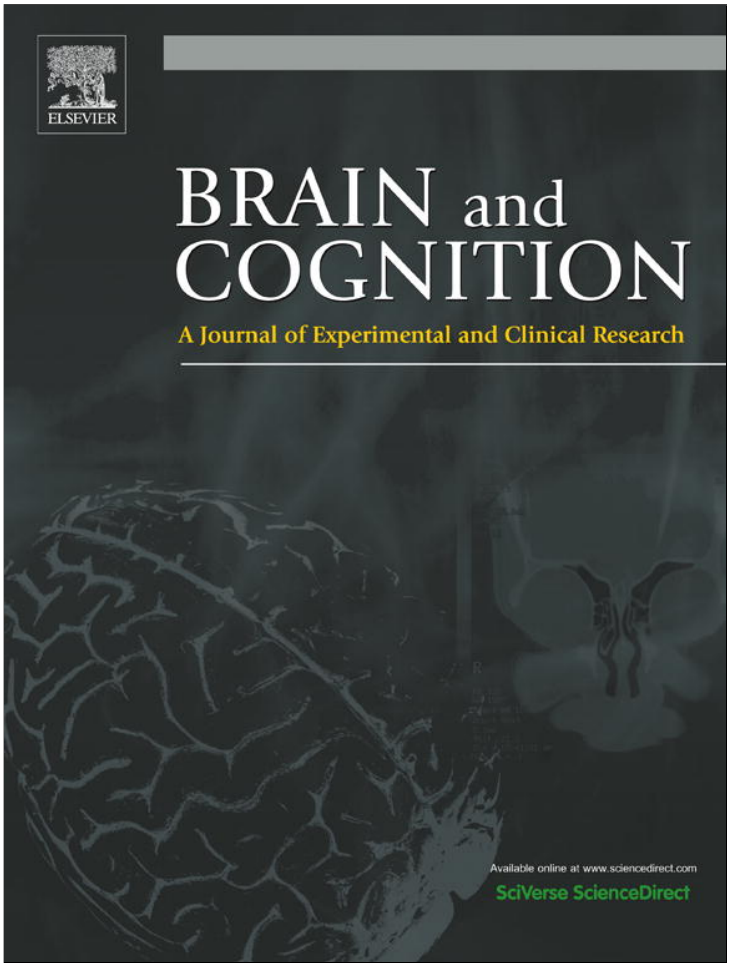

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Hemispheric asymmetries in meaning selection: Evidence from the disambiguation of homophonic vs. heterophonic homographs

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ABSTRACT

Research investigating hemispheric asymmetries in meaning selection using homophonic homographs (e.g., *bank*), suggests that the left hemisphere (LH) quickly selects contextually relevant meanings, whereas the right hemisphere (RH) maintains a broader spectrum of meanings including those that are contextually irrelevant (e.g., Faust & Chiarello, 1998). The present study investigated cerebral asymmetries in maintaining the multiple meanings of two types of Hebrew homographs: homophonic homographs and heterophonic homographs (e.g., *tear*). Participants read homographs preceded by a biasing, or a non-biasing sentential context, and performed a lexical decision task on targets presented laterally, 1000 ms after the onset of the sentence-final ambiguous prime. Targets were related to either the dominant or the subordinate meaning of the preceding homograph, or unrelated to it. When targets were presented in the LVF/RH, dominant and subordinate meanings, of both types of homographs, were retained only when they were supported by context. In a non-biasing context, only dominant meanings of homophonic homographs were retained. Alternatively, when targets were presented in the RVF/LH, priming effects for homophonic homographs were only evident when meanings were supported by both context and frequency (i.e., when context favored the dominant meaning). In contrast, heterophonic homographs resulted in activation of dominant meanings, in all contexts, and activation of subordinate meanings, only in subordinate-biasing contexts. The results challenge the view that a broader spectrum of meanings is maintained in the right than in the left hemisphere and suggest that hemispheric differences in the time course of meaning selection (or decay) may be modulated by phonology.

1. Introduction

Reading ambiguous words confronts the reader with the challenge of accessing and selecting from multiple semantic representations based on a single orthographic representation. The conflict between multiple representations is often resolved by relying on both lexical (e.g., degree of meaning dominance) and contextual (e.g., previous semantic information) sources of information (e.g., Duffy, Morris, & Rayner, 1988; Giora, 2003; Peleg, Giora, & Fein, 2001, 2004, 2008; Titone, 1998). Thus, whereas one's previous experience with one of the meanings of an ambiguous word (e.g., the monetary, institutional meaning of *bank*) may render that meaning more accessible, the immediate context may bias our interpretation towards any of the meanings of the word.

Research using the divided visual field (DVF) technique has led to the conclusion that the two hemispheres differ in the way they deal with lexical and contextual factors during ambiguity resolution (Burgess & Simpson, 1988; Faust & Chiarello, 1998; Faust & Gernsbacher, 1996). According to these studies, when ambiguous words are encountered, multiple meanings are available immediately in the left hemisphere (LH), but shortly afterwards, one meaning is selected on the basis of relative dominance and/or contextual information. The right hemisphere (RH), on the other hand, activates all meanings more slowly and maintains these meanings irrespective of context or dominance.

Numerous attempts have been made to account for such differential hemispheric patterns. The fine-coarse coding hypothesis postulates that the LH uses a fine semantic coding to quickly select relevant meanings, while the RH uses a coarse semantic coding scheme in which it weakly activates (and maintains) a broad spectrum of meanings, including subordinate or contextually irrelevant meanings (e.g., Beeman, 1998; Jung-Beeman, 2005). According to the "message-blind RH" model (e.g., Faust, 1998) the LH is sensitive to sentence level context, while the RH primarily processes word level meaning and is therefore less able to use sentential information for selection. Similarly, Gernsbacher and her colleagues (e.g., Faust & Gernsbacher, 1996) suggest that the RH lacks selection mechanisms. Finally, it was proposed that the RH is

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simply slower (Burgess & Lund, 1998): Because activation processes are slower, selection processes start later. As a result, alternative meanings are maintained for a longer period of time in the RH than in the LH.

Rather than focusing on semantic differences, we have recently suggested (Peleg & Eviatar, 2009, 2012) that asymmetries in accessing the multiple meanings of homographs can be explained more parsimoniously by hypothesizing a difference in the functional architecture of orthography/phonology relations between the hemispheres. Building on previous work (e.g., Halderman & Chiarello, 2005; Lavidor & Ellis, 2003; Marsolek, Kosslyn, & Squire, 1992; Marsolek, Schacter, & Nicholas, 1996; Zaidel, 1982; Zaidel & Peters, 1981), we postulated that both hemispheres can process print visually via orthographic-semantic connections, but that orthographic-phonological connections are available only to the LH. In principle, two are better than one; since in the LH meanings can be accessed both visually and phonologically; it is usually faster and more accurate.

Previous studies have focused mainly on homophonic homographs (a single orthographic and phonological representation associated with multiple meanings, such as *bank*). The unvowelled Hebrew orthography offers an opportunity to examine other types of homographs as well. In Hebrew, letters represent mostly consonants; vowels can optionally be superimposed on consonants as diacritical marks. Since the vowel marks are usually omitted, Hebrew readers frequently encounter not only homophonic homographs, but also heterophonic homographs (a single orthographic representation associated with multiple phonological codes, each associated with a distinct meaning, such as *tear*). Both types of homographs have one orthographic representation associated with multiple meanings. They are different however, in terms of the relationship between orthography and phonology.

According to our proposal, when orthographic and phonological representations are unambiguously related as in the case of homophonic homographs such as *bank*, in the LH, meaning activation should be faster than in the RH, because all related meanings are immediately boosted by both orthographic and phonological sources of information. In the RH, meanings are initially activated only via orthography and as a result meanings may be activated more slowly. However, when a single orthographic representation is associated with multiple phonological representations as in the case of heterophonic homographs such as *tear*, meanings may be activated more slowly in LH than in the RH, because the immediate activation of phonology from orthography in the LH results in competition between the different phonological alternatives. In the RH, because orthographic representations are not directly connected to phonological representations, meaning activation is not initially affected by phonological ambiguity.

In accordance with this proposal, we have previously shown (Peleg & Eviatar, 2008, 2009) that hemispheric differences in the onset of meaning activation can be modulated by the phonological status of the homograph. In these studies, a divided visual field technique was employed in conjunction with the lexical-priming paradigm. Participants read sentences that ended in either a homophonic or a heterophonic homograph and performed a lexical decision task on targets presented laterally (either to the left visual field (LVF) or to the right visual field (RVF)), 150 ms or 250 ms after onset of the final homograph (stimulus-onset asynchrony (SOA)). Sentential contexts were either biased towards one of the meanings of the final homograph, or unbiased. Targets were either related to one of the meanings of the ambiguous prime, or unrelated. The two types of homographs were equated in terms of length, degree of frequency, degree of polarization, degree of relatedness to the different sentential contexts, and degree of relatedness to the different targets (for details, see Peleg & Eviatar, 2009). Translated examples are presented in Table 1.

Results indicated that homophonic and heterophonic homographs, which diverge on how their meanings are related to phonology, were processed differently in the LH, whereas, in the RH, similar patterns were obtained for both types of homographs.

Overall, both hemispheres revealed sensitivity to both frequency and context: Irrespective of target location (RVF or LVF) or homograph type, dominant (frequent) and/or contextually appropriate meanings were activated faster and were also more likely to be maintained in comparison to less frequent and/or contextually inappropriate meanings. The phonological status of the homograph affected the activation of the less-frequent and/or the contextually inappropriate meaning of the homograph. In the case of homophonic homographs, these meanings were activated faster in the LH than in the RH. Specifically, when contexts were kept neutral, subordinate (less-frequent) meanings were activated earlier (150 ms SOA) in the LH than in the RH (250 ms SOA). In contrast, in the case of heterophonic homographs these meanings were activated more slowly in the LH than in the RH. Specifically, when contexts favored the subordinate meaning, dominant inappropriate meanings were available earlier in the RH (150 ms SOA) than in the LH (250 ms SOA).

Importantly, these earlier asymmetries in meaning activation may result in later asymmetries in meaning selection (the point in time in which the less frequent or the contextually inappropriate meaning is rendered inactive through attentional withdrawal, suppression, or decay). Given the short SOA's (150–250 ms) used in our previous studies, selection processes were evident only when contexts were kept neutral, only in the case of homophonic homographs, and only in the LH. In this condition, less frequent meanings were activated faster in the LH. As result, at an earlier (150 ms) SOA, both dominant and subordinate meanings were available in the LH, whereas only dominant meanings were available in the RH. However, 100 ms later, subordinate meanings were no longer activated in the LH, but were available, together with dominant meanings, in the RH. Thus, consistent with previous proposals (e.g., Burgess & Simpson, 1988), in the case of homophonic homographs presented in neutral (unbiased) contexts, both activation and selection processes were faster in the LH than in the RH.

Given that, heterophonic homographs revealed a different pattern of meaning activation, the present study aimed to examine whether selection processes can also be modulated by the phonological status of the homograph. On the basis of our previous findings we hypothesized that when less frequent or contextually inappropriate meanings are activated later in one hemisphere compared to the other hemisphere, selection (or decay) processes may start later as well. Thus, in the case of homophonic homographs, alternative meanings are more likely to be available at a later point in time in the RH than in the LH (as shown in our previous studies). However, in the case of heterophonic homographs, opposite patterns are expected. Specifically, our previous findings indicated that in the subordinate-biasing condition, while the subordinate contextually appropriate meaning was available immediately in both VFs and for both types of homographs, the activation of the dominant inappropriate meaning differed: In the case of homophonic homographs, dominant inappropriate meanings were activated immediately in both hemispheres. However, in the case of heterophonic homographs, they were activated more slowly in the LH (250 ms SOA) than in the RH (150 ms SOA). Nevertheless, both meanings were available at 250 ms SOA, irrespective of target location (RVF/LH or LVF/RH) or homograph type. Given that activation of the dominant but contextually inappropriate meaning of heterophones was faster in the RH than in the LH, we ask whether selection processes in this case will also be faster in the RH than in the LH.

The purpose of the present study was therefore to obtain priming effects of homophonic versus heterophonic homographs in the

Table 1
Translated examples of stimuli.

Homograph type	Sentence context	Homograph	Pronunciation	Target words
Homophonic homograph	Unbiased: They looked at the Dominant: The buyers signed the Subordinate: The Children of Israel listened to the	חוזה Contract/Seer	/XOZE/	Dominant-document Subordinate-prophet
Heterophonic homograph	Unbiased: The young man looked for the Dominant: The students were asked to buy the Subordinate: The bride made an appointment with the	ספר Book/Hairdresser	/SEFER/ /SAPAR/	Dominant-reading Subordinate-hair

two hemispheres by using a longer, 1000 ms SOA. On the basis of our previous findings, we predicted that asymmetries in meaning selection will be modulated by the phonological status of the homograph; In the case of homophonic homographs multiple meanings are more likely to be maintained in the RH than in the LH (as shown in our previous studies). In contrast, in the case of heterophonic homographs, we expected multiple meanings to be available in the LH but not in the RH, when embedded in a subordinate biasing context.

To test this prediction, we compared response times to related target words that were either consistent or inconsistent with the contextual bias, to response times to unrelated targets. Specifically, in the subordinate biasing condition, we expected targets related to the dominant, but contextually inappropriate, meanings of heterophones (but not homophones), to be facilitated in the RVF/LH but not in the LVF/RH. This prediction is in clear contrast with previous accounts suggesting that the LH is more likely to select the contextually consistent meaning, regardless of meaning frequency (e.g., Faust & Chiarello, 1998).

2. Method

2.1. Participants

Forty undergraduate students, aged 20–29 (mean age = 23.9, SD = 1.67). Eighteen males and 22 females participated in the study. They were all healthy, right handed, native speakers of Hebrew with normal vision. Handedness was assessed with the Edinburgh Handedness Questionnaire (Oldfield, 1971), with 80 as the cutoff point.

2.1.1. Stimuli

Materials are the same as those used in our previous studies, where a 150 and a 250 SOA were employed (Peleg & Eviatar, 2008, 2009). These include a total of 112 noun–noun polarized Hebrew homographs (56 homophonic and 56 heterophonic) which were used as primes (see Tables A1 and A2). Since in Hebrew there is no extensive database for word frequency that includes all the homographs used in this experiment, a pretest tested subjective frequency (overall word-form dominance). Fifty judges, who did not participate in the experiment, were presented with the list of homographs and asked to rate their degree of frequency on a 10 point frequency scale ranging from zero (never encountered) to nine (highly frequent). The average rates on the frequency scale were 7.3 and 7.4 for homophones and heterophones, respectively ($p > .6$). Four additional pretests established the degree and direction of polarity. Overall, the selected homograph corpus was polarized with the dominant meaning being chosen with a mean of 84% (homophones: 83% heterophones: 85%).

For each homograph, two target words were selected: one related to the dominant meaning and the other to the subordinate meaning. Unrelated targets were constructed by randomly re-pairing related primes and targets. Thus each homograph was paired with two related and two unrelated target words. Related targets were equated in terms of degree of semantic relatedness with their paired homographs. Targets were also equated in terms of their accessibility (lexical decision latencies) and length.

In addition, for each homograph, three sentence contexts were constructed, each preceding the final homograph: an unbiased, neutral context, one biased toward the dominant meaning, and another biased toward the subordinate meaning. Degree of relationship between biased sentences and their final ambiguous word was pre-tested. An analysis of variance revealed no significant difference between dominant and subordinate biasing contexts ($p > .2$). In addition, biasing contexts were rated significantly higher than unbiasing contexts (all $p < 0.001$). Translated examples of the stimuli are shown in Table 1.

2.1.2. Apparatus

Stimulus presentation and responses were controlled and recorded by a Dell GX-260 PC P4-1800-14H. An adjustable chin-rest kept participants at a fixed viewing distance from the computer screen (57 cm). Stimuli, constructed from characters presented in Arial font (size 20), were colored white and displayed on a gray colored screen. To ensure central fixation, participants' eye position was monitored using an ASL5000 eye-tracking system (Applied Science Laboratories).

2.1.3. Experimental design and procedures

The experiment used a 2 (homograph type: homophonic or heterophonic) × 3 (context type: biasing toward the dominant or the subordinate meaning or unbiasing) × 2 (target dominance: dominant or subordinate) × 2 (target relatedness: related or unrelated) × 2 (target location: LVF or RVF) within participants design. There were 2688 experimental permutations for the target words (56 × 2 types of 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 participants. Cell means are based on 14 experimental trials per condition per participant. Each list contained 112 experimental sentences (ending in homographs) which were paired with word targets and 112 sentence fillers that were paired with nonword targets (224 trials in total). Participants were randomly assigned to six experimental lists (two for each context condition). Each homograph appeared only once per list (six times total and the six 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 participants. In order to complete their assigned lists, each participant completed three experimental sessions (two 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.

Participants 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. Stimuli subtended a maximum of 2.5° of visual angle. 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, participants 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 all 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 850 ms ISI (1000 ms SOA), the target string was presented for 150 ms to the LVF or RVF for a lexical decision response.

Participants 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. The data collected for each subject included RT for target words and error rates for all conditions.

3. Results

Four participants were replaced because they failed to complete all three experiment sessions. Six items were excluded from the analysis due to over 50% overall error rate. The reported results are based on 106 items: 53 homophones and 53 heterophones. Cutoff response times of 200 ms for anticipations, and 2000 ms for late responses were used. No data were deleted due to these cutoffs. In addition, trials in which the ASL eye-tracker registered a shift in the participants' gaze of more than 1.5 cm. (corresponding to 1.5° of visual angle) from the central fixation point at the time of the target word onset were excluded from the sample. Analyses of RTs were based on participants' mean RT to correct responses (a total of 18.2% of trials were excluded due to incorrect response (11.1%) and fixation problems (7.1%)).

The data were analyzed using a linear mixed effects (LMEs) model (Baayen, Davidson, & Bates, 2008). This computation allows the testing of hypotheses while taking into account the variance due to participants and to items simultaneously. The model was constructed for the analysis with the effects of Type of Sentential Context (dominant-consistent, subordinate-consistent or unbiasing), Type of Homograph (homophonic or heterophonic), Target Dominance (dominant or subordinate), Target Relatedness (related or unrelated) and Visual Field (RVF or LVF) as fixed factors, and the effects of Item, and Subject as random factors on the reaction times (RTs) to the targets. The preliminary analysis using a distribution created by the Markov Chain Monte-Carlo (MCMC) method with 10,000 samples showed that the task was in general, well behaved: there was a significant overall main effect of VF (responses in the RVF were 16 ms faster than the LVF, $p < 0.0001$); a significant overall main effect of Target Relatedness (responses to related targets were 27 ms faster than to unrelated targets, $p < .0001$); and a significant overall main effect of Target Dominance (responses to targets related to the more frequent, dominant meaning were 22 ms faster than to targets related to the less frequent, subordinate meaning, $p < .0001$).

The use of 5 fixed factors in our model was proven to be justified by comparing the prediction power of all 4-way, 3-way and 2-way interaction models, as well as that of a model which included only the main effects of the fixed factors to that of the 5-way interaction model. The comparison showed that the 5-way interaction model had a significantly greater prediction power than the other combinations ($\chi^2 = 5.88$, $p = .053$). The 5-way interaction was examined using a distribution created by the Markov Chain Monte-Carlo (MCMC) method with 10,000 samples, and was shown to be significant, $p < .05$. The Mean RT, SDs, and error rate in all conditions are presented in Table 2.

The same analyses done on error scores, using the binomial distribution, revealed the same main effects: of Visual Field, $p < .0001$, with responses in the RVF 27.23% more accurate than in the LVF; of Target Relatedness, $p < .0001$, with responses to related targets 42.25% more accurate than on unrelated targets; of Target Dominance, $p < .0001$, with responses to targets related to the dominant meaning of the homographs 32.70% more accurate than to targets related to the subordinate meaning of the homographs. The test of

Table 2
Mean correct RT (in ms) computed over participants, as a function of visual field, sentence context, and target type, presented separately for each homograph type.

Visual field		LVF/RH			RVF/LH		
Sentence context		Dominant biased	Unbiased	Subordinate biased	Dominant biased	Unbiased	Subordinate biased
A. Heterophonic homographs							
Dominant target	Related	801 (145)	824 (136)	822 (170)	783 (126)	799 (151)	799 (142)
		3.6%	4.6%	5.7%	2.7%	3.4%	4.6%
	Unrelated	840 (133)	828 (136)	840 (168)	851 (155)	841 (157)	829 (159)
		9.1%	8.2%	9.3%	7.5%	10.5%	7%
Subordinate target	Related	872 (170)	829 (148)	813 (143)	847 (151)	819 (127)	806 (178)
		10.7%	8.4%	4.3%	9.1%	6.1%	5%
	Unrelated	876 (158)	848 (148)	864 (162)	833 (129)	837 (151)	847 (141)
		9.6%	10.4%	10.2%	9.3%	8.9%	6.1%
B. Homophonic homographs							
Dominant target	Related	808 (131)	816 (132)	837(167)	792 (126)	817 (160)	823 (155)
		4.3%	8.2%	7.3%	3.4%	5.7%	4.3%
	Unrelated	853 (152)	867 (168)	830 (138)	827 (125)	828 (150)	843 (172)
		8.2%	10.2%	8.8%	7.1%	6.8%	6.1%
Subordinate target	Related	873 (149)	858 (153)	807 (142)	854 (158)	835 (155)	821 (164)
		9.8%	8.8%	5.7%	9.1%	7.3%	3.8%
	Unrelated	880 (157)	853 (165)	898 (182)	865 (157)	854 (137)	836 (150)
		13.6%	10.4%	12.1%	7%	8.9%	11.1%

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

prediction power showed that a 3-way interaction is sufficient to obtain the greatest prediction power than the other models ($\chi^2 = 57.49$, $p < 0.0005$).

Correlations between RTs and error rates revealed no speed-accuracy tradeoffs. Because our main hypotheses are about the speed and efficiency of semantic access, we present our findings in terms of priming for RT in each of the sentential context conditions. We computed degree of priming by subtracting RT for related targets from RT for unrelated targets in each condition, for correct responses. These data are presented in Fig. 1.

3.1. Unbiasing (ambiguous) context

The top panel of Fig. 1 shows the magnitude of priming to targets presented after heterophonic and homophonic homographs in the two visual fields (LVF/RH -left panel, RVF/LH-right panel). It is evident from these graphs that for LVF target presentation, only responses to dominant targets of homophonic homographs were significantly facilitated relative to the unrelated conditions, $p < .05$. In contrast, for RVF target presentation, only responses to dominant targets of heterophonic homographs were significantly facilitated relative to the unrelated conditions, $p < .01$.

These results indicate that when homographs are embedded in an unbiasing (ambiguous) context, only the dominant meaning remains activated 1000 ms after homograph presentation. However location is different for the two types of homographs: In the case of homophonic homographs dominant meanings are maintained in the LVF/RH, while in the case of heterophonic homographs, dominant meanings are maintained in the RVF/LH.

3.2. Dominant biasing contexts

The middle panel of Fig. 1 shows the magnitude of priming to targets presented after heterophonic and homophonic homographs in the two visual fields (LVF/RH-left panel, RVF/LH-right panel). It is evident from these graphs that responses to targets related to the contextually appropriate, dominant meaning of the final homograph were significantly facilitated, irrespective to homograph type (homophonic or heterophonic) or target location, $p < .05$. Conversely, responses to subordinate targets

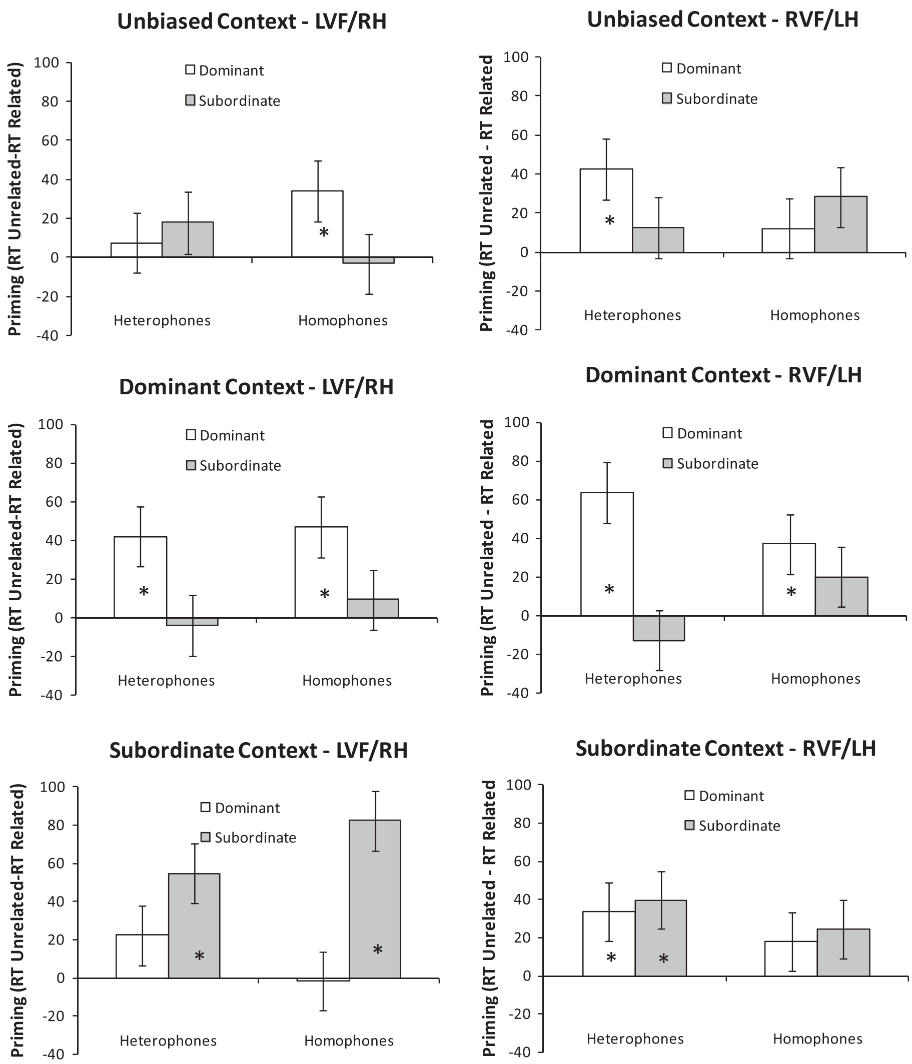

Fig. 1. Magnitude of priming in ms (mean difference: RT-unrelated – RT-related) for target words, presented separately for each visual field (LVF/RH-left panel, RVF/LH-right panel) and for each context condition: unbiased (top panel), dominant-biased (middle panel); or subordinate-biased (bottom panel). *Significant, $p < .05$. Error bars indicate standard errors.

were not significantly facilitated in any of the conditions ($p > .32$).

3.3. Subordinate biasing contexts

The bottom panel of Fig. 1 shows the magnitude of priming to targets presented after heterophonic and homophonic homographs in the two visual fields. It is evident from these figures that for LVF target presentation (left panel), only responses to subordinate targets were significantly facilitated relative to the unrelated conditions, irrespective of homograph type (homophonic homographs: $p < 0.001$; heterophonic homographs: $p < 0.001$).

In contrast, for RVF target presentation (right panel), we see a different pattern of responses for the two types of homographs: In the case of homophonic homographs, responses to targets related to both the dominant and the subordinate meaning were not significantly facilitated relative to the unrelated conditions, $p > .10$. Alternatively, for heterophonic homographs, targets related to both the contextually appropriate subordinate meaning and to the inappropriate dominant meaning were primed significantly, $p < .05$.

4. Discussion

Research investigating hemispheric asymmetries in meaning selection has suggested that the left hemisphere (LH) uses a fine semantic coding to quickly select relevant meanings, while the right hemisphere uses a coarse semantic coding scheme in which it weakly activates a broad spectrum of meanings (e.g., Jung-Beeman, 2005). According to this proposal, when readers encounter an ambiguous word, the LH quickly selects the appropriate meaning, while the RH does not select.

In contrast, we suggest that asymmetries in meaning activation and selection can be explained more parsimoniously by hypothesizing a difference in the functional architecture of orthography/phonology relations between the hemispheres. Specifically, we propose that while orthographic, phonological and semantic representations are fully interconnected in the left hemisphere (as suggested by the triangle model propose by Seidenberg and McClelland (1989)), there is no direct link between orthographic and phonological representations in the right hemisphere (e.g., Halderman et al., 2005). According to this proposal, asymmetries in the time course of meaning selection (or meaning decay) are modulated by phonology.

The results of the present study indicate that ambiguity resolution depends on both contextual processes (e.g., prior semantic information) and lexical processes sensitive to experiential familiarity (e.g., frequency of occurrence, or dominance). Both processes occur in both hemispheres. As a result, in both hemispheres, contextually appropriate and/or dominant meanings are more likely to remain active, while inappropriate and/or subordinate meanings are more likely to decay. However, as predicted, contextual and lexical processes may have differential effects for the two types of homographs.

In the case of polarized heterophonic homographs, contextually appropriate meanings are always retained, irrespective of VF of presentation. Frequency effects, however, are *more* pronounced in the LH than in the RH. As seen in Fig. 1, in the RVF/LH, dominant (more frequent) meanings were activated in all context conditions. This is because frequency affects both phonological and semantic representations. In contrast, in the RH, only semantic frequency affects lexical access, and its effect is therefore weaker. As a result, dominant meanings are retained only when they are supported by context. Thus, contrary to previous accounts (e.g., Jung-Beeman, 2005), when contexts favor the subordinate meaning, dominant inappropriate meanings are retained in the LH but not in the RH.

In the case of polarized homophonic homographs, context and frequency effects are *less* pronounced in the LH than in the RH. This is because the common phonological representation of the homograph supports both meanings, irrespective of context or frequency. As can be seen in Fig. 1, in the LH, priming for homophones is only evident when meaning is supported by both context and frequency (i.e., when context favors the dominant meaning, see Fig. 1, right panel). In the RH, context and frequency effects are stronger. Thus, when contexts are biased, only the contextually appropriate meaning is retained; and when contexts are kept neutral, only the dominant (more frequent) meaning is maintained (see Fig. 1, left panel).

Consistent with our previous findings, similar patterns were obtained for both types of homographs in the LVF/RH, when context was provided. Interestingly, however, when context was kept neutral, frequency effects were stronger for homophones than for heterophones (see Fig. 1, top left panel). Given that we hypothesize no connections between orthography and phonology in the RH, this result is unexpected. One possible explanation may be related to the long SOA used, which allows us to see interhemispheric interaction, resulting in a division of labor. Although, in both hemispheres, only the dominant meaning is retained, it can be seen in the two upper panels of Fig. 1, that when dominant meanings are still available in the LH (for heterophones), they are no longer primed in the RH, whereas when dominant meanings are no longer available in the LH (for homophones), they are still primed in the RH. Although we have replicated this complementarity in a study using semantic decisions, under similar conditions (neutral context, long SOA), further research is necessary in order to clarify the mechanism by which this occurs.

The results of the present experiment, together with our previous experiments using short SOAs, show that hemispheric differ-

Table 3
Summary of priming results as a function of Homograph Type (homophone, heterophone); Target Visual Field (RVF/LH, LVF/RH); SOA (150 ms, 250 ms, 1000 ms); and Sentential Context (unbiased, dominant-biasing, subordinate-biasing).

Type of homograph:	Homophonic Homographs						Heterophonic Homographs					
Visual Field	LVF/RH			RVF/LH			LVF/RH			RVF/LH		
SOA (in ms)	150	250	1000	150	250	1000	150	250	1000	150	250	1000
Unbiased contexts	Dom	Dom Sub	Dom	Dom Sub	Dom	–	Dom	Dom Sub	–	Dom	Dom	Dom
Dominant biasing contexts	Dom	Dom	Dom	Dom	Dom	Dom	Dom	Dom	Dom	Dom	Dom	Dom
Subordinate biasing contexts	Dom Sub	Dom Sub	Sub	Dom Sub	Dom Sub	–	Dom Sub	Dom Sub	Sub	Sub	Dom Sub	Dom Sub

Dom = significant priming for target words related to the dominant meaning of the homograph; Sub = significant priming for target words related to the subordinate meaning of the homograph.

ences in the onset of meaning activation predict later asymmetries in meaning selection. Importantly, both processes are modulated by the phonological status of the homograph. A summary of these patterns is presented in Table 3.

In the case of *homophonic homographs*, both activation and selection/decay processes may be faster in the LH than in the RH. Specifically, in neutral contexts, we have shown (Peleg & Eviatar, 2008, 2009) that both meanings were activated immediately in the LH (150 ms SOA). However shortly afterwards (250 ms SOA), the dominant, more frequent meaning remained active, while the subordinate less frequent one decayed. In the present study, at a 1000 SOA, we see no priming effects for either meaning. In contrast, in the RH, less-frequent meanings were activated more slowly, and were therefore available at a later point in time (250 ms SOA). Interestingly, the results of the present experiment reveal that at an even later point in time (1000 ms SOA) the dominant meaning was still active, while the subordinate meaning was not. Essentially, the RH at the 1000 ms SOA shows the same pattern as the LH at the 250 ms SOA (Peleg & Eviatar, 2012).

Alternatively, in the case of *heterophonic homographs*, both activation and selection/decay processes may be faster in the RH than in the LH. Specifically, when contexts were biased towards the subordinate less-frequent meaning, multiple meanings were activated immediately in the RH (150–250 ms SOA). However at 1000 ms SOA, only the contextually appropriate meaning remained active, whereas the inappropriate was not. In contrast, in the LH, contextually inappropriate meanings were activated more slowly (250 ms SOA) and were still available at a later point in time (1000 ms SOA). This stands in clear contrast with previous accounts suggesting that the LH is more likely to select the contextually appropriate meaning, regardless of meaning frequency (e.g., Faust & Chiarello, 1998).

Taken together, our results indicate that when less frequent and/or contextually inappropriate meanings are activated later in one hemisphere compared to the other hemisphere, selection (or decay) processes may start later as well. As a result, in the case of homophonic homographs, these meanings are more likely to be available at a later point in time in the RH, whereas in the case of heterophonic homographs, these meanings are more likely to be available at a later point in time in the LH. These reverse asymmetries in the time course of meaning activation and decay can only be explained by taking into account phonological asymmetries.

Thus, rather than assuming differences in the scope of meaning activation (e.g., Jung-Beeman, 2005), or in the processes involved in meaning selection (e.g., Copland, Chenery, & Murdoch, 2002; Faust & Chiarello, 1998; Faust & Gernsbacher, 1996), we propose that hemispheric differences in the links between orthographic and phonological representations underlie hemispheric asymmetries in meaning selection. This proposal not only explains existing data based on homophonic homographs, but also accounts for reverse asymmetries in the disambiguation of heterophonic homographs.

It is important to note that previous hemispheric models of ambiguity resolution were based on studies (including studies conducted in Hebrew) which focused mainly on homophonic homographs. In order to test our model against other models, we take advantage of the fact that in Hebrew, vowels are mostly deleted so that heterophonic homographs are as common as homophonic homographs. Importantly, with regards to homophonic homographs, our results (e.g., Peleg & Eviatar 2008, 2009) and other studies that have been done in Hebrew (e.g., Faust & Chiarello, 1998) have shown similar patterns to studies done in English (e.g., Burgess & Simpson, 1988). The fact that the results differ for heterophones, we believe, has to do with hemispheric differences in orthography-phonology relations, not with Hebrew-specific characteristics. Thus, although Hebrew differs on many levels from English (see Eviatar, 1999 for a detailed discussion of these differences), we expect to find similar patterns for heterophones in English and in Hebrew. This study is currently being done in our lab.

In sum, our findings suggest that both hemispheres have access to both lexical and contextual sources of information; however, as a result of the differences in the links between orthographic and phonological representations these may be used differently, and at different temporal stages. A similar view is presented in Federmeier's "Production Affects Reception in Left Only" (PARLO) framework which emphasizes differences in the links between conceptual and lexical representations (Federmeier, 2007). According to this model, because language comprehension and production share resources only in the LH, connections between lexical and conceptual representations in the LH are bi-directional, whereas in the RH, information only flows forward from the lexical to the conceptual level. Thus, although both hemispheres have access to both lexical and contextual sources of information, these may be used at different temporal stages: Feedback connections in the LH allow for early use of contextual information and predictions of meanings, whereas feed-forward connections in the RH allow for integration of meanings in later processing stages. Indeed, in accordance with this proposal our previous findings (with short SOAs) showed that contextual processes (activation of less frequent but contextually appropriate meanings) may precede lexical processes (activation of frequent but contextually inappropriate meaning) in the LH, but not in the RH (Peleg & Eviatar, 2008, 2009). Moreover, beyond asymmetries in lexical-conceptual connections, "Production Affects Reception in Left Only" can also explain hemispheric differences in the links between orthography and phonology: Given that speech production (e.g., reading aloud) is mediated by the LH, orthographic-phonological connections are more likely to be established in the LH than in the RH.

We thus propose that RH processing reflects a different pattern of interaction between orthographic, phonological, and semantic information, rather than, as suggested by other models, lower sensitivity to lexical and contextual constraints. This view of RH abilities converges with many neuropsychological studies, both behavioral and imaging studies, showing RH involvement in comprehending the full meaning of words, phrases, and texts (e.g., Coulson & Williams, 2005; Eviatar & Just, 2006; Federmeier & Kutas, 1999; Giora, Zaidel, Soroker, Batori, & Kasher, 2000; Mashal, Faust, & Hendler, 2005; McDonald, 1996, 1999).

It is clear that during normal reading, both hemispheres are involved in accessing the meaning of print stimuli. In real life, multiplicity of meaning is very common, and skilled readers are able to access and manipulate these multiple meanings easily and flexibly. We have begun to specify how the hemispheres may cooperate in this very complex task, and suggest complementary hemispheric contributions during the disambiguation processes of homographs, which are much more dynamic than previously assumed. The next obvious step is to investigate the role and manner of interhemispheric interactions in the process of meaning disambiguation. This is currently being done in our lab.

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Appendix A

See Tables A1 and A2.

Table A1
Homophonic Homographs.

Homophonic homographs: Hebrew print	IPA	Meaning Dominant/Subordinate	Overall dominance values (0–9 scale)
אב	ʔav	Father/11th Month of Jewish year	8.29
אבוב	ʔabuv	Oboe/ Tire (rubber tube–heel)	6.5
אות	ʔot	Letter (character)/Signal	8.38
אח	ʔax	Brother/Fireplace	8.5
אמה	ʔama	Third finger/Maid	4.59
בסיס	basis	Military base/Basis	7.32
בית	bajit	House/Verse (poem)	8.74
בר	baʁ	Bar/Grain	7.23
גיל	gil	Age/Happiness	8.5
דרור	dʁoʁ	Sparrow/Freedom	6.96
הגה	hege	Steering wheel/Sound	8.08
הדחה	hadaxa	Dismissal/Washing	6.64
הנחה	hanaxa	Reduction/Assumption	7.87
הקפה	hakafa	Encircling/Credit	5.64
השלמה	haʃlama	Completion/Acceptance	7.17
חבל	xevel	Rope/Geographic region	6.09
חוזה	xoze	Contract/Seer	6.73
חולות	xolot	Sand dunes/Female patients	6.82
חילול	xilul	Playing the flute/Desecration	5.83
חלוק	xaluk	Robe /Small stone	7.18
חלל	xalal	Space/Dead	7.18
חרוז	xaʁuz	Bead/Rhyme	7.92
טוש	tuʃ	Shower/Indian ink	7.88
טיפוס	tipus	Type/Climbing	6.09
יד	jad	Hand/Memorial	8.71
ישיבה	jeʃiva	Meeting/Rabbinical college	7.83
מחילה	mexila	Forgiveness/Hole	7.83
מטה	mate	Headquarters/Stick	5.36
מילה	mila	Word/Circumcision	8.64
מנה	mana	Dish /Quotient	7.83
מנצח	menatseax	Winner/Conductor	7.41
מפה	mapa	Map/Tablecloth	7.09
מקור	makoʁ	source/Beak	5.77
מתח	metax	Tension/Stretching	7.59
נס	nes	Miracle/Flag	7.3
סרט	seʁet	Movie/Ribbon	8.59
סרטן	saʁtan	cancer/Crab	7.52
עדה	ʔeda	Witness/Community	7.14
עמודים	ʔamudim	Pages/Pillars	7.36
עצב	ʔetsev	Sadness/Nerve	8.18
ערבים	ʔaʁavim	Arabs/Evenings	7.59
פריטה	pʁita	Playing (stringed instrument)/Changing (money)	5.86
פרקים	pʁakim	Chapter/Joint	7.3
ציפורן	tsipoʁen	Nail/Carnation (flower)	7.91
ציר	tsiʁ	Axis/Delegate	7.04
קבלה	kabala	Receipt /Kabala (Jewish mysticism)	8.26
קליעה	kliʔa	Shooting/Weaving	7.83
קרן	keren	Corner/Horn	7.71
רגל	ʁegel	Leg/Foot (measure)	8.38
רווח	ʁevax	Profit/Gap	7.36
רוק	ʁok	Spit/Rock (music)	7.32
רימון	ʁimon	Grenade/Pomegranate (fruit)	6.32
שאיפה	ʃeʔifa	Breathing/Ambition	7.45
שיח	siax	Bush/Talk	6.95
שקדים	ʃkedim	Almonds/Tonsillitis	6.59
תו	tav	Note (music)/The 22nd letter in Heb. alphabet	6.68

Table A2
Heterophonic Homographs.

Heterophonic homographs: Hebrew print	IPA	Meaning Dominant/Subordinate	Overall dominance values (0–9 scale)
אוצר	ʔotsaʁ/ʔotseʁ	Treasure/Curator	6.96
אלה	ʔela/ʔala	Truncheon/Goddess	7.21
אלף	ʔelef/ʔalef	1000/First letter of Heb. Alphabet	7.92
אמן	ʔaman/ʔamen	arTist/"Amen"	6.05
אתר	ʔataʁ/ʔeteʁ	Site/Ether	7.61
בוקר	ˈbokeʁ/boˈkeʁ	Morning/Cowboy	8.91
בור	boʁ/buʁ	Hole/Ignorant	7.77
ביצה	bejtsa/bitsa	Egg/Swamp	7.86
בירה	ˈbiʁa/biˈʁa	Beer/Capital city	8.32
גז	gaz/gez	Gas/Sheep shearing	7.5
גיס	gis/gajis	Brother-in-law/Force (army)	6.83

(*continued on next page*)

Table A2 (*continued*)

Heterophonic homographs: Hebrew print	IPA	Meaning Dominant/Subordinate	Overall dominance values (0–9 scale)
גנים	ganim/genim	Gardens/Genes	8.17
דבר	davaʁ/deveʁ	Object (thing)/Epidemic	7.39
דוד	dod/dud	Uncle/Boiler	7.5
הורה	hoʁe/hoʁa	Parent/Israeli folk dance	6.36
זר	zaʁ /zeʁ	Foreigner/Bouquet of flowers	7.13
חבורה	xavuʁa/xabuʁa	Group/Bruise	6.36
חזקה	xezka/xazaka	Power (mathematics)/Right of possession	7.41
חלב	xalav/xelev	Milk/Tallow	7.22
חסידות	xasidot/xasidut	Storks/Hasidism	7.21
טבח	tabax/tevax	Cook/Slaughter	8.46
טחינה	'txina/txi'na	Sesame paste/Grinding	7.73
יוד	jud/jod	Iodine/10th letter in Heb. Alphabet	5.68
כרך	keʁax/kʁax	Volume/Metropolis	6.46
לבנה	levana/levena	Moon/Brick	6.74
מאפיה	maʔafiya/maʔfya	Bakery/Mafia	7.41
מטר	meteʁ/mataʁ	Meter/Rain	6.96
מלון	malon/melon	Hotel/Melon	8.21
מלח	melax/malax	Salt/Sailor	8.22
מקלט	miklat/maklet	Shelter/Receiver	7.41
מראה	maʁʔa/maʁʔe	Mirror/View	8.63
נבל	naval/nevel	Villain/Harp	5.87
סבל	sevel/sabal	Suffering/Porter	8.21
סמל	semel/samal	Symbol/Sergeant	7.96
ספק	safek/sapak	Doubt/Supplier	7.36
ספר	sefeʁ/sapaʁ	Book/Hairdresser	8.23
עגלה	ʔagala/ʔegla	Wagon/Heifer	7.3
עיר	ʔiʁ/ʔaiʁ	City/Donkey-foal	8.68
עצירות	ʔaciʁot/ʔaciʁut	Stops/Constipation	6.87
פועל	poel/poal	Worker/Verb	6.64
פיה	pija/feja	Mouthpiece/Fairy	6.26
פנים	panim/pnim	Face/Inside	8.75
פתח	petax/patax	Aperture/Vowel sign	7.73
צדיק	tsa'dik/'tsadik	Honest/The 18th letter in Heb. alphabet	7.41
ציונים	tsijunim /tsijonim	Grades/Zionists	8.61
קופה	kupa/kofa	Cashier/Female monkey	8
קסטה	kasata/kaseta	Cassette/Ice-cream	4.32
קצב	ketsev/katsav	Tempo/Butcher	7.14
ריבה	ʁiba /ʁiva	Jam/Girl	6.91
רצף	ʁetsef/ʁatsaf	continuity/Floorer	7
שד	ʃed/ʃad	Demon/Breast	7.22
שומר	ʃomeʁ/ʃumaʁ	Guard/Fennel	8.04
שוק	ʃuk/ʃok	Market/Shock	7.82
שליש	ʃliʃ/ʃaliʃ	Third (1/3)/Adjutant	7.88
שמש	ʃemeʃ/ʃamaʃ	Sun/Janitor	8.75
שרות	ʃeʁut/saʁot	Service/(female) Minister	6.57

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