 prime-target relations × 2 VF presentations). Twelve lists (four for each context) were created such that all factors were counterbalanced across items and subjects. Cell means are based on 28 experimental trials per condition per participant. Each list contained 112 experimental sentences (ending in homographs) that were paired with word targets (such that, within each context, there were 14 experimental trials per condition: 2 Visual Fields × 2 Target

Table 1
Translated examples of stimuli

Sentence context	Homograph	Target word	
		Dominant-related	Subordinate-related
Unbiased: The young man looked for the	Book/barber	Reading	Hair
Dominant: The students were asked to buy the	"ספר"		
Subordinate: The bride made an appointment with the			
Unbiased: They looked at the	Contract/seer	Document	Prophet
Dominant: The buyers signed the	"חוזה"		
Subordinate: The children of Israel listened to the			
Unbiased: They talked about the	Receipt/ mystical books	Invoice	Judaism
Dominant: The customer asked the salesman for a	"קבלה"		
Subordinate: The religious student studied the			
Unbiased: She told him about the	Discount/ assumption	Reduction	Hypothesis
Dominant: The price was high even after the	"הנחה"		
Subordinate: The results of the study supported the			

Dominance × 2 Target Relatedness), and 112 sentence fillers that were paired with nonword targets (224 trials in total). Subjects were randomly assigned to six experimental lists (two for each context condition). Each homograph appeared only once per list (6 times total and the 6 presentations appeared in different conditions). Trials within each list were presented in random order, with randomization controlled by the computer and the order of lists was counterbalanced across subjects. In order to complete their assigned lists, each participant completed three experimental sessions (2 lists per session). The testing sessions lasted approximately 60 min (20 min for each list with a 10–20 min break between them). The sessions were administered with an interval of 1–3 weeks between them to avoid carry-over repetition effects.

Subjects were seated 57 cm from the computer screen and placed their heads in the head and chin-rest. All target stimuli were presented such that their innermost boundary, whether to the right or left of center, was exactly 2° of visual angle from the central fixation marker. Each session comprised 28 practice trials presented in one block, 224 experimental trials and fillers presented in blocks of 28, with a rest period between blocks, a 10 min break, and a second set of 224 experimental trials and fillers presented in the same manner.

At the start of each trial, subjects were presented with a central fixation marker for 650 ms. The offset of the marker was followed by a 100 ms pause, and the sentential context (i.e., the sentence without the final homograph) was then presented in the same position (center of the screen) for 1500 ms (a period which had been previously identified as comfortable for reading any of the sentences presented in the experiment). The offset of the sentence was followed successively by a 200 ms blank period and a central fixation marker for 300 ms. The prime (homograph) was then presented in the same central position for 150 ms. At 100 ms ISI (250 ms SOA), the target string was presented for 150 ms to the LVF or RVF for a lexical decision response.

Subjects made lexical decision responses by pressing the up/down arrows with their right index finger for word/nonword responses. They were instructed to maintain gaze on the central fixation marker and to make responses based on what they can see from the periphery as quickly and accurately as possible. In order to insure close reading of sentential contexts, yes/no comprehension questions were included in 25% of the trials. The data collected for each subject included RT for target words and error rates for all conditions.

3. Results

A 3 × 2 × 2 × 2 ANOVA was conducted for both RT data and error data across subjects ($F1$) and items ($F2$) with type of sentential context (dominant-consistent, subordinate-consistent or unbiased), location of target (RVF or LVF), Target Dominance (dominant or subordinate) and Target Relatedness (related or unrelated) as factors. Cutoff response times of 250 ms for anticipations, and 2500 ms for late responses were used. No data were excluded. Analyses of RTs were based on participants' mean RT for correct responses. Mean RT, SDs and error rate in all conditions are given in Table 2. A correlation analysis of response times and error rates revealed highly significant positive correlations in all of the conditions, indicating that these measures tapped the same underlying process.

The main effect of visual field was significant in the item analysis for both RT ($F2(1,444) = 22.52$, $p < .0001$, $\mathrm{MSE} = 13295.38$) and errors ($F2(1,444) = 24.03$, $p < .0001$, $\mathrm{MSE} = 57.74$) and showed the same tendency in the subject analysis (RT: $F1(1,35) = 2.44$, $p = .13$; errors: $F1(1,35) = 1.19$, $p = .28$), indicating that targets were responded to more quickly and accurately when they were presented to the RVF/LH. The main effect of Target Relatedness was significant in both analyses for both RT ($F1(1,35) = 124.67$, $p < .0001$, $\mathrm{MSE} = 2458.87$; $F2(1,444) = 45.04$, $p < .0001$, $\mathrm{MSE} = 25250.05$) and errors ($F1(1,35) = 55.32$, $p < .0001$, $\mathrm{MSE} = 82.50$; $F2(1,444) = 29.56$, $p < .0001$, $\mathrm{MSE} = 198.50$), indicating that related targets were more rapidly and accurately responded to than unrelated targets. In addition, a main effect of context type was found for RT, in both the item and subject analyses ($F1(2,70) = 14.19$, $p < .0001$, $\mathrm{MSE} = 13318.55$; $F2(2,888) = 56.52$, $p < .0001$, $\mathrm{MSE} = 10423.12$) and for errors, in the item analysis ($F2(2,888) = 4.44$, $p < .02$, $\mathrm{MSE} = 31.09$), reflecting an advantage for biased contexts, especially for contexts biased toward the subordinate meaning.

Importantly, for RT data, the four-way interaction between context type, Visual Field, Target Dominance, and Target Relatedness was significant in both analyses ($F1(2,70) = 4.51$, $p < .02$, $\mathrm{MSE} = 1805.50$; $F2(2,888) = 5.24$, $p < .006$, $\mathrm{MSE} = 4521.85$). This interaction was fur-

Table 2
Mean correct RT (in ms) as a function of visual field, sentence context and target type

	LVF sentence context			RVF sentence context		
	Dominant-biased	Unbiased	Subordinate-biased	Dominant-biased	Unbiased	Subordinate-biased
Target type						
Dominant-related	693(136) 4.6%	723(154) 6.6%	692(143) 8%	666(119) 3.6%	697(130) 5.2%	662(113) 6.7%
Unrelated	789(168) 15.1%	770(165) 12.4%	722(141) 13%	743(146) 10.7%	697(130) 10.8%	700(126) 11.3%
Subordinate-related	765(178) 11.6%	725(146) 10.5%	671(138) 6.3%	727(129) 11.1%	742(131) 9.1%	653(119) 4.3%
Unrelated	761(164) 14.8%	762(171) 13%	736(153) 12.6%	746(144) 9.3%	745(136) 10.6%	707(135) 9.1%

Standard deviations (in ms) are presented in parenthesis and error rates (in %) are presented below.

ther examined by testing the Target Dominance × Target Relatedness × Visual Field interaction separately for each context condition.

3.1. Unbiased (ambiguous) contexts

The three-way interaction between Visual Field, Target type and Relatedness was significant in the item analysis ($F2(1, 888) = 4.80$, $p < .03$, $\text{MSE} = 8114.42$; $F1(1, 35) = 2.06$, $p < .16$, $\text{MSE} = 2904.54$). We computed degree of priming by subtracting RT for related targets from RT for unrelated targets in each condition. The top panel of Fig. 1 shows the magnitude of priming in the two visual fields. It is evident from this figure that for LVF target presentation, responses to both dominant and subordinate targets were significantly facilitated relative to the unrelated conditions (*by subjects*: dominant: $t(35) = 3.16$, $p < .004$; subordinate: $t(35) = 2.46$, $p < .02$; *by items*: dominant: $t(111) = 2.65$, $p < .01$; subordinate: $t(111) = 3.04$, $p < .004$). In contrast, for RVF target presentation, priming for dominant targets was significant (*by subjects*: $t(35) = 5.65$, $p < .0001$; *by items*: $t(111) = 3.11$, $p < .003$), while priming for subordinate targets was not significantly different from 0 (*by subjects*: $t(35) = 0.27$, $p > .8$; $F2$ $t(111) = 0.27$, $p > .8$). These results indicate that when homographs are embedded in an unbiased (ambiguous) context, only the dominant meaning is activated in the RVF/LH, while both meanings are activated in the LVF/RH.

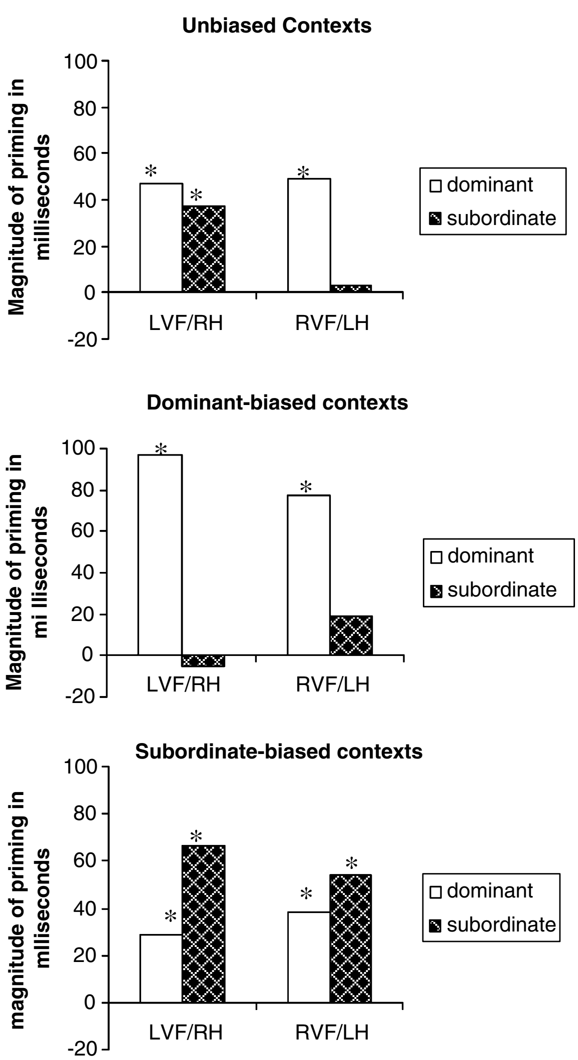

Fig. 1. Magnitude of priming in ms ($\text{RT}_{\text{unrelated}} - \text{RT}_{\text{related}}$) for target words as a function of visual field, presented separately for each context condition: unbiased (top panel), dominant-biased (middle panel); or subordinate-biased (bottom panel). *Note.* *Significant, $p < 0.5$.

3.2. Dominant-biased contexts

The Target Dominance × Target Relatedness × Visual Field ANOVA revealed a significant interaction of Target Dominance × Target Relatedness ($F1(1, 35) = 37.39$, $p < .0001$, $\text{MSE} = 42.04$; $F2(1, 444) = 22.03$, $p < .0001$, $\text{MSE} = 13596.56$). The main effect of visual field was significant in the item analysis ($F2(1, 444) = 22.63$, $p < .0001$, $\text{MSE} = 9111.09$). As mentioned earlier, planned comparisons included two baselines: the magnitude of semantic priming was calculated by subtracting RT for related targets from RT for unrelated targets. In addition, pure sentential priming was calculated by contrasting the reaction time for related targets presented in the dominant-biased condition with those obtained in the unbiased condition.

The middle panel of Fig. 1 shows the difference between RTs to related and unrelated targets in dominant-biased contexts. It is evident from this figure that, in both visual fields, responses to targets related to the contextually appropriate, dominant meaning of the final homograph were significantly facilitated relative to the unrelated condition. (In the LVF: *by subjects*: $t(35) = 7.74$, $p < .0001$; *by items*: $t(111) = 6.29$, $p < .0001$. In the RVF: *by subjects*: $t(35) = 8.09$, $p < .0001$, *by items*: $t(111) = 7.10$, $p < .0001$.) Conversely, responses to subordinate targets were not significantly facilitated. (In the LVF: *by subjects*: $t(35) = -0.76$, $p > .45$; *by items*: $t(111) = -0.39$, $p > .7$; in the RVF: *by subjects*: $t(35) = 1.77$, $p > .09$, *by items*: $t(111) = 1.51$, $p > .13$.)

The top panel of Fig. 2 shows the difference between RTs to related targets presented after an unbiased (ambiguous) context and a context consistent with the dominant meaning of the final homograph, in the two visual fields. It is evident from this figure that, in both visual fields, only targets related to the contextually compatible, dominant meaning were significantly facilitated. (In the LVF: $F1(1, 70) = 7.18$, $p < .01$, $\text{MSE} = 2722.97$; $F2(1, 333) = 6.08$, $p < .02$, $\text{MSE} = 10475.60$; in the RVF: $F1(1, 70) = 11.22$, $p < .002$, $\text{MSE} = 1953.50$; $F2(1, 333) = 9.44$, $p < .003$, $\text{MSE} = 6608.08$.) Moreover, in the LVF, responses to targets related to the subordinate contextually inappropriate meaning were even significantly slowed (or inhibited) in comparison to the unbiased neutral condition ($F1(1, 70) = 8.68$, $p < .005$, $\text{MSE} = 3483.85$; $F2(1, 333) = 7.72$, $p < .0006$, $\text{MSE} = 12864.98$).

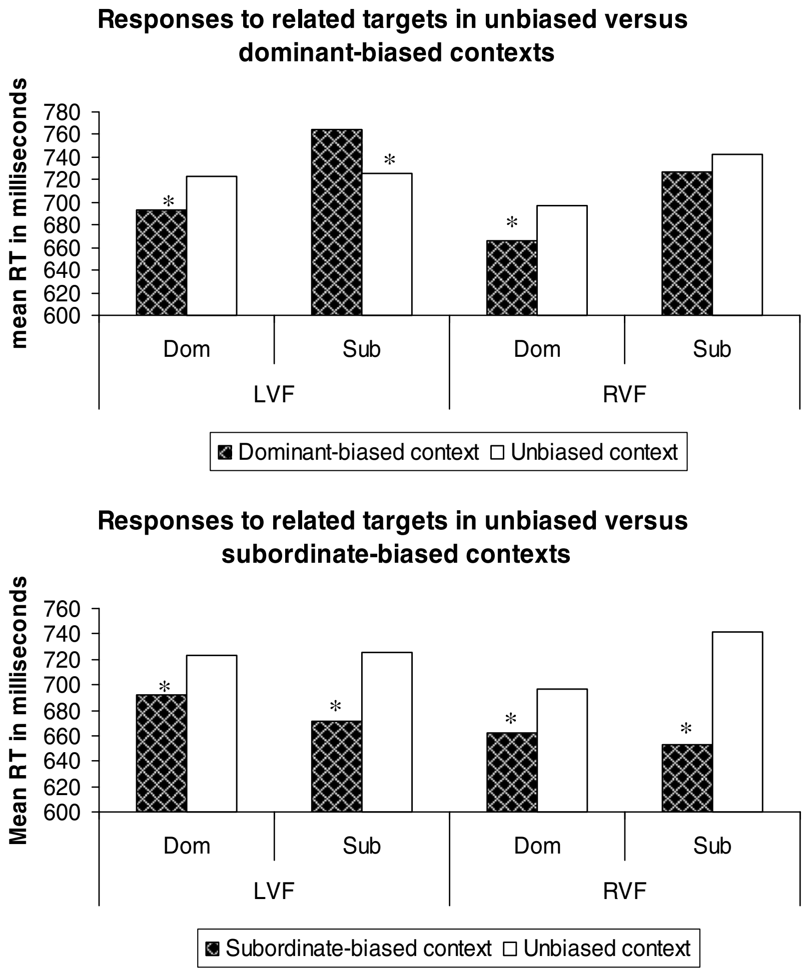

Fig. 2. Mean RT (in ms) for target words presented in unbiased versus dominant-biased contexts (top panel); or unbiased versus subordinate-biased contexts (bottom panel) as a function of visual field. *Note.* Dom, dominant; Sub, subordinate. *Significant, $p < .05$.

3.3. Subordinate-biased contexts

The Target Type × Relatedness × Visual Field ANOVA revealed a significant interaction of Target Dominance × Target Relatedness ($F1(1,35) = 6.67$, $p < .02$, MSE = 1736.98; $F2(1,444) = 4.72$, $p < .03$, MSE = 9043.52). The main effect of visual field was significant in the item analysis ($F2(1,444) = 16.91$, $p < .0001$, MSE = 6786.83) and approached significance in the subject analysis ($F1(1,35) = 3.26$, $p < .08$, MSE = 14666.33). Again planned comparisons included two baselines: the amount of semantic priming was calculated by subtracting RT for related targets from RT for unrelated targets. In addition, pure sentential priming was calculated by contrasting the reaction time for related targets presented in the subordinate-biased condition with those obtained in the unbiased condition.

The bottom panel of Fig. 1 shows the difference between RTs to related and unrelated targets in subordinate-biased contexts. As is evident from this figure, in both visual fields responses to targets related to both the contextually inappropriate dominant meaning and the contextually appropriate subordinate meaning were significantly facilitated relative to the unrelated conditions. (In the LVF, dominant: *by subjects*: $t(35) = 2.57$, $p < .02$; *by items*: $t(111) = 1.96$, $p = .05$; subordinate: *by subjects*: $t(35) = 5.59$, $p < .0001$; *by items*: $t(111) = 4.50$, $p < .0001$. In the RVF, dominant: *by subjects:* $t(35) = 4.02$, $p = .0003$; *by items*: $t(111) = 3.44$, $p < .001$; subordinate: *by subjects*: $t(35) = 7.09$, $p < .0001$; *by items*: $t(111) = 4.78$, $p < .0001$.)

The bottom panel of Fig. 2 shows the difference between RTs to dominant and subordinate targets presented after an unbiased (ambiguous) context and a context consistent with the subordinate meaning of the final homograph, in the two visual fields. As is evident from this figure, in both visual fields, both the dominant and subordinate meanings were significantly facilitated when the homograph was embedded in a context biased toward the subordinate meaning. (In the LVF, dominant: $F1(1,70) = 6.83$, $p < .02$, MSE = 2722.97; $F2(1,333) = 5.89$, $p < .02$, MSE = 10475.60; subordinate: $F1(1,70) = 15.83$, $p < .0002$, MSE = 3483.85; $F2(1,333) = 11.61$, $p = .0007$, MSE = 12864.98. In the RVF, dominant: $F1(1,70) = 12.39$, $p = .0008$, MSE = 1953.50; $F2(1,333) = 11.32$, $p = .0009$, MSE = 6608.08; subordinate: $F1(1,70) = 70.10$, $p < .0001$, MSE = 2183.43; $F2(1, 333) = 43.79$, $p < .0001$, MSE = 11123.80.)

4. Discussion

The present study utilized a divided visual-field priming paradigm to further investigate the extent to which each hemisphere uses lexical (frequency) and contextual sources of information during the processing of homographs. Hemispheric asymmetry was found in the absence of a biasing context: dominant meanings were exclusively activated in the LH, whereas both dominant and subordinate meanings were activated in the RH. Hemispheric symmetry was found in the presence of a biasing context: dominant meanings were exclusively activated in dominant-biasing contexts, whereas both dominant and subordinate meanings were activated in subordinate-biasing contexts, to the same extent in both visual fields. Taken together, these results indicate that both hemispheres are sensitive to lexical and contextual sources of information, however the LH may be more sensitive than the RH to the influence of lexical factors such as frequency or degree of salience.

As mentioned earlier, the majority of previous DVF studies addressing hemispheric involvement in ambiguity resolution have led to the conclusion that the main difference between the two hemispheres is in their ability to select a single alternative when encountering an ambiguous word. This "standard model" maximizes the LH ability. According to this model, the LH can use both lexical and contextual information, and therefore, in the absence of contextual bias, it quickly selects the salient, more frequent meaning (e.g., Burgess & Simpson, 1988), while in the presence of a biased prior context, it quickly selects the contextually appropriate meaning (e.g., Faust & Chiarello, 1998; Faust & Gernsbacher, 1996). The RH abilities, however, are minimized: it is viewed as insensitive to meaning salience or contextual information and therefore maintains alternate meanings regardless of their frequency or contextual appropriateness (e.g., Burgess & Simpson, 1988; Faust & Chiarello, 1998; Faust & Gernsbacher, 1996). The present results, however, indicate that this "standard model" suggests a much too strong, if not inaccurate, asymmetry. Instead, it may be posited that both hemispheres can use both lexical and contextual information during ambiguity resolution, at least 250 ms after the onset of an ambiguous word.

The goal of this study was to assess two major proposals of the "standard model". The first proposal is that during word processing, different ranges of meanings or semantic associates are activated in each hemisphere: narrow, focused meaning activation in the LH and weak, diffuse activation in the RH. Accordingly, subordinate, less salient meanings are more likely to be activated and maintained in the RH (Beeman, 1993, 1998). The second proposal is that the RH is less sensitive to sentence-level information (Faust, 1998; Faust & Kravetz, 1998). Accordingly, contextually inappropriate meanings are more likely to be activated and maintained in the RH.

The results of the present study are consistent with Beeman's view that subordinate, less salient meanings are more likely to be activated in the RH. Indeed, without contextual constraints, the data patterns in the RVF suggest that dominant meanings were activated exclusively in the LH. In contrast, the patterns in the LVF show that both dominant and subordinate meanings were activated in the RH. As such, these results are consistent with studies showing that after a short period of initial exhaustive activation, the LH suppresses weakly related meanings (e.g., Anaki et al., 1998; Burgess & Simpson, 1988), as well as studies showing initial selective activation of dominant meanings in the LH (Coney & Evans, 2000). Given the 250 SOA used in this study, it is clearly evident that meaning selection in the LH is indeed very fast. However, in order to determine whether the subordinate meaning was initially activated in the LH (as suggested by e.g., Burgess & Simpson, 1988) or not (as suggested by Coney & Evans, 2000), earlier SOAs are needed. This is currently being tested in our laboratory.

While LH meaning activation seems to be more sensitive to lexical factors such as frequency or degree of salience, it is obvious that frequency also plays a role in RH processing: dominant meanings are always activated regardless (or independent) of context, while subordinate meanings are activated only if they can be integrated with previous context. Thus, whereas both hemispheres activate dominant meanings automatically, they differ in their tendency to activate subordinate meanings: the RH activates subordinate meanings, unless previous context *does not allow* this interpretation. Alternatively, the LH activates subordinate meanings, only when previous context *requires* this interpretation.

As for hemispheric sensitivities to contextual information, our results do not support the hypothesis that the RH is insensitive to context. If the RH was insensitive to sentential context, then we would expect all meanings to be activated, irrespective of context condition. However the responses to the different context conditions in the LVF indicate that meaning activation in the RH is modulated by sentential context: dominant meanings were exclusively activated in dominant-biasing contexts, whereas both dominant and subordinate meanings were activated in subordinate-biasing contexts. Moreover, when compared with an unbiased condition, responses to subordinate targets were significantly faster following subordinate-biased contexts and significantly slower following dominant-biased contexts. Thus, in accordance with previous claims (e.g., Coney & Evans, 2000; Coulson et al., 2005; Federmeier & Kutas, 1999; Titone, 1998), these findings suggest that the RH is sensitive to sentential context.

It is important to note, however, that we examined sensitivity to semantic context. Therefore our results, like previous DVF findings examining this issue, pertain to the ability of the RH to use semantic and/or pragmatic constraints, and do not imply sensitivity to other levels of sentence processing (such as syntax). Because semantic contexts often include words that are semantically related to or associated with each other, it is also possible that the context effects obtained in our study are due to stronger semantic relations between the sentence and target words rather than message-level processes per se.

Diverging from previous studies using longer SOAs, that reported maintenance of contextually inappropriate meanings only in the RH (Faust & Chiarello, 1998; Faust & Gernsbacher, 1996), our results show that inappropriate *subordinate* meanings were not activated in the RH 250 ms after the onset of the ambiguous prime. Given our relatively short SOA (250 ms), it is impossible to determine whether the activation of inappropriate subordinate meanings was blocked, suppressed, or just delayed (this is currently being tested in our lab using both earlier and later SOAs). In any event, our results do support the conclusion that the RH *is* sensitive to prior semantic context. Moreover, we show that 250 ms after the onset of an ambiguous prime neither hemisphere is able to suppress *dominant* incompatible meanings. These findings converge with those reported by Titone (1998, Exp. 2) and Coney and Evans (2000), but do not exclude the possibility that hemispheric processing asymmetries will occur at later SOAs (as suggested by Faust & Chiarello, 1998; Faust & Gernsbacher, 1996).

To sum up, our results suggest that both context and meaning salience affect meaning activation in the two hemispheres. The activation of dominant meanings in both hemispheres seems to be the outcome of an automatic lexical process that occurs ballistically, independently of context. The activation of subordinate meanings seems to be more dependent on sentential context; in the LH, subordinate meanings seem to be accessed only if they are predicted by the context (as in the context biased toward the subordinate meaning of the ambiguous word). In the RH, lexical processes activate the subordinate meanings whenever they are not ruled out by the context (i.e., subordinate meanings were available in both the neutral and in the context biased toward the subordinate meaning of the ambiguous word). As a result, subordinate, less salient meanings of words are more likely to be activated and maintained in the RH than in the LH.

Beyond hemispheric differences, these results have important implications for general models of ambiguity resolution. Contrary to the predictions of the direct-access models, suggesting that a strong context can selectively activate one meaning, regardless of frequency, we show that *both* context and frequency influence the retrieval of word meanings (for a similar argument see Twilley & Dixon, 2000). Importantly, in agreement with hybrid models, such as the Reordered model or the Graded Salience Hypothesis, we show that context can enhance activation of the contextually appropriate meaning, but it cannot inhibit the contextually inappropriate meaning, if it is very frequent or salient. Thus, 250 ms after the onset of an ambiguous word, dominant, highly salient frequent meanings are still activated in both hemispheres, even when they are highly incompatible with previous context. A shorter SOA is needed, however, in order to show if both factors exert their influence immediately, as suggested by the hybrid models mentioned above, or only after an initial exhaustive stage as suggested by "two-stage" models.

The overall picture that emerges from the present results is that hemispheric processes may be more similar than assumed earlier. It seems that both hemispheres have access to the same sources of information (lexical and contextual constraints); however, these may be used differently, and with different temporal stages (for a similar argument, see Coulson et al., 2005). We show that the cerebral hemispheres do not differ in their access to the dominant meanings of polarized ambiguous words, and that these are accessed in both hemispheres. The difference emerges in the ease of activation of subordinate meanings, where the LH *tends not to activate and/or maintain* subordinate meanings unless previous context strongly requires them. In contrast, the RH *tends to activate and maintain* subordinate meanings unless they are ruled out by context inviting the dominant meaning of the word. Thus, the differences between the hemispheres will be more pronounced in unbiased (as in our study) or in a weakly biased context, as shown by Titone (1998, Exp. 3).

These patterns tie in with clinical, neuropsychological findings that testify to the involvement for both hemispheres in ambiguity resolution (Grindrod & Baum, 2003). The LH tendency to select the salient, dominant meaning of an ambiguous word makes it fast, and in most cases, accurate. However, it is less efficient than the RH when a subordinate, less salient interpretation is required. Alternatively, the RH tendency to activate less salient, subordinate meanings alongside the dominant meanings makes it less efficient than the LH in selecting a single alternative, but extremely efficient in situations that require consideration of the less salient meaning. In addition, the idea that RH processing reflects a different pattern of interaction between contextual and lexical information rather than insensitivity to these sources of information, converges with many studies showing RH involvement in comprehending the full meaning of words, phrases and text (e.g., Bihrle, Brownell, & Gardner, 1986; Bottini et al., 1994; Brownell, Michel, Powelson, & Gardner, 1983; Brownell et al., 1986; Brownell et al., 1990; Coulson & Williams, 2005; Eviatar & Just, 2006; Federmeier & Kutas, 1999; Giora, Zaidel, Soroker, Batori, & Kasher, 2000; Joanette, Goulet, & Hannequin, 1990; Kuperberg et al., 2000; Mashal, Faust, & Hendler, 2005; McDonald, 1996; McDonald, 1999). Taken together, the results of the present study suggest a more coherent picture of how both hemispheres make their unique and critical contribution to language comprehension. Further research is needed to fully explore the mechanisms underlying these observed hemispheric patterns.

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