Differences and Interactions Between Cerebral Hemispheres When Processing Ambiguous Words

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Abstract. It is well known that the brain (especially the cortex) is structurally separable into two hemispheres. Many neuropsychological studies show that the process of ambiguity resolution requires the intact functioning of both cerebral hemispheres. Moreover, these studies suggest that while the Left Hemisphere (LH) quickly selects one alternative, the Right Hemisphere (RH) maintains alternate meanings. However, these hemispheres are connected through the corpus callosum and presumably the exchange of information is useful. In addition, many works show that the Left Hemisphere (LH) is more influenced by the phonological aspect of written words whereas lexical processing in the Right Hemisphere (RH) is more sensitive to visual form. This distinction suggests that the interconnections between the hemispheres may be used to strengthen or correct incorrect interpretations by one hemisphere. We test this hypothesis by (I) postulating that in the Left Hemisphere (LH) orthography, phonology and semantics are interconnected while (II) the Right Hemisphere (RH), phonology is not connected directly to orthography and hence its influence must be mitigated by semantical processing (III) seeing if corrections in ambiguous word processing can be aided by information in the other hemisphere. We investigate this by complementary human psychophysical experiments and by dual (one RH and one LH) computational neural network model architecturally modified from Kawamoto's (1993) model to follow our hypothesis. Since the different models have different rates of convergence, we test (III) by halting processing, and using an analogue to priming to compare the rate of convergence to a corrected semantics in the LH working alone and working with information obtained from the RH at the same point in processing. In this paper we present results of the computational model and show that (I) the results obtained from the two hemispheres separately are analogous to the human experiments and (II) the use of the RH information does indeed help such corrections.

1 Introduction

We are interested in helping explain why there are two different contemporous lexical processing in the brain. Neuropsychological studies have shown that both cerebral hemispheres process written words, but they do it in somewhat different ways (e.g., [29,

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13, 26, 9, 11, 2, and 10]) Our underlying hypothesis was that these observed differences arise from the difference in the way interactions between orthographic, phonologic and semantic elements occur. Specifically, in the Left Hemisphere we imagine that all these elements influence each other directly, while in the Right Hemisphere they are not all directly connected; i.e. phonology is not connected directly to orthography and hence its influence must be mitigated by semantical processing.

We point out that abstract theoretical descriptions of processes underlying mental processes are difficult to test, but can be approached in at least two ways. First, one can directly examine human subjects with psychophysical experiments and see if the measured responses correspond to the theoretical explanations. This requires delicate design of experiments. Secondly, we can try to construct artificial networks designed according to the theoretical explanation and see if under such constraints the expected responses do in fact emerge. The delicacy in this approach is to make the model as simple as possible so that one can be sure that the response is in fact emerging from the theoretical description. Thus both methods complement each other.

In our laboratory, we have attempted to measure subtle differences in human subjects partially by using the richness of Hebrew in both homophonic and heterophonic homographs (in standard orthography Hebrew is written without vowels) and measuring the difference in response when presenting homographs directly to one hemisphere or the other. To compare our human results with computational ones, we designed and present here a connectionist (neural network) model of each hemisphere for lexical disambiguation based on the well-known Kawamoto [14] model.

Our model includes two separate networks, one for each hemisphere. One network incorporates Kawamoto's version in which the entire network is completely connected. Thus orthographic, phonological and semantical "neurons" are not distinguished architecturally. This network successfully simulated the time course of lexical disambiguation in the Left Hemisphere. In the other network, direct connections between orthographic and phonological units are removed. The speed of convergence in resolving ambiguities were studied in these two networks under a variety of conditions simulating various kinds of priming. The comparative results presented are analogous to the results obtained under our human subject testing thereby strengthening our belief in the correctness of our psychological explanation of the processing.

We then investigated how the LH might use the information of the RH in a specific task; i.e. one where initially the information available leads the LH to one solution of the ambiguity; but during the processing new information arises that indicate the other solution. Our results show that because of the different time courses in the hemispheres this information is indeed useful.

2 Background

Behavioral studies have shown that the LH is more influenced by the phonological aspect of written words whereas lexical processing in the RH is more sensitive to visual form. In addition, semantically ambiguous words (e.g., "bank") were found to result in different time-lines of meaning activation in the two hemispheres. However, computational models of reading in general and of lexical ambiguity resolution in particular, have not incorporated this asymmetry into their architecture.

A large amount of psycholinguistic literature indicates that readers utilize both frequency and context to resolve lexical ambiguity (e.g., [24, 20, and 21]). The idea that multiple sources of evidence (relative frequency as well as context) affect the degree to which a particular meaning is activated and the eventual outcome of the resolution, as well as the process, can be nicely captured within a neural network (connectionist) approach to language processing. In connectionist terminology, the computation of meaning is a constraint satisfaction problem: the computed meaning is that which satisfies the multiple constraints represented by the weights on connections between units in different parts of the network.

2.1 Hemispheric Differences in Ambiguity Resolution

Hemispheric asymmetries were found to be of particular importance in the processing of ambiguous words because both context and frequency have been shown to have differential implications for the processing of language in the hemispheres (e.g., [2, 10]). Moreover, these studies show that the process of ambiguity resolution requires the intact functioning of *both* cerebral hemispheres [11].

Neurological studies suggest that all meanings of an ambiguous word are initially activated in both hemispheres. It is only after this initial exhaustive stage that processing in the hemispheres seems to diverge: While the LH quickly selects one alternative (the contextually compatible meaning when prior contextual information is biased, or the salient, more frequent meaning when embedded in non-constraining contexts), the RH maintains alternate meanings (including less salient, subordinate and contextually inappropriate meanings). In the literature, this proposal is referred to as the "standard model" of hemispheric differences in meaning resolution.

Three major proposals have been advanced to account for the sustained activation of less frequent or/and contextually incompatible meanings in the RH as opposed to their fast decay in the LH. First, according to The Coarse Coding Model suggested by Beeman [1], meaning representations in the LH are finely-coded (narrow representations that include only closely related meanings), whereas semantic representations in the RH are coarsely coded (broader representations that include less-related meanings as well). Second, several researchers proposed that hemispheric differences in word meaning activation result from a selection mechanism, specific to LH processing, that inhibits or suppresses less related meanings [26]. Finally, Burgess and Lund [4] suggested that differences in speed of activation onset could account for differences in meaning activation. In this view, meaning dominance lead to both stronger and longer activations of word meanings for both LH and RH processing. As a result, less-related meanings decay faster. However, because RH processing has a slower onset of speed activation, less related meanings are still activated at a point.

In the following, we briefly present a preliminary model for lexical disambiguation in the two cerebral hemispheres that is based on the work of Kawamoto. In our work, we obtain the meaning activation discrepancy without needing to postulate variant onset speeds for the hemispheres; rather it is a consequence of the architectural choices of the networks.

2.2 Kawamoto Model

A connectionist account of lexical ambiguity resolution was presented by Kawamoto [14]. In his fully recurrent network, ambiguous and unambiguous words are represented as distributed pattern of activity over a set of simple processing units. Each lexical entry is represented over a 216 bit vector divided into separate sub-vectors representing the “spelling”, ”pronunciation”, "part of speech" and “meaning”. The network is trained with a simple error correction algorithm by presenting it with the pattern to be learned. The result is that these patterns (the entire word including its orthographic, phonological and semantic features) become "attractors" in the 216-dimensional representational space. The network is tested by presenting it with just part of the lexical entry (e.g., its spelling pattern) and testing how long various parts of the network take to settle into a pattern corresponding to a particular lexical entry. Kawamoto trained his network in such a way that the more frequent combination for a particular orthographic representation was the "deeper" attractor; i.e. the completion of the other features (semantic and phonological) would usually fall into this attractor. (This was accomplished by biasing the learning process of the network.). However, using a technological analogy of "priming" to bias the appropriate completion, the resulting attractor could in fact be the less frequent combination – which corresponds nicely to human behavioral data. Indeed, consistent with human empirical results, after the network was trained, the resolution process was affected by the frequency of the different lexical entries (reflected in the strength of the connections in the network) and by the context. Kawamoto's network, however, does not model hemispheric differences.

2.3 Two-Hemisphere Model

The model includes two separate networks. One network incorporates Kawamoto’s version, and successfully simulates the time course of lexical disambiguation in the LH. In the other network based on the behavior of the disconnected RH of split brain patients [30], we made a change in Kawamoto's architecture, removing the direct connections between orthographic and phonological units. Taken together, the two networks produce processing asymmetries comparable to those found in the behavioral studies.

2.4 The Disambiguation of Homophonic Versus Heterophonic Homographs

In Latin orthographies (such as English), the orthographic representation (the spelling) of a word is usually associated with one phonological representation. Thus, most studies of lexical ambiguity have used homophonic homographs (homonyms - a single orthographic and phonological representation associated with two meanings). As a result, models of hemispheric differences in lexical processing have focused mainly on semantic organization [1]. We suggest that this reliance on homonyms may have limited our understanding of hemispheric involvement in meaning activation, neglecting the contribution of phonological asymmetries to hemispheric differences in semantic activation and has limited the range of models proposed to describe the process of reading in general.

Visual word recognition studies demonstrate that, even though both hemispheres have access to orthographic and phonological representations of words, the LH is more influenced by the phonological aspects of a written word (e.g., [29, 30, and 15]), whereas lexical processing in the RH is more sensitive to the visual form of a written word (e.g., [18, 19, and 15]). Given that many psycholinguistic models suggest that silent reading always includes a phonological factor (e.g., [3, 7, 28, 16, and 17]), it is conceivable that such asymmetries may also impact the assignment of meaning to written words during on-line sentence comprehension.

This study takes advantage of Hebrew orthography that in contrast to less opaque Latin orthographies, offers an opportunity to compare different types of ambiguities within the same language [8].

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. Thus, in addition to semantic ambiguities (a single orthographic and phonological form associated with multiple meanings), the relationship between the orthographical and the phonological forms of a word is also frequently ambiguous. For example, the printed letter string "מלח" in Hebrew has two different pronunciations (/melach/ or /malach/), each of which has a different meaning ('salt' or 'sailor').

2.5 The Model

We propose a model that incorporates a right hemisphere structure (i.e. network) and a left hemisphere structure (i.e. network) that differ in the coordination and relationships between orthographic, phonological and semantic processes. The two structures are homogeneous in the sense that all computations involve the same sources of information. However, the time course of meaning activation and the relative influence of different sources of information at different points in time during this process is different, because these sources of information relate to each other in different ways. A graphic representation of the model is presented below:

2.6 The Split Reading Model

LH Structure: Orthographic, phonological and semantic codes are fully connected. The connections between these different sources of information are bi-directional and the different processes may very well run in parallel. However, the model incorporates a sequential ordering of events that results from some processes occurring faster than others. For example, in the LH, orthographic codes are directly related to both phonological and semantic codes. However, because orthography is more systematically related to phonology than to semantics, the phonological computation of orthographic representations is faster than the semantic computation of these same representations. As a result, meaning activation in the LH is initially influenced primarily by phonology, [15] resulting in immediate exhaustive activation of all meanings related to a given phonological form, regardless of frequency or contextual information (e.g., [8, 24 and 23]).

RH Structure: Phonological codes are not directly related to orthographic codes and are activated indirectly via semantic codes. This organization predicts a different

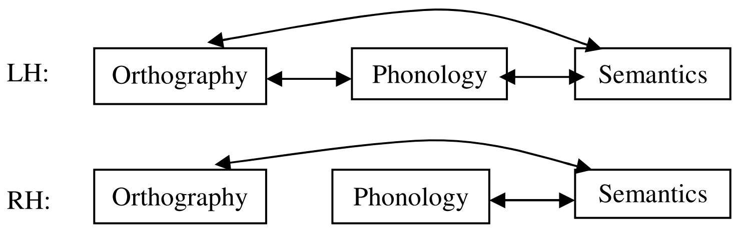


Fig. 1. Left / Right Hemisphere Structures

sequential ordering of events in which the phonological computation of orthographic representations begins later than the semantic computation of these same representations. As a result, lexical access in the RH is initially influenced by orthography [15] and by semantic information, so that less frequent or contextually inappropriate meanings are not immediately activated. Nevertheless, these meanings can be activated later when phonological information becomes available (e.g., [5, 24]).

3 Testing the Model

This model is tested according to the philosophy describe in the abstract in two complementary ways:

1. By psychophysical experiments with human subjects.
2. By a computational neural network model.

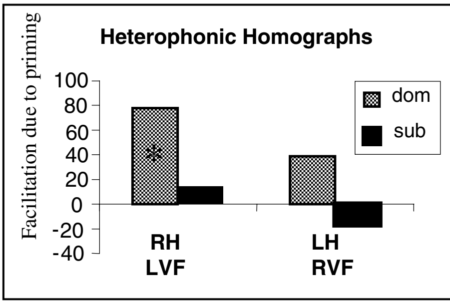
(In this paper we mainly describe the computation network and its results).
If our ideas are correct and orthographic codes activate phonological codes directly in the LH and indirectly in the RH, we should observe that the distinction in processing the two kinds of word types (i.e. homophonic and heterophonic homographs) should occur at different stage in processing in the LH and RH.

Specifically within the LH these differences will be seen in the early stage of lexical access, while with the RH, these differences will only be seen at a later point in time.

3.1 Brief Description of Preliminary Human Results

We investigated the role phonology plays in silent reading by examining the activation of dominant and subordinate meanings of homophonic and heterophonic homographs (a single orthographic representation associated with two phonological representation, each associated with a different meaning) in the two hemispheres. We used a divided visual field paradigm that allows the discernment of differential hemispheric processing of tachistoscopically presented stimuli. Heterophonic and homophonic homographs were used as primes in a lexical decision task, where the target words were either related to the dominant meaning or to the subordinate meaning of the ambiguous word, or were unrelated.

We measured semantic facilitation by response times. A significant interaction between visual field of presentation (right or left), type of stimulus (heterophonic or homophonic homograph) and type of target words suggested that heterophonic and homophonic homographs were disambiguated differently in the two visual fields, and by implication, in the two hemispheres. With homophonic homographs, targets related to both dominant and subordinate meanings were activated in the RVF/LH, while in the LVF/RH only dominant meanings evoked facilitated responses (Figure 2). Alternatively, with heterophonic homographs only dominant meanings evoked facilitated responses, and only in the LVF/RH (Figure 3)



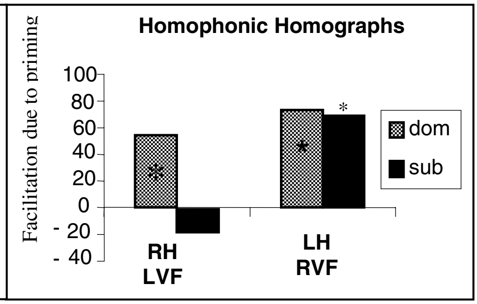


Fig. 2. LVF/RH advantage for heterophones **Fig. 3.** RVF/LH advantage for homophones

3.2 Computational Simulations

The units in the LH and RH networks were implemented as described by Kawamoto [14] with the following changes:

1. The original 48 4-letters words were replaced with 48 patterns representing 24 pairs of polarized Hebrew 3-letter homographs, half heterophonic and half homophonic.
2. 45 features (instead of 48) represented the word's spelling and 60 features (instead of 48) represented its pronunciation.

This is because the pronunciation includes the vowels that were omitted from the spelling. The representation for "part of speech" (all nouns) and "meaning" remains the same as in the original model. Overall, each entry is represented as a vector of 270 binary-valued features. Both networks were trained with a simple error correction algorithm [1, 2]:

$$\Delta W_{i,j} = \eta(t_i - i_i)t_j \text{, where} \quad i_i = \sum_j W_{ij} t_j \qquad (1)$$

Here η is a scalar learning constant fixed to 0.0015, t_i and t_j are the target activation levels of units i and j, and i_i is the net input to unit i. The magnitude of the change in connection strength is determined by the magnitude of the learning constant and the magnitude of the error (t_i - $i_{i.}$). The activity of a single unit in the network is represented as a real value ranging between -1.0 and + 1.0.

$$\text{LIMIT} = \begin{cases} +1 & x > +1 \\ -1 & x < -1 \\ x & \text{otherwise} \end{cases} \quad (2)$$

This activity is determined by the input from the environment], the units connected to it, and the decay in its current level of activity. These influences lead to changes in the activity of a unit as a function of time (where time changes in discrete steps).
That is, the activity of a unit (a) at time t + 1 is:

$$a(t+1) = \text{LIMIT}\left[\delta a(t) + \left[\sum_j w_{ij}(t) a_j(t)\right] + s_i(t)\right] \quad (3)$$

Where δ is a decay variable that changes from 0.7 to 1.0. $s_i(t)$ is the influence of the input stimulus on unit a_i at time (t+1). And LIMIT bounds the activity to the range from -1.0 to +1.0.

In each simulation, 12 identical LH and RH networks were used to simulate 12 subjects in an experiment by varying their training randomly. Each network was trained on 1300 learning trials. On each learning trial an entry was selected randomly from the lexicon. Dominant and subordinate meanings were selected with a ratio of 5 to 3 roughly based on linguistic considerations. After the networks were trained they were tested by presenting just the spelling part of the entry as the input (to simulate neutral context) or by presenting part of the semantic sub-vector together with the spelling (to simulate prior contextual bias). In each simulation the input sets the initial activation of the units. The level was set to +0.25 if the corresponding input feature was positive, -0.25 if it was negative and 0 otherwise. In order to assess lexical access, the number of iterations through the network for all the units in the spelling, pronunciation or meaning fields to become saturated, was measured. A response was considered an error if the pattern of activity did not correspond with the input; non-convergent if all the units did not saturate after 50 iterations.

3.2.1 Results and Discussion

Table 1 below presents a summary of the number of iterations needed for all units of homophonic and heterophonic homographs to become saturated in the LH and in the RH networks when no context, a dominant context or a subordinate context is presented.

Table 1. Iteration to 100% saturation of entire vector

	LH		RH	
context	Homo	Hetero	Homo	Hetero
No	14.91	17.69	19.37	18.58
Dominant	7.42	7.69	8.36	8.52
Subordinate	13.24	10.47	14.27	14.76

Homo = homophonic homographs Hetero = heterophonic homographs

Table 2 below presents a summary of the time to saturate units in the phonological and meaning sub-vectors in the LH and in the RH networks when no context, a dominant context or a subordinate context is presented.

Table 2. Iteration to 90% saturation of sun-vector

	LH				RH			
	Homo		Hetero		Homo		Hetero	
context	phono	sem	phono	sem	phono	sem	phono	sem
No	8.53	14.09	11.66	14.73	14.69	18.35	14.68	16.60
dominant	6.15	6.19	6.19	6.72	7.19	6.71	7.47	7.17
Subordinate	6.85	10.67	6.70	8.60	9.16	10.45	9.36	10.20

phono = phonological sub-vector sem = semantic sub-vector

When homographs are presented without a biasing context, only the dominant meaning is accessed in both networks. However, in the LH network, meanings are accessed faster. This is consistent with LH advantage for lexical processing reported in the literature. Importantly, homophonic and heterophonic homographs are processed differently in the two networks. In the LH network, lexical access is longer for heterophonic homographs then for homophonic homographs (Table 1) due to the time-consuming competition between the two phonological representations. Indeed, more iterations were needed for the phonological units to become saturated in the case of heterophonic homographs than for homophonic homographs (Table 2). This is consistent with the idea that in the LH, phonological information guides early stages of meaning activation. Alternatively, in the RH network, phonological differences are less pronounced (Table 2) and processing times of homophonic and heterophonic homographs are similar (Table 1). This is consistent with the idea that in the RH, orthographic and semantic sources of information exert their influence earlier than phonological information. Moreover, in this case of no bias, there are (data not presented here) many more non-convergent situations which is consistent with the interpretation that the RH keeps both possibilities open longer than the LH (see the following section). When homographs are presented with a biasing context, only the contextually compatible meaning is accessed in both networks, In addition dominant meanings in dominant contexts are accessed faster than subordinate meanings in subordinate contexts (Table 1). Interestingly, in the LH network, homophonic advantage in processing time disappears when a biasing context is provided. Moreover, when homographs are presented with a subordinate context, it takes longer to access the subordinate meaning of homophones compare to heterophones (Table 1). In both cases, as predicted phonological disambiguation precedes meaning disambiguation (Table 2).

Because heterophonic homographs have different pronunciations, these homographs involve the mapping of a single orthographic code onto two phonological codes. As a result, when no context is presented, the speed of lexical access is slower for heterophonic homographs then for homophonic homographs. On the other hand, when context is provided, the single phonological code of homophonic homographs is still associated with both meanings, whereas the phonological representation of heterophonic homographs is associated with only one meaning. As a result, when homographs are presented in a subordinate context, a longer period of competition between dominant and subordinate meanings is observed in the case of homophonic homographs. In contrast, in the case of heterophonic homographs, meanings are accessed immediately after a phonological representation is computed.

4 Interactions of the Two Hemispheres

Given the results of the above experiments, the natural question is what is the computational advantage of this dual processing. In other words, how might an interaction between the two networks in different hemispheres (presumably via the corpus callosum) affect the results computationally?

Rather than attempt to resolve this physiologically or by examining anatomical connections, we ask here a preliminary more abstract question. Is there a way, or an example of a circumstance in which the information from one of the networks might naturally be used in the other hemisphere?

To judge what the possibilities might be, we looked at the time course of activation level of each of the possible resolutions of the lexical ambiguity. Figure 4 gives the graph of both the dominant and subordinate meanings during the time course in both the right and left hemispheres in our models. In the asymptote, the subordinate meaning disappears in both hemispheres, however the time course is different in each.

The subordinate activation in the left hemisphere increases more sharply and to a higher degree but then falls more sharply. We interpret this as meaning that the secondary possibility remains available for a longer period in the right hemisphere. In terms of artificial neural network dynamics, this means that during a period (in grey in Figure 4) the right hemisphere, while dynamically on its way to the "attractor" corresponding to the dominant meaning, is less "deep" in the attractor well.

To test this hypothesis, we imagine the following scenario: (1) first the networks commence with the orthography. If there is no priming, then they will start the dynamics toward convergence to the dominant attractor. If there is subordinate priming, then it will start the dynamics towards convergence to the subordinate attractor.

Now assume that during the period of time indicated during the grey area in Figure 4 additional information is given to the network that the other attractor is appropriate. During reading, this might occur by information coming from the end of a sentence, for example. In the artificial network, we model this by assuming there is new input to the semantical units of the model that biases the results. This is similar to our analogue of "priming", i.e. giving clues to the network used above. The difference is that this is not done at the initial stage of the network, but during the time course of processing.[1]

[1] There are different technical possibilities as to how the clues should be given; e.g. what percentage of semantical units are primed, whether the priming is one-shot or whether it is continual during the remaining processing, and whether or not to "reset" the other semantical units. We exhaustively investigated the differences, but the bottom line is that qualitatively it does change our results, although there is some difference quantitatively. This is described further below.

We can then ask how the networks behave under different conditions. First, as a baseline, how fast the networks individually react under the same external "clues" from the initial position, and how it reacts from the temporal point inside the grey area. Now we can also compare this with the reaction of the LH if we assume it receives the RH information. (We focus on the LH because it has an earlier time-course, and thus we anticipated that during the grey area window of time the RH information would help.) We model this by simply replacing the values in the LH by the values from the RH. Figure 5 shows the course of activation when the clues are presented at the time indicated by the arrow.

Table 3 shows the results for changes when the network is first converging to the dominant meaning and then is given clues towards the subordinate disambiguation, and vice versa. The two rows have similar qualitative results.
Indicated are the number of "errors" (i.e. words that do not converge and words that converge to the wrong disambiguation); and the average time of convergence.

For both errors and iteration the first column shows the situation when the LH does not receive any information from the RH, the second column indicates the situation when the external clues are presented to the network *after* transferring the values of the RH and only the specific percentage of semantical units are presented. The values indicated are for four out of eight units being given clues; the use of different numbers of clues changes the values of the errors and the iteration times; but does not change the qualitative order of the columns. The third column shows the results when the non-clues are given random values.

Thus the distinction between column 2 and 3 is that in column 2 the LH has the values in the "non-clued" semantical units the same as the RH prior to the clues arriving and in column 3 those non-clued units are simply randomized. The results show that (column 1) running the LH without information from the RH has substantially worse performance, both in number of iterations to convergence and in the number of “errors". This is as predicted and shows a computational advantage of having two distinct networks. Column 3 technically performs better than column 2, which is also as expected, because the non-clued neurons are more biased towards the incorrect attractor in column 2, whereas in column 3 they are neutral.

Table 3. The network is first converging to the dominant meaning and then is given clues towards the subordinate disambiguation, and vice versa

	Error / Non-convergence (out of 288)						Speed of convergence (Iteration)		
Method	LH only		LH+RH (prior)		LH+RH (post)		LH only	LH+RH (prior)	LH+RH (post)
Dominant to Subordinate	49	129	9	81	0	0	40.75±3.9	34.74±6.68	18.1±6.04
Subordinate to Dominant	0	60	0	60	0	55	26.7±5.3	26.48±5.12	22.38±4.67

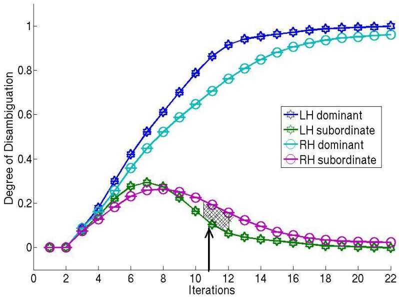


Fig. 4. Time Course of Disambiguation -No clues. Note grey area - see text.

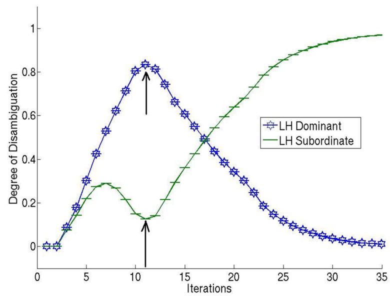


Fig. 5. Time course of disambiguation when clues applied at time of arrow

5 Summary

These results have important implications for the role phonology plays in accessing the meaning of words 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 mediated by phonology (for reviews see [7, 27]). Our results supports the idea that in the LH words are read more phonologically (from orthography to phonology to meaning), whereas in the RH, words are read more visually (from orthography to meaning).

Overall, the two networks produce processing asymmetries comparable to those found in behavioral studies. In the LH network, orthographic units are directly related to both phonological and semantic units. However, because orthography is more systematically related to phonology than to semantics, the phonological computation of orthographic representations is faster than the semantic computation of these same representations. As a result, meaning activation in the LH is initially influenced primarily by phonology. In the RH network, phonological codes are not directly related to orthographic codes and are activated indirectly via semantic codes. This organization results a different sequential ordering of events in which the phonological computation of orthographic representations begins later than the semantic computation of these same representations. As a result, lexical access in the RH is initially more influenced by orthography and by semantic.

We see a computational advantage of two different networks, in the example where a network has to change after substantial convergence. It is not inconsistent with the results presented here to suggest that the LH can converge more quickly than the RH but at the price of loss of information when it has to "change its mind". Fortunately, the different time course in the RH allows the LH recovery by copying its information into its network and then proceeding under the LH architecture.

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