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Understanding Written Words: Phonological, Lexical, and Contextual Effects in the Cerebral Hemispheres

Orna Peleg and Zohar Eviatar

In this chapter we present a model of the functional architecture of the way in which meaning is accessed during reading. The model is based on well-established general models of reading, and is applied to what we know about the division of labor in the cerebral hemispheres in the process of visual word recognition and meaning activation.

It is an arresting fact that all of the major models of language use in general, and of reading in particular, have been triangular, from Lichtheim Wernicke's and model of the relations between the centers for motor images, sound images, and concepts, to Seidenberg and McClelland's (1989) well-known connectionist model with orthographic, phonological, and semantic units. This triangular structure is based on the fact that the processing of written words requires readers to rapidly access and integrate knowledge about spelling, pronunciation, and meaning

The model we present is a general account of how this integration occurs in the two cerebral hemispheres. We propose that phonological, orthographic, and semantic representations are related to each other differently in each hemisphere. Specifically, we propose that there are no direct connections between orthographic and phonological representations in the right hemisphere (RH), whereas all three processes are completely interactive in the left hemisphere (LH) (see Figure 4.1).

The model is parsimonious, in that this single difference in architecture can account for many hemispheric asymmetries in reading reported in the literature. The model is general, because it is tested on a language that is very different from English, allowing for more precise generalizations about how the modal brain works. The model is timely, reflecting our growing realization of the dynamism and complexity of hemispheric abilities and relations, as it is clear that these

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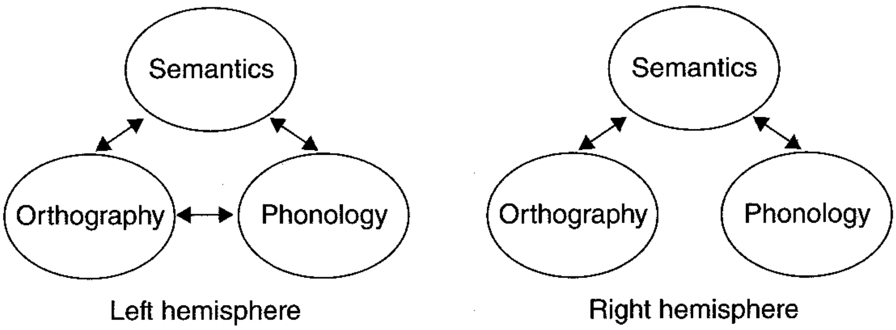

Figure 4.1 The functional architecture of reading in the two hemispheres.

underlie our experience of unity and diversity of consciousness, and higher cognitive functions.

Introduction

Phonological and orthographic asymmetries in visual word recognition

Although visual word recognition is normally conceptualized as being driven primarily by the analysis of orthography, it is now commonly accepted that the processing of a printed word is also influenced by information concerning its pronunciation. For example, behavioral studies using the masked-priming paradigm (e.g., Ferrand & Grainger, 1992, 1993) show that target recognition is speeded by the prior brief presentation of a masked pseudo-homophone prime (e.g., koat – COAT) relative to an orthographic control (poat – COAT). This literature has led a number of researchers (e.g., Frost, 1998) to suggest that phonological recoding is a mandatory, automatic phase of print processing.

Research on commissurotomy patients, however, suggests that this automatic phonological process proposed by Frost (1998) may be an accurate description of reading processes supported by the LH, but may not be applicable to the RH (e.g., Baynes & Eliassen, 1998; Zaidel, 1985; Zaidel & Peters, 1981). The basic finding, reported by Zaidel and Peters (1981), revealed that while the disconnected RH is able to connect the "sound image of a word" (i.e., its phonological representation) with a picture (i.e., its semantic representation) and to access the meaning of a word from its written form (i.e., its orthographic representation), it is unable to access the phonological form of a word from its written form. The disconnected LH, of course, can access all the representations of the word from its written form.

The majority of the studies examining hemispheric differences during reading in healthy participants use the divided visual field (DVF) 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 RH and vice versa. Although information presented that way can be later transmitted to both hemispheres, the interpretation of DVF studies 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 LH processes and responses to targets in the LVF reflect RH processes. (For theoretical and electrophysiological support for this assumption, see Banich, 2003; Berardi & Fiorentini, 1997; Coulson, Federmeier, van Petten, & Kutas, 2005).

Similar to the split-brain results, DVF studies with intact participants demonstrate that the LH is more influenced by the phonological aspects of written words, whereas word recognition processes in the RH are more influenced by orthography (e.g., Lavidor & Ellis, 2003; Marsollek, Kosslyn, & Squire, 1992; Marsolek, Schacter, & Nicholas, 1996; Smolka & Eviatar, 2006). For example, Halderman and Chiarello (2005) utilized a backward masking paradigm in conjunction with a DVF display. In that experiment, target words (e.g., *bowl*) were presented and backward masked by nonwords that differed in the degree to which they shared orthographic and phonological information with the target. Three types of nonwords were used: pseudo-homophone (e.g., *bowl* – BOAL), orthographically similar, but phonologically less similar (e.g., *bowl* – BOOL), or unrelated controls (e.g., *bowl* – MANT). Stimuli were briefly presented to the LVF or to the RVF. The results indicated that responses to targets presented to the RVF/LH were facilitated in the phonological, pseudo-homophone condition relative to the orthographically similar condition. In contrast, responses to targets presented to the LVF/RH showed a greater degree of facilitation for the orthographically similar condition relative to the unrelated condition. Overall, these observations are consistent with the view that both hemispheres can recognize words visually via orthographic–semantic connections, but orthographic–phonological connections are available only to the LH.

Asymmetries in meaning activation

Lexical and contextual effects on ambiguity resolution Understanding written words during sentence comprehension requires readers to rapidly access and integrate not only lexical knowledge related to the word itself (e.g., its spelling, pronunciation, and meaning), but also contextual knowledge related to the sentential context in which the word is embedded. This process is further complicated by the fact that many words have more than one distinct meaning and thus part of the comprehension process entails a selection of one of those meanings. Ample evidence from behavioral research 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, the processes underlying ambiguity resolution are still controversial and not fully fleshed out.

On the one hand, serial models argue that all meanings of an ambiguous word are immediately activated regardless of either frequency or contextual bias. According to this view, contextually inappropriate meanings are discarded only at a later, postlexical selection stage (e.g., 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, Morris, & Rayner, 1988) or the Graded Salience Hypothesis (Giora, 1997, 1991, 2003; Peleg, Giora, & Fein, 2001, 2004) suggest that both contextual and lexical factors influence meaning activation immediately and independently of each other. According to these models, context can facilitate the activation of the contextually appropriate meaning, but it cannot override relative meaning frequency. Thus, salient (frequent) meanings would be activated, even when contexts favor the less salient meaning of an ambiguous word.

Importantly, recent neuropsychological studies show that ambiguity resolution requires the intact functioning of both hemispheres. For example, not just unilateral LH damage, but also unilateral RH damage leads to deficits in ambiguity resolution (e.g., Grindrod & Baum, 2003). Similarly, imaging studies reveal bilateral activation during ambiguity resolution (e.g., Mason & Just, 2007). However, the unique contribution of each hemisphere to reading in general and to the resolution of homographs in particular remains to be elucidated.

Hemispheric asymmetries in lexical ambiguity resolution – The received view Research using the DVF technique has led to the conclusion that the hemispheres differ significantly in the way they deal with lexical and contextual factors during ambiguity resolution (e.g., Burgess & Simpson, 1988; Faust & Chiarello, 1998; Faust & Gernsbacher, 1996). According to the received view, in the LH all meanings are immediately activated and shortly afterwards one meaning is selected on the basis of frequency and/or contextual information. The RH, on the other hand, activates all meanings more slowly and maintains these meanings irrespective of context or frequency.

Within this "standard model," the functioning of the LH is maximized: it has the ability to immediately activate both salient and less salient meanings and then to use both lexical and contextual information in order to select a single appropriate meaning. As a result, 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 biasing prior context, it quickly selects the contextually appropriate meaning (e.g., Faust & Chiarello, 1998; Faust & Gernsbacher, 1996). The RH abilities, however, are minimized: first, activation of the less salient meaning is slower (e.g., Burgess & Simpson, 1988). In addition, it is viewed as less able to use lexical and/or contextual information for selection. As a result, it maintains alternate meanings regardless of their salience or contextual appropriateness (e.g., Burgess & Simpson, 1988; Faust & Chiarello, 1998; Faust & Gernsbacher, 1996).

A number of attempts have been made to account for this pattern of asymmetries. The fine/coarse coding hypothesis postulates that the cerebral hemispheres differ in their breadth of semantic activation, with the LH activating a narrow, focused semantic field and the RH weakly activating a broader semantic field (e.g., Beeman, 1998; Jung-Beeman, 2005; Mirous & Beeman, Volume 1, Chapter 16). As a result, meaning activation in the RH is relatively sustained and nonspecific, whereas meaning activation in the LH is faster and restricted to more frequent or closely associated meanings. 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. Finally, it was proposed that the RH is simply slower (e.g., 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. Taken together, current models of hemispheric differences in ambiguity resolution converge on a proposal that LH language processing is relatively more focused and faster than RH language processing, and takes place at higher (e.g., the sentence message) levels of analysis.

However, the idea that the RH is insensitive to higher-level, contextual processes seems at odds with neuropsychological studies reporting discourse-level deficits after RH damage (e.g., Brownell, Potter, Birhle, & Gardner, 1986), as well as the findings that patients with damage to either hemisphere display deficits in their ability to exploit sentence-level information to determine the appropriate meaning of homographs (e.g., Grindrod & Baum, 2003). Further, in contrast to the message-blind model, recent behavioral and neurological studies suggest that context sensitivity characterizes *both* hemispheres (e.g., Coulson et al., 2005; Federmeier & Kutas, 1999; Gouldthorp & Coney, 2009). We therefore suggest an alternative explanation for asymmetries in meaning activation from written words. Our explanation relates to the different ways in which orthographic, phonological, and semantic processes interact in the two hemispheres. Thus, rather than assuming asymmetries at higher (e.g., semantic) levels of analysis, we propose asymmetries at lower (e.g., phonological) levels of analysis.

Alternative Proposal

The dual hemispheric reading model

Generally speaking, there are two ways to access meaning from print: visually (from orthography directly to meaning) and phonologically (from orthography to phonology to meaning). As mentioned earlier, previous studies suggest that orthographic–semantic connections exist in both hemispheres, whereas orthographic–phonological direct associations are available only to the LH (e.g., Lavidor & Ellis, 2003; Smolka & Eviatar, 2006; Zaidel & Peters, 1981). On the basis of these findings, we propose a simple model in which both hemispheres exploit orthographic, phonological, and semantic information in the processing of written words. However, in the LH, orthographic, phonological, and semantic representations are fully interconnected, while there are no direct connections between phonological and orthographic units in the RH. The model is illustrated in Figure 4.1. We make no other assumptions about the nature of these representations in the two hemispheres. Indeed, we claim that this single difference in hemispheric functional architecture results in hemisphere asymmetries, in the disambiguation of homographs in particular, and, more broadly, in the processing of written words.

Processing implications – Homophonic versus heterophonic homographs

Because an orthographic representation of an English word (as well as other Latin orthographies) is usually associated with one phonological representation, most studies of lexical ambiguity used *homophonic homographs* – multiple meanings associated with a single orthographic and phonological representation (e.g., *bank*). As a result, models of hemispheric differences in lexical processing focus mainly on semantic organization (e.g., Jung-Beeman, 2005). We suggest that this reliance on homonyms has limited our understanding of hemispheric involvement in meaning activation, neglecting the contribution of phonological and orthographic asymmetries to hemispheric differences in semantic activation.

The unvoweled Hebrew orthography offers an opportunity to examine other types of homographs as well. In Hebrew, letters represent mostly consonants, and 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 (*bank*), but also *heterophonic homographs* – a single orthographic representation associated with multiple phonological codes each associated with a different meaning (e.g., *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 proposed model (Figure 4.1), when orthographic and phonological representations are unambiguously related (as in the case of homophonic homographs like *bank*), meaning activation is faster in the LH than in the RH, because all related meanings are *immediately* boosted by both orthographic and phonological sources of information. However, when a single orthographic representation is associated with multiple phonological representations, (as in the case of heterophonic homographs like *tear*) meanings may be activated more slowly in LH than in the RH, due to the competition between the different phonological alternatives.

In order to contrast the received view with our proposal, we examined the disambiguation of homophonic versus heterophonic homographs in the two hemispheres: if hemispheric differences in processing homophonic homographs are due to differences in scope of semantic activation or in the ability to select a single meaning, then a similar pattern should be observed with heterophonic homographs. If, however, hemispheric differences in processing homophonic homographs are due to phonological asymmetries, then opposite asymmetries should be observed in the case of heterophonic homographs.

Table 4.1 Translated examples of stimuli.

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

Experiments Demonstrating That Semantic Asymmetries are Modulated by Phonological Asymmetries

In our studies (Peleg & Eviatar, 2008, 2009, in preparation), a DVF technique was employed in conjunction with the lexical-priming paradigm. Participants were asked to silently read sentences that ended with either homophonic or heterophonic homographs and to perform a lexical decision task on targets presented laterally (to the LVF or to the RVF), 150 ms, 250 ms, or 1000 ms after the onset of the final homograph. Sentential contexts were either biased towards one interpretation of the final homograph, or unbiased. Targets were either related to one of the meanings of the ambiguous prime, or unrelated. Magnitude of priming was calculated by subtracting reaction time (RT) to related targets from RT to unrelated targets. Translated examples of the stimuli in the different conditions are presented in Table 4.1.

Predictions – Phonological, lexical, and contextual effects

Although the model does not assume any architectural asymmetries in sensitivity to contextual (e.g., prior semantic information) or experiential (e.g., frequency of occurrence) factors, it does make a number of predictions with regard to the way phonological asymmetries (direct orthographic–phonological connections in the LH vs. indirect connections in the RH) interact with lexical and contextual processes.

Effects of phonology First, the model predicts that phonological effects will occur earlier in the reading process in the LH than in the RH. As a result, at early sites of activation (SOAs), differences between heterophonic and homophonic homographs will be more pronounced in the LH than in the RH. Specifically, it predicts that direct connections between orthographic and phonological representations in the LH should speed up lexical (bottom-up, stimulus driven) processes in the case of homophonic homographs, but should slow down lexical processes in the case of heterophonic homographs. Thus, in the case of homophonic homographs, multiple meanings may be activated faster in the LH than in the RH. Importantly, however, in the case of heterophonic homographs, multiple meanings may be activated more slowly in the LH than in the RH.

Effects of context When a sentential context is biased, meanings can be activated via two separate routes: the contextual predictive route, and the lexical bottom-up route (e.g., Peleg et al., 2001, 2004). When contexts favor the salient meaning, activation of this meaning is facilitated by both contextual and lexical processes. However, when contexts favor the less salient meaning, contextually appropriate meanings would be activated via the contextual predictive route, whereas salient, more frequent meanings would be activated via lexical bottom-up processes. Importantly, when lexical bottom-up processes are fast, contextually inappropriate meanings are more likely to be immediately activated, resulting in simultaneous activation of multiple meanings. In contrast, when lexical bottom-up processes are slowed down, contextually inappropriate meanings are less likely to be immediately activated, resulting in a more ordered meaning activation, where the contextually appropriate meaning is activated before the more frequent but contextually inappropriate meaning. Thus, in the case of homophonic homographs, where lexical processes are faster in the LH, contextually inappropriate meanings may be activated more slowly in the RH than in the LH. However, in the case of heterophonic homographs, where lexical processes are slowed down in the LH, contextually inappropriate meanings may be activated more slowly in the LH than in the RH.

Effects of lexical frequency (salience) The direct connections between orthography and phonology in the LH have implications for frequency effects as well. In principle, when homographs are polarized (one meaning is more frequent or salient than the other), we expect salient meanings to be activated before less salient meanings (Giora, 1997, 2003; Peleg et al., 2001, 2004). Given that heterophonic homographs are both phonologically and semantically ambiguous, whereas homophonic homographs are only semantically ambiguous, we expect larger effects of frequency for heterophones than for homophones. Frequency effects are found in both semantic and phonological representations of words. For homophonic homographs, frequency differences reflect relative exposure to different meanings. For heterophonic homographs, frequency differences reflect not only relative exposures to different meanings, but also relative exposures to different pronunciations. As a result, polarization (difference between the dominant and the subordinate meanings) should be larger for heterophonic homographs than for homophonic homographs. Thus, in the case of heterophonic homographs, frequent meanings may be more activated in the LH, whereas less frequent meanings may be more activated in the RH.

Effects of time While our model predicts differences at earlier stages of the reading process, we assume that these differences affect later stages as well. First, given our assumption that both hemispheres are sensitive to lexical and contextual constraints, we expect salient and/or contextually appropriate meanings to be retained for a longer period of time in both hemispheres. In addition, we assume that when meanings are activated later in one hemisphere relative to the other hemisphere, decay processes may start later as well. As a result, in the case of homophonic homographs, meanings are more likely to be retained in the RH, whereas in the case of heterophonic homographs, meanings are more likely to be retained in the LH.

Results

As predicted by our model, different patterns of priming were found between homophonic and heterophonic homographs, indicating that hemispheric contributions to ambiguity resolution are modulated by the phonological status of the homograph. Overall, we show that in the case of homophonic homographs, meanings are activated and decay faster in the LH than in the RH. In contrast, the opposite pattern was found with heterophonic homographs: both activation and decay processes are faster in the RH than in the LH. In the following we report the timeline of ambiguity resolution for each context condition separately.

When contexts are kept neutral In a neutral, non-biasing context, we see a different pattern of results in the two visual fields and for the two types of homographs. These are illustrated in Figure 4.2. In the RVF/LH (see Figure 4.2b), both meanings of homophonic homographs were available at 150 SOA. However, 100 ms later, only the dominant, more frequent meaning remained active. At 1000 SOA, none of the meanings were retained. In the LVF/RH (see Figure 4.2a), the less salient meaning was activated more slowly, so that 150 ms after the onset of the ambiguous prime, only salient meanings were significantly activated. Shortly afterwards (at 250 SOA), the less salient meaning was activated alongside the salient one. At 1000 SOA, only the dominant meaning remained active. Overall, these results indicate that in the case of homophonic homographs, multiple activation and decay processes are faster in the LH.

Heterophonic homographs, however, revealed a different pattern of results. In the RVF/LH (see Figure 4.2d), salient meanings were activated exclusively, regardless of SOA. Alternatively, in the LVF/RH (see Figure 4.2c), 150 ms after homograph presentation, only salient meanings were significantly activated. However, shortly afterwards (at 250 SOA), the less salient meaning was activated alongside the salient one. At 1000 SOA none of the meanings were retained. Overall, these results indicate

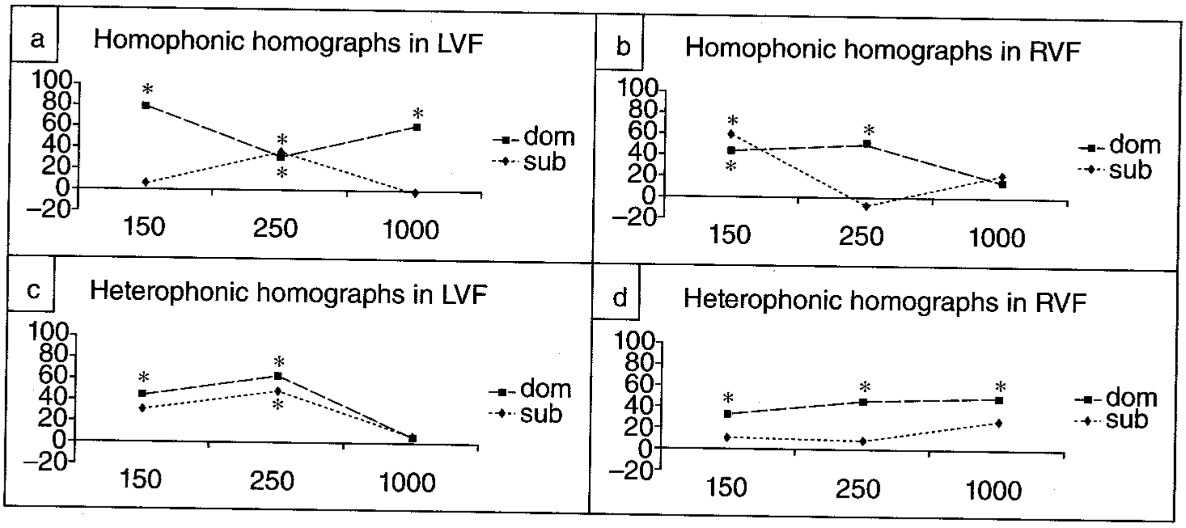

Figure 4.2 Magnitude of priming effects (in ms) for targets related to the dominant/frequent, more salient meaning of homographs (dashed lines), and to targets related to the less salient meaning (dotted lines), as a function of SOA (150 ms, 250 ms, or 1000 ms), when contexts are kept neutral. Note: *Significant, $p < 0.5$.

that in the case of heterophonic homographs, multiple activation and decay processes are faster in the RH.

When contexts favor the salient meaning In a context biasing towards the salient, more frequent meaning, this meaning is activated exclusively, regardless of SOA, location of target (LVF or RVF), or type of homograph. This indicates that *both* hemispheres are able to selectively access the contextually appropriate meaning, when this meaning is both salient and supported by contextual information.

When contexts favor the subordinate meaning In a context biasing towards the less salient meaning, we see a different pattern of results in the two visual fields and for the two types of homographs. These are illustrated in Figure 4.3. For homophonic homographs, both meanings (the contextually compatible less salient meaning as well as the contextually inappropriate salient meaning) were activated at 150 SOA and remained active at 250 SOA, regardless of target location (RVF or LVF). However, at 1000 SOA, only the compatible subordinate meaning remained active and only in the LVF/RH (see Figure 4.3a,b). Overall, these results indicate that in the case of homophonic homographs, meanings are retained for a longer period of time in the RH.

Heterophonic homographs, however, were processed differently: in the RVF/LH (see Figure 4.3d), at 150 SOA, the contextually subordinate meaning was activated exclusively. Shortly afterwards, however, at 250 SOA, the salient inappropriate meaning was also activated. Both meanings remained active at 1000 SOA. In contrast, in the LVF/RH (see Figure 4.3c), both meanings were immediately activated (150 SOA) and remained active at 250 SOA. However, at 1000 SOA, the contextually appropriate subordinate meaning was activated exclusively. Overall, these results

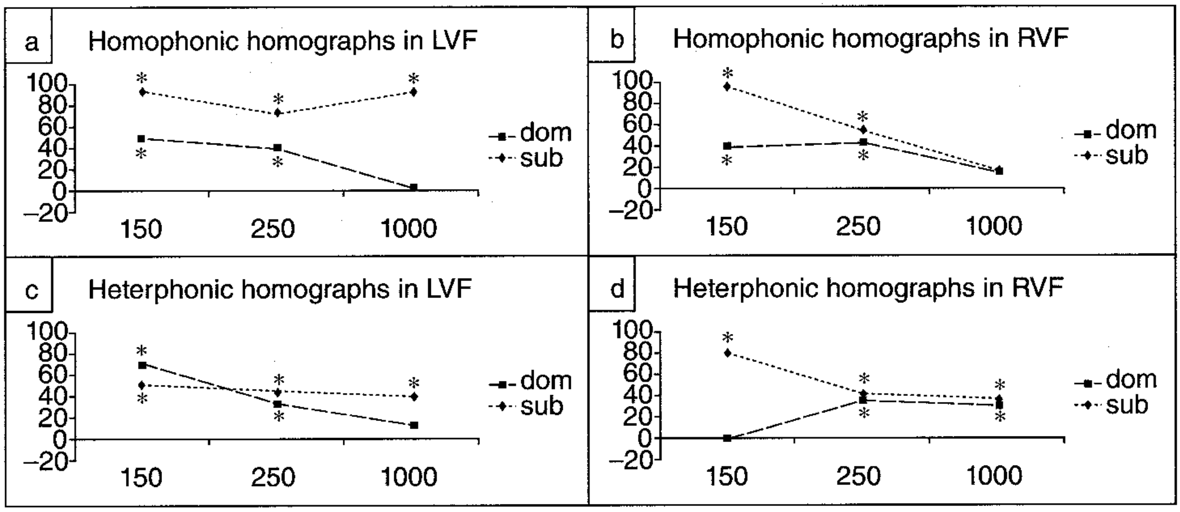

Figure 4.3 Magnitude of priming effects (in ms) for targets related to the dominant/frequent, more salient meaning of homographs (dashed lines), and to targets related to the less salient meaning (dotted lines), as a function of SOA (150 ms, 250 ms, or 1000 ms), when contexts favor the less salient, subordinate meaning. Note: *Significant, $p < 0.5$.

indicate that in the case of heterophonic homographs, salient but contextually inappropriate meanings are available earlier in the RH, but are retained for a longer period of time in the LH.

Conclusions

According to the received view, when readers encounter an ambiguous word, multiple meanings are available immediately in the LH, but shortly afterwards one meaning is selected on the basis of relative frequency and/or contextual information. The RH, on the other hand, activates all meanings more slowly and maintains these meanings irrespective of context or frequency. On the basis of such findings, current hemispheric models of ambiguity resolution have converged on the proposal that LH language processing is relatively more focused, faster, and takes place at higher levels of analysis than RH language processing. The work we have described here and in Peleg and Eviatar (2008, 2009, in preparation) suggests a different, more complex picture of hemispheric abilities. Our use of heterophonic homographs in a language in which these are frequent, reveals complementary hemispheric contributions which are much more dynamic than previously assumed.

As predicted by our model, our findings show that hemispheric differences in the time course of meaning activation and meaning decay are modulated by the phonological status of the homograph. In the case of homophonic homographs, our results converge with the received view. Both activation and decay processes are faster in the LH than in the RH. In neutral contexts, both meanings are activated immediately in the LH (150 SOA). However, shortly afterwards (250 SOA), the salient, more frequent meaning remains active, while the less frequent one decays.

In contrast, in the RH, less frequent meanings are activated more slowly and are therefore available at a later point in time (250 SOA).

Importantly, however, in the case of heterophonic homographs, our results diverge from the received view. Both activation and decay processes may be faster in the RH than in the LH. When contexts are biased towards the less salient meaning, multiple meanings are activated immediately in the RH (150 SOA). However, at 1000 SOA, the contextually appropriate meaning remains active, whereas the inappropriate one decays. In contrast, in the LH, contextually inappropriate meanings are activated more slowly (250 SOA) and are therefore available at a later point in time (1000 SOA).

None of the existing hemispheric models can explain our findings with heterophonic homographs. Whereas testing ambiguity resolution with homophonic homographs in Hebrew results in patterns similar to previous findings using English (e.g. Burgess & Simpson, 1988), testing heterophonic homographs, which are quite common in Hebrew but quite rare in English, results in patterns of activation and decay quite different from those found in previous studies. In fact, as shown above, the RH seems to be able to immediately activate multiple meanings, and also to quickly choose the contextually appropriate meaning. In contrast, when dealing with these heterophonic homographs, the LH activates meanings more slowly and retains them for a longer period of time. Recall that this pattern is reversed relative to the pattern described by the received view.

Our model is highly parsimonious: rather than assuming differences in the scope of meaning activation (e.g., Beeman et al., 1994; Jung-Beeman, 2005; Mirous & Beeman, Volume 1, Chapter 16), or in the processes involved in meaning selection (e.g., Faust & Chiarello, 1998; Copland, Chenery, & Murdoch, 2002), we propose that all these asymmetries can be accounted for by one difference in the functional architecture in the two hemispheres. Specifically, our model postulates no direct connections between orthographic and phonological representations in the RH. However, in the LH, phonological, orthographic, and semantic representations are entirely interactive (see Figure 4.1). Importantly, as mentioned above, this model not only explains existing data based on homophonic homographs, but also accounts for reverse asymmetries in the disambiguation of heterophonic homographs.

We assume that meaning activation depends on both contextual processes (e.g., prior semantic information) and lexical processes sensitive to experiential familiarity (e.g., frequency of occurrence, or salience; see Giora, 1997). Both processes occur in both hemispheres. As a result, contextually appropriate and/or salient meanings are more likely to be activated earlier and to remain active for longer periods of time, while inappropriate and/or less salient meanings may be activated more slowly and are more likely to decay faster. However, as a result of the two functional architectures (see Figure 4.1), contextual and lexical processes may occur at different temporal stages in the two cerebral hemispheres and may have differential effects for the two types of homographs.

First, in the case of polarized heterophonic homographs, frequency effects may be more pronounced in the LH than in the RH, because in the LH they immediately affect not only semantic processes but also phonological processes. In contrast, in the RH phonological effects are delayed. As a result, when a biasing context is not provided and meaning activation is guided only by frequency, frequent meanings are more likely to be activated and retained in the LH, whereas less frequent meanings are more likely to be activated in the RH. Second, when lexical processes are fast, frequent meanings are more likely to be immediately activated, regardless of context. However, when lexical information is activated more slowly, as in the case of heterophonic homographs in the LH, context (predictive) effects may precede relative frequency effects. As a result, when contexts favor the less frequent meaning, inappropriate frequent meanings are activated more slowly in the LH than in the RH.

Thus, in agreement with other studies examining homophonic homographs (e.g., Burgess & Simpson, 1988), our findings demonstrate that, when contexts are kept neutral or favor the less salient meaning, multiple meanings are immediately activated in the LH. Under similar circumstances (when contexts are kept neutral), a more ordered activation is observed in the RH. In contrast, in the case of heterophonic homographs, our findings demonstrate that, when contexts favor the less salient meaning, immediate activation of multiple meanings is observed in the RH, whereas a more ordered activation is observed in the LH.

While our model mainly explains differences at earlier stages of the reading process, these differences also affect later processing stages. First, recall that in accordance with our assumption that both hemispheres are sensitive to lexical and contextual constraints, we show that in both hemispheres, salient and/or contextually appropriate meanings are retained for a longer period of time, whereas less frequent and/or contextually inappropriate meanings are more likely to decay earlier. In addition, our results indicate that when meanings are activated later in one hemisphere compared to the other hemisphere, decay processes may start later as well. As a result, in the case of homophonic homographs, meanings are more likely to be retained in the RH, whereas in the case of heterophonic homographs, meanings are more likely to be retained 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.

Beyond hemispheric differences, our results have implications for general models of reading and ambiguity resolution. Contrary to the predictions of the direct-access (context-sensitive) model (e.g., Vu et al., 1998), suggesting that a strong context can selectively activate the contextually appropriate meaning, regardless of salience, we show that *both* context and salience influence the retrieval of word meanings. Importantly, in agreement with hybrid models such as the Graded Salience Hypothesis (e.g., Giora, 1997, 2003; Peleg et al., 2001, 2004, 2008), our results show that context can enhance activation of the contextually appropriate meaning, but it cannot inhibit salient meanings even when these are contextually inappropriate.

Thus, even when contexts favor the less salient meaning, salient, more frequent meanings are still activated: in the case of homophonic homographs, both meanings were activated immediately (150 SOA) and remained active 100 ms later, regardless of visual field. Interestingly, even when contextual processes preceded lexical processes, as in the case of heterophonic homographs, in which the contextually appropriate meaning was activated exclusively in the LH (150 SOA), 100 ms later (250 SOA) the salient but contextually inappropriate meaning also became available, regardless of context.

In addition, our results shed light on one of the main controversies in the reading literature; namely, the role phonology plays in silent reading. One class of models suggests that printed words activate orthographic codes that are directly related to meanings in semantic memory. An alternative class of models asserts that access to meaning is always mediated by phonology. (For a review, see Frost, 1998; van Orden & Kloos, 2005.) Current models of reading incorporate both phonological and orthographic processes. Dual route models (e.g., Coltheart & Kohnen, Volume 2, Chapter 43; Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001) assume that meanings can be accessed either via the direct, orthographic/visual route, or via orthography–phonology decoding. Connectionist models (e.g., Harm & Seidenberg, 2004) propose an interactive system that always uses both orthography and phonology to access the meaning of words.

By looking at differential hemispheric involvement in orthographic and phonological processes, we may be able to resolve these differences. Recall that our model assumes that in the LH orthographic units are directly related to both phonological and semantic units. It therefore predicts that meaning activation in the LH will be instantly influenced by phonology. As expected, our results indeed show that when a short SOA (150 ms) was used, homophonic and heterophonic homographs, which diverge on how their meanings are related to phonology, were processed differently in the LH. Recall further that our model assumes that in the RH, phonological codes are not directly related to orthographic codes and are activated indirectly, via semantic codes. This organization, in the RH, should result in a different timing of activation: the phonological computation of orthographic representations should begin later than the semantic computation of the same representations. As a result, lexical access in the RH should initially be affected to a greater extent by orthography than by phonology. As expected, our results demonstrate that, in the RH, at a short SOA (150 ms) similar patterns (in terms of significant priming effects) were obtained for both types of homographs. These results converge with previous studies showing that the LH is more influenced by the phonological aspects of a written word (e.g., Halderman & Chiarello, 2005; Lavidor & Ellis, 2003; Zaidel, 1982; Zaidel & Peters, 1981), whereas lexical processing in the RH is more sensitive to the visual form of a written word (e.g., Halderman & Chiarello 2005; Lavidor & Ellis, 2003; Marsollek et al., 1992; Marsolek et al., 1996; Smolka & Eviatar, 2006).

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 (orthographic, phonological, lexical, and contextual); however, as a result of the two functional architectures (see Figure 4.1) these may be used differently, and at different temporal stages. 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. By exploiting the distinction between homophonic and heterophonic homographs in Hebrew, we show that a single architectural difference (namely, direct vs. indirect orthographic–phonological connections) can explain existing data based on homophonic homographs (in Hebrew and English), as well as reverse asymmetries in the disambiguation of heterophonic homographs. In this way, our model provides a more comprehensive, coherent, and general framework for understanding the hemispheres' separable abilities and tendencies during normal reading comprehension.

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