Lateralized Noun/Verb Decision: Part of Speech, Functor Context, and Two Models of the Concrete Effect

by

Lise Menn

Linguistics Department

University of Colorado
Campus Box 345
Boulder, CO 80309-0345

Eran Zaidel and Jan Rayman
Psychology Department, UCLA

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Lise Menn

Linguistics Department, University of Colorado

Eran Zaidel and Jan Rayman

Psychology Department, University of California, Los Angeles

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Abstract

To determine whether the expected right visual field/left hemisphere superiority in processing functors could be demonstrated with a lateralized visual grammatical-class decision task, right-handed adult native English speakers were tested on go/no go responses to nouns and verbs, with functor or neutral cues, and also to category-ambiguous noun-verbs, with noun-compatible or verb-compatible functor cues.

As a check on the sensitivity of the procedure, half the nouns were concrete and half were abstract. A significant lateralized concreteness effect was found, but the predicted differential sensitivity to functors was not. Two models for these and other data are offered: a direct access model in which the right hemisphere can process functors as well as concrete nouns, and a new PDP hemispheric-interaction model in which only the left hemisphere has a lexicon in most right-handers.

Introduction

The traditional view of aphasiologists has been that in most right handers, the left cerebral hemisphere (LH) is exclusively specialized for language in general and for speech, and reading, grammar and syntax in particular (e.g. Goodglass & Kaplan, 1983). More recently, clinical neurological evidence has been accumulating for right cerebral hemisphere (RH) participation in lexical semantics and pragmatics (Chiarello, 1988; Molloy, Brownell, & Gardner, 1989). Research with complete commissurotomy patients, on the other hand, has shown substantial language competence in the disconnected RH, including rich lexical semantics, rudimentary syntax, and better auditory comprehension than reading comprehension (Zaidel, 1973, 1978a,b). In particular, when words are presented to the left visual field (LVF) of split brain patients, these patients show some deficit in initiating actions indicated by printed verbs, but not in comprehending them, as shown by pointing to multiple-choice pictures. They read nouns better than function words (Zaidel, 1983a) and concrete nouns better than abstract ones (Eviatar, Menn, & Zaidel, submitted), although they can comprehend many abstract words as well (Zaidel, 1973, 1976, 1982, in press). Finally, laterality experiments in normal subjects appear to show an even greater linguistic repertoire in the normal than in the disconnected RH (Zaidel, 1989).

Behavioral studies that claim RH involvement in lexical semantics usually demonstrate an interaction between visual field of stimulus presentation and some lexical variable. Such interactions in lexical decision were shown for word length (e.g. Bub, 1982; Eviatar & Zaidel, submitted; Young & Ellis, 1985), the word superiority effect (Krueger, 1975), word frequency (Hines, 1977), part of speech

(Eviatar et al., submitted), imageability (Day, 1977; Marcel & Patterson, 1978) and noun concreteness (e.g. Ellis & Shepherd, 1974; Eviatar et al., submitted, among many others), emotionality (Graves, Landis, & Goodglass, 1981), and phonological structure, including the pseudohomophone effect (Cohen & Freeman, 1978) and rhyming judgements (Crossman & Polich, 1988; Rayman & Zaidel, submitted). These variables tap the orthographic, semantic, and phonological components of lexical access. Although some of the above effects are controversial (Chiarello, 1988; Patterson & Besner, 1984), the thrust of the above results suggests independent normal RH contribution to the orthographic, semantic, and phonological components of lexical access.

Zaidel (1989) presents new evidence not only for RH contribution to these central decision variables of lexical access, but also to input variables as indexed by medium of stimulus presentation (Copeland, David, & Zaidel, in preparation), output variables as indexed by response programming (Measso & Zaidel, in press), and control variables as indexed by error correction in lexical decision (Stein & Zaidel, in preparation; Zaidel, 1987).

Chiarello (1988) reviews laterality studies of visual word recognition in normal subjects, in relation to the widely-used serial processing model which distinguishes pre-lexical, lexical, and post-lexical processes, all of which are involved to various degrees in the standard experimental tasks of word naming, lexical decision, and semantic classification (cf. Seidenberg, Waters, Sanders, & Langer, 1984; Stanovich & West, 1986). Although there is no universal agreement on the exact boundaries between these categories, prelexical processes refer to visual sensory processing and orthographic analysis, including letter identification, which is taken to yield an abstract representation for accessing the lexicon. This stage is presumed to be sensitive to stimulus degradation and to word length. The lexical processing stage refers to access to semantic, syntactic, and phonological properties of words and is generally considered to be sensitive to frequency, concreteness, emotionality, part of speech, etc. The post-lexical stage refers to processes that act on information retrieved from the lexicon, including pronunciation, metalinguistic classification, semantic comparison, and lexical decision. Our present task of noun/verb classification clearly falls into the 'metalinguistic classification' category.

Seidenberg et al. (1984) argue that variables which affect naming and lexical decision differently are likely to involve post-lexical components, since these two tasks presumably draw on the same pre-lexical processes. Chiarello concludes her review by noting that at pre-lexical-access and lexical access levels, "consistent visual field differences in the processing of content and function words have not been demonstrated" (p. 52) and that "there is to date no convincing data to suggest that certain classes of words are any less accessible than other word types when presented to the right hemisphere" (p. 55). Chiarello indicates that such lateralized concreteness effects as have been found can all be accounted for as involving post-lexical semantic processing.

However, she then argues that existing data nevertheless support the position that the normal brain has 1) extensive, perhaps complete representations of the whole lexicon in each hemisphere, but 2) specialized processes for reading orthographically standard print in the left hemisphere, and 3) specialization of some post-lexical processes involving abstract words to the left hemisphere also. A major element in deriving conclusion 1) is her claim that "findings of differential hemispheric performance for postlexical operations ... imply independent hemispheric processing for earlier (prelexical and lexical) processes. This would argue against a unilateral left hemisphere locus for the semantic store, and in favor of a bihemispheric, redundant representation of semantic information." (p.66) One of the findings she refers to here is a strong concreteness effect in semantic classification tasks (citing Chiarello, Senehi, & Nuding, 1987; Day, 1977; Rodel, Dudley, & Bourdeau, 1983; and Urcuioli, Klein, & Day, 1981; but cf. McMullen & Bryden, 1987); another is a differential hemispheric response bias in lexical decision (citing Babkoff, Genser, Sing, Thorne, & Hegge, 1985; Chiarello, Dronkers, & Hardyck, 1984; Chiarello, Nuding, & Pollock, in press; Chiarello, Senehi, & Soulier, 1986). These tasks are both considered to have a significant post-lexical-access component in the model that she is using.

The interpretation of an interaction between visual hemifield of presentation and some lexical variable as evidence for RH contribution to processing rests on an anatomical model of laterality effects in the normal brain. A preliminary partial version of this model was first articulated by Moscovitch (1973), developed in Zaidel (1983b), and extended in Zaidel et al. (in press). The basic assumption of the model is that callosal transfer results in measurable loss of speed as well as in loss of stimulus quality, which, in turn, results in loss of accuracy. Because transferred information may differ in its complexity as well as in the diameter and myelinization of the fibers used to carry it, the delay caused by callosal relay may range from few to several hundred milliseconds. A second assumption of the anatomical model is that major processing stages are independent and serial.

The assumption of serial independent processing stages is not required a priori, but is heuristic and subject to modification by new data. If processes proceed in parallel and are not dependent upon one another's final outcome, then effects of callosal relay become more difficult to measure. A parallel data processing (PDP) model (usually called connectionist when there is no danger of confusing the term with the neuropsychological model of the same name) can be constructed which accounts for the kinds of RH contributions to lexical analysis that are suggested by the accumulating data. A PDP model can even be compatible with a unilateral LH lexicon as long as there are interactive RH contributions to visual pre-lexical stages of word recognition and to the full arousal of connotative word meaning. We will refer to such a unilateral-lexicon PDP model of hemispheric interaction as a transhemispheric PDP model, and we will show how it might work in the discussion section.

In this paper we use a metalinguistic task, noun/verb classification; such a task should have a strong post-lexical component in a sequential psycholinguistic processing model. Based on the clinical data, we predicted a selective RVF advantage in recognizing verbs. In the only previous version of this experimental task known to us, Babkoff, Ben-Uriah, and Eliashar (1980) used grammatical class judgement of Hebrew verbs and nouns, and found that verbs were responded to faster but less accurately than nouns. They also found a visual field (VF) x part-of-speech interaction in latency, showing a right visual field advantage for verbs but not for nouns. No comparable studies have been published for English. Eviatar, Menn, and Zaidel (submitted) found a general advantage for nouns over verbs in both accuracy and latency, but they used a (lateralized) lexical decision task.

The second stimulus dimension that varied in the present paper was noun concreteness/abstractness. The mixed findings on the laterality effect of word concreteness in word recognition notwithstanding, we predicted an interaction between VF and noun concreteness. This prediction is based on two considerations: first, that both hemispheres, normal as well as disconnected, are indeed sensitive to concreteness (e.g. Eviatar et al., submitted); and second, that an asymmetric concreteness effect may show up only when processing resources are taxed, which might well be the case in a grammatical decision task.

Finally, we addressed the effect of function-word/content-word agreement on grammatical classification in the two hemispheres. The present study differs in method from previous studies of functor processing (lateralized or central), since the information carried by the functor is actually relevant to the subject's task, namely, grammatical categorization. Previous studies have used either lexical decision or word-naming, with the object of exploring the possible effect of syntactic information on lexical access itself and/or working out the time-course of interaction of syntactic and lexical processing (e.g. Goodman, McClelland, & Gibbs, 1981; Gurjanov, Lukatela, Moskovljević, Savić, & Turvey, 1985; Gurjanov, Lukatela, Lukatela, Savić, & Turvey, 1985; Seidenberg, Waters, Sanders, & Langer, 1984; Tanenhaus & Donnenwerth-Nolan, 1984; Tanenhaus, Leiman, & Seidenberg, 1979; West & Stanovich, 1986; Wright & Garrett, 1984; see Tanenhaus & Lucas, 1987 for a review). Phrasal and longer syntactic contexts were shown to facilitate lexical decision in both English and Serbo-Croatian, and the West and Stanovich study also showed facilitation of word-naming. The term 'grammatical priming' for these facilitation effects is rejected by some of the authors above, in order to avoid the suggestion that the observed effects of syntax are due to spreading activation. This is because the mechanism would have to be quite different from mechanism of the operation of spreading activation in the lexicon.

In this body of work, the syntactic effect of the functor or bound grammatical morpheme can be interpreted as being at least partly below the level of consciousness, whether facilitating or inhibiting. In the present study, however, the subjects were quite aware that the functors that they saw bore information relevant to the judgement that they were asked to make.

The present task was deliberately chosen in the attempt to extend the small existing repertoire of visually-lateralized verbal experimental paradigms: we wanted to see whether a lateralized effect could be obtained with this metalinguistic task. We predicted that the RVF presentations would show greater sensitivity to the presence of the function word, based on aphasiological studies which show grammatical comprehension problems in all aphasics (e.g. Heeschen, 1985; Kurowski, 1981), on possible LH superiority in decoding function words (Bradley & Garrett, 1983; Zaidel, 1982), and on LH superiority in appreciation of grammatical structure (Zaidel, 1978a,b). An RVF superiority for latency of functor recognition greater than the RVF superiority for latency of content word recognition was also found by Chiarello and Nuding (1987) using lexical decision and naming. Chiarello and Nuding also compared acceptablity judgements for phrases consisting of function word + content word with acceptablity judgements of content word + content word pairs. Finding an equal RVF advantage for acceptability judgements of both types of phrases, they suggested that all syntactic computation appeared to be carried out by the LH. But the absence of a visual field advantage is also compatible with the view that both hemispheres carry out syntactic computations independently.

Initial hypotheses. Our experiment, as mentioned above, was a metalinguistic classification task using lateralized presentation of stimuli. Subjects were shown three types of content words: 1) words that are always nouns (e.g. child), 2) words that are always verbs (e.g. bring), or 3) words that are category ambiguous (e.g. walk). They were asked to respond either to the question "Is this a noun?" or to the question "Is this a verb?"

The catgory-unambiguous stimuli were shown in one of two conditions: either together with a preceding xxx or with a syntactically appropriate preceding functor. The category-ambiguous stimuli were also shown in two conditions: either with a functor that determines a noun reading (e.g. my walk) or with one that determines a verb reading (e.g. we walk).

Since the right hemisphere of brain-damaged and commissurotomized patients gives no sign of being able to carry out tasks involving the comprehension of function words, we planned to test the hypothesis that the classification of stimuli presented to the left visual field/right hemisphere would be unaffected by any accompanying functors, while the classification of stimuli presented to the right visual field/left hemispere would be strongly affected by the functors. As a check on the sensitivity of the experimental paradigm, half of the unambiguous noun stimuli used were concrete and half were abstract. The hypothesized differential sensitivity to the functors was not found in this task, but the concreteness effect was.

Method

Stimuli

100 content words were used. All words were monosyllables from four to six letters long. They were divided into three major groups matched for frequency distribution: 32 pure nouns, 32 pure verbs, and 36 words which can be either nouns or verbs. The 32 pure nouns were subdivided into 16 abstract and 16 concrete nouns, again matched for frequency distribution; the 36 verbs were balanced for frequency of use as nouns and as verbs. All stimuli and their frequencies are presented as Appendix 1; frequencies are from Kučera and Francis (1982). Frequencies ranged from 10 to 300 uses per million words of written text. Concreteness/imagery norms were obtained from Toglia and Battig (1978) as much as possible, but norms were not available for all of the words used. Additional concreteness and imagery norms obtained later from the larger set of Colorado Concreteness and Imagery Norms (ms., Institute for the Study of Intellectual Behavior, University of Colorado) confirmed our concrete/abstract classification for all of the words that were on this larger list (see appendix).

In making up these lists, homophones and highly polysemous words were avoided, as were words which had listed occurrences as any part of speech other than verb or noun. To minimize intra-list priming, no two words in the list were related morphemically (e.g. since plead was used among the verbs, plea was excluded from the list of abstract nouns). Practice items met the same requirements as test items except that some of them were of higher frequency or had fairly common homophones.

The presentation was divided into four test blocks, each preceded by a practice block. Prior to the first and the third blocks, the subjects were instructed to push a response key if the answer to the question "Is this a noun?" was "Yes", regardless of what other part of speech it might also be. Prior to the second and fourth blocks, the subjects were instructed to push the key if the answer to the question "Is this a verb?"was "Yes", again regardless of what other part of speech it might also be. They were told before beginning the task that any context shown with the word could be taken into account in making this decision. Category-unambiguous and category-ambiguous words were mixed within blocks. No subject appeared to have any uncertainties about what the terms noun and verb meant.

The accompanying functors were two to four letters long. They were divided into two groups: noun-congruent (i.e. congruent with the next word being a noun) and verb-congruent (congruent with the next word being a verb). The noun-congruent words were the possessive pronouns my, his, and your and the article the; the verb-congruent words were we, you, and they and the infinitive marker to. These sets were chosen to be roughly balanced for person/impersonality, number (singular/plural), and word length. Assignment of noun-congruent functors to nouns and verb-congruent functors to verbs was quasi-random, but semantically odd or threatening combinations (e.g. my noon, your death) were avoided. Each of the eight functors appeared an approximately equal number of times.

Each category-unambiguous content word appeared in one cue condition with an xxx displayed immediately above it, and in the other cue condition with one of the congruent functors displayed immediately above it. An asterisk was used as the fixation point. The functors were presented in lower-case and the content words in upper case, keeping the font and type size constant, so that what the subject saw looked like this:

*   xxx   or like this: their   *

POND   GLOOM

Each category-ambiguous word appeared in one cue condition with a noun-congruent cue and in the other cue condition with a verb-congruent cue. Person of the pronoun was held constant across cue conditions. Assignment of functors to content words was done as above, but in addition, *to* was not used in any instance where it could be intepreted as a preposition (e.g. *to bounce* was used, but not *to land*).

It should be noted that this grammatical classification task really comprises two quite distinct sub-paradigms: when the stimulus is category-unambiguous, the accompanying functor cue gives redundant information about the grammatical category of the stimulus and so may be thought of as a "syntactic prime" with zero stimulus onset asynchrony, but when the simulus is category-ambiguous, the functor cue is the piece of information that actually determines its grammatical category and is not a prime in any sense.

Four counterbalanced presentation lists were used; each subject saw one list. On the first list, half of the words appeared in one of the two possible appropriate cue conditions and half in the other. On the second list, each word appeared in the opposite cue condition from the one in which it appeared in the first list. The third and fourth lists were left/right mirror images of the first and second lists respectively. Order of presentation was the same for all subjects.

Subjects

The subjects were 48 Tufts University undergraduate students, 25 males and 23 females, who were participating as part of course requirements or as volunteers. All subjects were right-handed monolingual English speakers at least until school age. All subjects were between the ages of 18 and 22 years except for one woman of 38.

Presentation

The stimuli were presented on a CRT in a darkened room; the subject's chin was supported and his/her forehead rested on a frame so that the bridge of the nose was about 22 inches from the screen. The distance from the midline to the nearest letter of the stimulus subtended about 1.8 degrees of arc. Each stimulus was displayed for 100 msec, followed by 1900 msec of darkness. The brightness and contrast were adjusted so that there was no visible afterimage on the screen. As mentioned, an asterisk, displayed for 500 msec prior to each stimulus, was used as the central fixation point; subjects were instructed at the beginning of each block of stimuli to make sure that they looked at the asterisk until the next stimulus was flashed.

Results

I. Sensitivity to functor cues

Reaction time results

Main effects. A 2 x 2 x 3 (VF x part of speech x cue type) ANOVA was used to analyze subject's average reaction times on correct trials. Contrary to expectations, there was no significant main effect of visual field on reaction time: mean RT for the LVF was 913 ms, and for the RVF, 918 ms. We found an unexpected and strong main effect of grammatical class on reaction time: verbs were categorized faster in all conditions (893 ms) than nouns (938 ms); (F(1,47) = 6.33, MSe = 45247, p = .015); see Table 1.

Planned comparisons were used to separately examine this verb advantage by cue type. As shown in Figure 1, significant differences between the response times to verbs and nouns were found when the cue was congruent (RT difference = 67 ms, t(1,47) = 2.23, p < .05) and for determining cues (RT difference = 52 ms, t(1,47) = 2.15, p < .05), but not for the xxx cue condition (RT difference = 15 ms, t(1,47) = 0.48, p > .50)

Insert Figure 1 about here

Insert Table 1 about here

A post-hoc check (by inspection) showed that the high affective loading of many of the abstract nouns had no discernable effect on reaction time, so no statistical analysis was performed. However, we note that two of these words, gloom and guilt, were always the slowest stimuli in their cells, regardless of cue condition or visual field of presentation.

There was a tendency for the average reaction time to be longer on category-ambiguous words (933 ms) as compared to category-unambiguous presented either with xxx (912 ms) or with congruent cues (902 ms); F(2, 94) = 2.614, p = .077, Wilk's Lambda (2, 46) = 2.372, p = .103, but these results fall short of the standard level of significance.

Interactions. The predicted interaction of visual field with cue type was not found, nor were any other interactions significant.

Accuracy results

Main effects. A 2 x 2 x 2 x 3 repeated measures ANOVA (visual field x error type x part of speech x cue type) was used for a preliminary analyis of subjects' mean error rates. These results are presented in Table 2.

Insert Table 2 about here

Errors to category-ambiguous words (you brush, your brush) were defined as responses incongruent with their functors. There was a strong effect of cue type, F(2,94) = 72.942, MSe = .073, p < .001; Wilk's Lambda (2,46) = 78.77, p < .001). Category-ambiguous words were categorized much less accurately (.373 overall error rate) than either the xxx-cued (.198), t(1,46) = 3.178, p < .001), or the functor-cued (.150) unambiguous grammatical class words, t(1,46) = 3.178, p < .001. A significant error by part of speech interaction was also found, F(1,47) = 9.163, MSe = .049, p = .004, with more misses than false alarms occurring to noun stimuli and more false alarms than misses occurring to verbs. As shown in Figure 2, this difference in the types of errors made to noun vs. verb stimuli held true for the xxx and congruent cued conditions, but did not occur for the category-ambiguous words. The interaction between error type and cue type was also significant, F(2,94) = 14.153, MSe = .056, p < .001, Wilk's Lambda (2,46) =

9.38, p < .001, with more false alarms occurring to category-ambiguous words, t(1,47) = 3.064, p < .01, and the two types of category-unambiguous words having false alarm rates about equal to their hit rates. An interaction between part of speech and cue type was also found, F(2,94) = 5.015, p=.009, Wilk's Lambda (2,46) = 4.966, p = .011, with verbs having a higher error rate than nouns in the xxx cue condition, but nouns having a higher error rate in the determining cue condition, and error rates being about equal for nouns and verbs in the congruent cue condition.

Insert Figure 2 about here

As the meaning of an error is somewhat different for category-ambiguous and category-unambiguous words, further separate analyses were performed on these two stimulus types.

Category-unambiguous word error rates were subjected to a 2 x 2 x 2 x 2 (visual field x error type x part of speech x cue type) repeated measures ANOVA. The category-unambiguous words presented with congruent cues (the coal, we greet) gave significantly fewer errors (mean error rate = .150) than those presented only with xxx cues (mean error rate = .198), F(1,47) = 11.219, MSe = .040, p = .002. Therefore, function words were indeed having a major effect on the performance of this categorization task. However, performance on the xxx-cued words was still over 80% correct, making it clear that the subjects were also attending to the nouns and verbs themselves.

Although more errors were made in the LVF (mean error rate = .183) than in the RVF (mean error rate = .165), contrary to expectation the effect of visual field did not approach significance, (_F_(1,47) = 1.730, MSe = 0.42, p = .223) , nor did it interact with functor presence or any other factors.

A significant interaction between part of speech and error type was again found: verbs had more false alarms and nouns had a higher miss rate _F_(1,47) = 8.66, MSe = .046, p = .005. (Recall that in this go - no go presentation paradigm, a false alarm to a verb means that the subject sees a verb in the target=noun condition - i.e. in an "Is this a noun?" block - and responds with a key press.) In the congruent cue condition, there were more misses than false alarms on nouns (i.e. a bias against responding to nouns, regardless of whether the categorization question was "Is this a noun?" or "Is this a verb"), but more false alarms than misses on verbs (a bias towards responding to verbs, regardless of the categorization question). Overall, verbs had fewer misses and more false alarms than nouns, indicating a bias to respond in the presence of a verb. We also obtained a significant cue type by part of speech interaction, _F_(2,94) = 5.015, MSe = .028, p = .009. As shown in Figure 3, the differences in error rates to nouns and verbss changed as a function of cue type.

Insert Figure 3 about here

Since errors to category-ambiguous words were defined as responses incongruent with their functors, a trial with an ambiguous word accompanied by a verb functor (e.g. _we walk_) was regarded as a miss if the subject failed to respond to it during the target=verb condition, and as a false alarm if the subject did respond to it during the target=noun condition. If functors were disregarded entirely for these words, subjects should always have responded "yes" to them regardless of the target condition, giving a low miss rate and a high false alarm rate. Although the mean error rate was high (.373), as mentioned, average performance was still above the .500 chance level, t(1,47) = 6.11, p < .01, again showing that the functors were being processed to some extent. A 2 x 2 x 2 (VF x Error Type x Functor) ANOVA was used to analyze the number of errors that subjects made to category-ambigous words. We again failed to find the predicted main visual field effect. As expected, the proportion of false alarms (mean error rate = .447) was greater than the proportion of misses (mean error rate = .299), F(1, 47) = 11.125, MSe = 0.187, p = .002. Significantly more errors were made to ambiguous words accompanied by a noun functor (.396) than to those accompanied by a verb functor (.350), F(1,47) = 4.524, MSe = .046, p = .036.

Speed-accuracy trade-offs

Responses to category-ambiguous words tended to be slower (p = .077) than responses to category-unambiguous words in both the xxx and the functor-cued condition (Table 1), as well as less accurate (Table 2). Inspection of the reaction times and the accuracy data within the two cue conditions for category-unambiguous words shows no general speed-accuracy trade-off: the functor-cued responses overall were faster and also more accurate than the xxx condition responses. However, a trade-off may be involved in the odd slowing of the response to the functor-cued nouns in the left visual field: the accuracy is higher for the functor-cued nouns (error rate .145, RT 952 ms) in the left visual field than for the xxx-cued nouns (error rate .185, RT 913 ms).

II. Concreteness effect

Reaction time

Reaction time for category-unambiguous nouns showed the predicted main effect of concreteness vs. abstractness; mean reaction time to concrete nouns was 879 ms, but abstract nouns were significantly slower at 934 ms ($\underline{F}(1,47) = 4.98$, MSe = 41658, $p = .023$). The expected main effect for visual field ($\underline{F}(1,47) = 4.63$, MSe = 37534, $p = .023$) was also found, with the mean reaction time for nouns in the LVF being 932 ms, as compared with mean reaction time of 881 ms for nouns in the RVF.

Insert Figure 4

The interaction of visual field by concrete/abstract was also significant and in the predicted direction ($\underline{F}(1,47) = 4.11$, MSe = 28614, $p = .028$), by the above criterion: the responses to LVF presentation were as fast as the RVF for concrete nouns, but they were about 100 ms slower for abstract nouns, $t(1,47) = 4.21$, $p < .01$, and the concreteness effect was significant only in the LVF, $t(1,47) = 4.34$, $p < .01$, as presented in Figure 4. Thus, the experimental paradigm used here was capable of replicating this somewhat controversial laterality result, even though it failed to show the predicted hemispheric differentiation for processing of functors.

Accuracy

Error rates were analyzed by a 2 x 2 x 2 (concreteness x cue type x VF) ANOVA. The mean error rate for concrete nouns was .148, and for abstract nouns it was .181, giving a significant directional main effect for abstractness (F (1, 47) = 3.478, MSe = .029, p = .033). The effect of visual field, although the means appear to differ in the expected direction (RVF .174, LVF. 155), did not reach significance (F(1,47) = .797, MSe = .023, p = .380). A significant effect of cue type was also observed in this analysis, F(1,47) = 5.845, MSe = .029, p = .019, with more errors occurring in the xxx cue condition (.185) than in the congruent cue condition (.145). The interaction of abstractness with visual field, presented in Figure 5, does not approach significance, but the raw means again conform to expectations: the error rate for concrete nouns in the right visual field is considerably better than the error rate in the other three conditions.

Insert Figure 5 about here

A separate 2 x 2 (cue type x VF) analysis of the concrete nouns again revealed a main effect of cue type, F(1,47) = 7.231, MSe = .026, p = .01, but planned comparisons showed it to be significant only in the LVF, t(1,47) = 3.37, p < .01, as shown in Figure 6.

Insert Figure 6 about here

Discussion

In the present paper, we used stimuli very similar to those used by Goodman et al. and by Seidenberg et al. (1984), Experiment 1. However, a conscious decision component which directly refers to the functor category is quite likely to be involved in our work, and the relatively long reaction times of our subjects (averaging over 800 msec) are compatible with this notion. We would therefore not encourage an interpretation of the present results in terms of syntactic priming or even of syntactic facilitation of responses in the same sense that phrasal and longer syntactic contexts have been shown to facilitate lexical decision (by the Goodman et al., 1981; Gurjanov, Lukatela, Lukatela, Savić, & Turvey, 1985; Gurjanov, Lukatela, Moskovljević, Savić, & Turvey, 1985; Seidenberg et al., 1984; West & Stanovich, 1986; and Wright & Garrett, 1984 studies cited above), and to facilitate word-naming (by West & Stanovich 1986). Our task (1) uses lateralized rather than central processing, (2) appears to tap more overt linguistic knowledge, and so (3) presumably taps a post-lexical stage which is even later than lexical decision.

In this experiment, we (like Chiarello and Nuding, 1987, Experiment 2) failed to find differentially lateralized processing of the information contained in functors, yet our procedure was sufficiently sensitive to show the concreteness effect, i.e. differentially lateralized processing of abstract vs. concrete nouns.

There are two main ways in which these data can be modeled. The anatomical model has been described elsewhere (Zaidel, 1983b; Zaidel, Clarke, & Suyenobu, in press) and so will only be summarized here. Our second model is, as far as we know, the first attempt to apply PDP modeling to language laterality data, and so it will be presented here at somewhat greater length.

A. Anatomical Model

1. Direct access vs. callosal relay

For the interpretation of these data, it is necessary to introduce the following inferential methods. Consider a hemifield tachistoscopic experiment with unimanual responses. A behavioral laterality effect is ambiguous. It suggests that one hemisphere is superior, but it does not by itself specify the competence of the inferior hemisphere. Two limit cases are conceivable. First, the "inferior" hemisphere may be unable to process the information at all. In that case, the superior hemisphere is exclusively specialized for the task, and the laterality effect reflects callosal transfer from the incompetent to the competent hemisphere. Second, the inferior hemisphere may be able to process the information independently, but use less efficient strategies. In that case, the laterality effect reflects the difference in competence between the two independent hemispheres. We refer to the first limit case as callosal relay and to the second limit case as direct access (Zaidel, 1983, 1985; Zaidel, Clarke, & Suyenobu, in press). Given the assumptions of the anatomical model, direct access implies parallel and independent processing of lexical information by each hemisphere. Indeed, an important possibility is that each hemisphere contains its own perceptual, linguistic, and mnestic functions, its own representation of reality, and its own information processing strategies (Zaidel et al., in press). In particular, each may have its own lexicon and access routes to it (Zaidel, 1983a). If so, then lateralized tasks may show evidence for direct access at any stage of processing (cf. Zaidel, 1989).

The most common pattern for inferring direct access or hemispheric independence is an interaction between visual hemifield of presentation and a lexical variable. Three possible relations between these two variables are encountered (Figure 7). If there is no hemispheric difference at either level of the experimental variable, then each hemisphere must be processing both levels and show the same difference between levels (Figure 7a). The zero slope implies that no callosal transfer is involved, given our initial assumption that callosal relay decreases accuracy and speed.

Insert Figure 7 about here

The pattern in Figure 7b is ambiguous. On the one hand, the pattern is logically consistent with direct access. Both hemispheres may show the same difference between level I and level II, but the RH may be slower by a constant amount corresponding to the slope. On the other hand, the pattern is also consistent with callosal relay. The LH may be exclusively specialized for the task, and the slope then represents callosal transfer, which is the same for level I and level II stimuli. In the absence of further information about the actual costs of callosal transfer for specific stimuli in a particular test, it is not possible to determine whether the slope represent callosal relay or hemispheric independence. The pattern in Figure 7c is common and includes a significant interaction of the experimental variable with visual field (processing dissociation, cf. Zaidel, 1983). It is clear that level I stimuli are processed independently by either hemisphere. The interpretation of processing level II stimuli is ambiguous for the same reasons that apply to Figure 7b. Thus, it is possible that the RH can process level I stimuli independently, but relays level II stimuli to the LH for processing. Alternatively, the RH may process both level 1 and level II stimuli, but be particularly poor at processing level II stimuli, as compared to the LH.

The ambiguity of direct access in pattern 7c can be partly resolved through demonstrating another processing dissociation in an orthogonal experimental variable. The "direct access" processing of one level of the orthogonal variable (say y_1) implies direct access processing of both levels (say x_1, x_2) of the original variable x, since both levels occur in stimuli in y_1. For example, consider the present noun/verb decision experiment. Here, x is cue type and y is noun concreteness. We have concluded that the latency data show direct access of concrete nouns (y_1). This means that both xxx cues (x_1) and determining cues (x_2) presented with concrete nouns are processed direct access-fashion as well.

Another potential sign of hemispheric independence is a different speed-accuracy relation in the two visual hemifields. When processing is data-limited (i.e. when adding more resources does not improve performance, Norman & Bobrow, 1975), and when accuracy as well as speed is emphasized, the two dependent variables should be positively correlated across items, and should exhibit the same laterality effects both within subjects, with trials as a random variable, and between subjects, with subjects as the random variable. On the other hand, when processing is resource-limited, spontaneous tradeoffs between speed and accuracy, which signal choices of processing strategy, can occur and may differ between the hemispheres.

2. Part of speech effect

We found that verbs were categorized consistently faster than nouns. This latency difference was significant for both the congruent cue condition (category-unambiguous targets) and for the determining cue condition (category-ambiguous targets) but not for the xxx-cue condition (category-unambiguous targets); see Figure 1.

This constrasts with results obtained in a lexical decision task with concrete and abstract nouns and "active" and "quiet" verbs, where (concrete) nouns were recognized faster and more accurately than verbs (Eviatar et al., submitted). Moreover, our results show that verbs had more false alarms while nouns had more misses (i.e. that subjects responded more frequently in the presence of verb stimuli than of noun stimuli in this go-no go paradigm), suggesting that the present task calls on different search or decision processes, which would presumably operate postlexically in the model reviewed by Chiarello.

The finding that the significant latency advantage of verbs over nouns is absent in the xxx-cue condition, but present whenever a functor is presented with the verb or noun, implies that this reaction time difference is due to the functors or to the functor+content word phrases, rather than to the content words themselves. As for why the verbs are faster, it is intriguing to note that three of the four types of functor+verb pairs form complete sentences (most of the verbs happen to be intransitives), while the functor+noun pairs are only noun phrases. Further experimentation would be required to test any hypothesis based on this observation. Since all eight functors used here have extremely high text frequencies, it does not seem likely that a frequency-of-functor explanation could account for these results.

Recent results (Berndt, 1989; Boch, 1989; Mitchum & Berndt, 1989; Shapiro, 1989; Weinrich & Steele, 1989; Zingeser, 1989) raise the question of whether the syntactic frames associated with a verb are separable from its semantics. If these are a tight unit, then the present experiment, which shows no right hemisphere deficit in verb recognition, suggests the apparent general right hemisphere difficulty with sentence construction (Zaidel, 1978) cannot be blamed on verb problems.

If, on the other hand, the semantics is separable from the full syntactic frame specification needed for sentence construction, then our present work cannot speak to this issue, since the right hemisphere may be able to access sufficient semantic information for classification of verbs without being able to access their syntactic frames.

3. Concreteness effect

We found the predicted concreteness x VF interaction in latency, suggesting direct access and independent hemispheric processing, at least for concrete nouns. This would also imply that any variable which is crossed with concrete nouns, particularly cue type, is processed independently in each hemisphere, i.e. by direct access, even if it fails to show a VF advantage.

4. Cue x visual hemifield effects

The failure of a significant cue x VF interaction to emerge, even though there was a strong effect of cue type on accuracy, suggests that both hemispheres are equally sensitive to the grammatical facilitation offered by phrasal context or to the metalinguistic grammatical information conveyed by the functors. However, it is also possible that the apparently equal effect across hemifields of the determining cue was produced by noise in our data. With the error variance that is present in these latency data, a visual field asymmetry in latency would have to be greater than about 50 msec to reach accepted levels of significance.

Since concrete nouns showed unequivocal evidence for right hemisphere participation in the decision task (for direct access, within the anatomical model, or for right hemisphere image arousal, in the PDP model), planned comparisons of the cue x VF accuracy data for concrete nouns were carried out to test the predictions made, even though the cue x VF interaction only approached significance (p = .088). Contrary to expectation, the congruent cue appeared to be more effective in relation to the xxx cue in the LVF than in the RVF, as shown in Figure 6. Taking the xxx cue condition as a baseline for the usual RVF advantage, the congruent cue erases the VF difference, resulting in zero VF advantage for the congruent cue condition. Thus, grammatical facilitation of the part-of-speech decision for concrete nouns seems to be stronger in the RH than in the LH. This surprising finding is contrary to our expectations. It is presently unclear how the RH takes advantage of the grammatical relationship contained in the functor+noun phrases. It may be that the RVF-LVF is able to determine the part of speech from the word itself, but that the LVF-RH is aided by the cue, at least for these unambiguous concrete noun stimuli.

II. Trans-hemispheric Interaction model: A PDP approach

We can also begin to lay out a completely a new transhemispheric interaction model with these data, although this is still just a schema for a model, rather than one ready for computer simulation. We present it here in the spirit of trying to move beyond box-and-arrow representations of cognitive processes. In spite of its current lack of constraints, this PDP model has several distinct advantages. First, some desired results, such as the absence of a word-superiority effect in the LVF (see below) follow logically from its architecture. Second, it can model a number of various apparently incompatible empirical findings by small changes in processing parameters; the particular data of most interest to us are the finding of a lateralized concreteness effect in the present study (and in the literature) vs. the finding of a bilateral concreteness effect in previous work from our laboratory (Eviatar et al., submitted) and elsewhere.

We start from the analysis of lexical processing tasks into pre-lexical-access, lexical, and post-lexical-access levels, but let us revise it via a more detailed consideration of how information might be propagated in the brain. These considerations are derived from the parallel data processing model of Rumelhart and McClelland (McClelland & Rumelhart, 1981 etc.), but they are not tied to any particular version of that model (or to any claims that grammatical processing can be accounted for without symbol manipulation), and our general approach bears close comparison to that of Seidenberg (1988). We use Rumelhart and McClelland's terminology and speak of the structures that become activated as "nodes", reminding the reader that linking this notion directly with neural structures is still problematic (Bruce McNaughton, personal communication). For the sake of simplicity, we will assume that a single node, whatever its physiological correlate might be, lies entirely within one or the other hemisphere. We find it interesting that Stephen Kosslyn has been developing a parallel data processing model for visual processing; it uses slightly different assumptions from the present PDP verbal processing model but seems to have been constructed in much the same spirit (see Kosslyn, 1987).

We will restrict ourselves here to accounting for the concreteness and emotionality effects. The nature of syntactic "priming" is still extremely unclear

(Goodman, McClelland, & Gibbs 1981; Saidenberg, Waters, Sanders, & Langer, 1984; Tanenhaus & Donnenwerth-Nolan, 1984, Tanenhaus, Leiman, & Saidenberg, 1979; West & Stanovich, 1986; Wright & Garrett, 1984), and about all that can presently be said, as a result of the concerted efforts of the cited researchers and their colleagues, is that it seems to be a post-lexical effect. "Priming" is in fact a misnomer for the sort of facilitation effect we found: the works cited make it clear that spreading activation during lexical access is not a likely model for any form of syntactic facilitation.

PDP modeling is well-developed only for lexical access; syntax processing models are still under development. Furthermore, functor-processing data such as the ones we obtained in the present experiment are still too scanty to support detailed model building. The only moderately comparable data are those from Chiarello and Nuding's (1987) Experiment 2, mentioned above: they studied acceptablity judgements of lateralized content + content vs. functor + content phrases, and their findings on functor processing were fully compatible with ours: there was no difference between the two types of phrases due to visual field of presentation (either in reaction time or accuracy of judgement). As they say (p.546), "The absence of any reliable wordclass effect in the phrase judgement task ... precludes interpretation of hemispheric differences in post-access processing of content vs. function words."

Assumptions of the Trans-Hemispheric PDP Model of Lexical Arousal

We will present the assumptions specific to the Trans-hemispheric Interaction model of word-recognition here; properties common to PDP models in general are reviewed in Appendix 2.

1) Information (conceived of as neural activation patterns) propagates rapidly along neural connections, and crosses the corpus callosum freely. (Remember that the transfer time across the corpus callosum for simple impulses is 6 msec, while response times in typical experiments are at least 500 msec and in our experiment were often over 1000 msec).

2) Highly specific and familiar stimuli have corresponding nodes whose threshold is low and whose activation fades slowly. The "slow fade" is modeled by allowing such a node to be connected with itself as well as with others, so that it is re-activated by the impulses that it has sent out. Thus, words (in the LH) and images (in the RH; also in the LH, but that is not relevant here) are aroused more and for a much longer time than general diffusely linked sets of associations. This hypothesis is intended to correspond to the subjective feeling that words and images are things one can hold onto in the mind, while many mental states that are not encoded as words or images seem to fade rapidly and irretrievably.

3) In the connected brain, a decision is not made 'by' one hemisphere or the other, but by the summation of the activations which arrive at the nodes controlling the final reponse pathway: ex duobus unum. Cf. the suggestion of Churchland and Sejnowski (1988), p.742: "Decisions to act and the execution of plans and choices could be the outcome of a system with distributed control, rather than a single control center." This would be the natural mode of operation for a connectionist model.

4) Understanding a word sufficiently to operate on it requires arousing a certain amount of its association network. Different tasks - naming, lexical

decision, semantic classification, grammatical classification - may require different subsets of the network to be aroused.

5) In the typical left-language dominant brain, ONLY the left hemisphere has a lexicon, defined explicitly as a set of connections between the (written or spoken) forms of words and their meanings and grammatical specifications; each word is represented by a node (or set of nodes). Note that this is congruent with the finding of Zaidel and Peters (1983) that the right hemisphere has no access to the phonological forms of words.

6) The right hemisphere has a stored set of abstracted images, represented by nodes (or sets of nodes); images of letters are included as well. (The left hemisphere also has imaging abilities, but for simplicity, we will leave those out of our account. For an elaborated account of the imaging capacities of the two hemispheres, see Kosslyn, 1987, 1988).

7) Both hemispheres have a network of associations with a word; together, these are tantamount to one's knowledge of all the meanings of a word (normally accessed during any form of processing, if we follow Swinney, 1979 - but see also Tabossi, 1988) and then, at slightly greater remove, all of one's associations with a word and with its meanings. They therefore collectively include all the information needed for lexical decision, grammatical categorization, and all the other linguistic and metalinguistic tasks that people can perform. These networks probably differ to some extent in the two hemispheres. In the normal brain they are well-connected via the corpus callosum.

Now let us work through what happens after visual exposure to the written form of a concrete noun; the information here is summarized in Chart 1. We will focus on showing how the model can yield either the left-lateralized concreteness effect found in the present paper and in other cited works or the bilateral concreteness effect which was found in previous work in our lab and elsewhere. Steps which are not essential to our argument but which are noted because they relate to other important phenomena of word perception are parenthesized in the chart.

Insert Chart 1

Step 1, RVF-LH (see Figure 8). Visual input of a normal written form - let us say the letters A-P-P-L-E to the right visual field - left hemisphere starts to arouse letter nodes (etc., creating the phenomena of visual short-term memory). RH gets the relayed letter image, but nothing is subsequently aroused by it within the RH.

Step 1, LVF-RH. Visual input of a normal written form (A-P-P-L-E) to the left visual field - right hemisphere activates nodes for those letters, but this information does not activate anything else in the RH. LH gets relayed visual data and letter images.

Insert Figure 8 about here

Step 2, RVF-LH (see Figure 9). Activation of letter nodes rapidly and interactively activates the lexicon. (Pre-lexical phonological information nodes are also activated.) Lexical information propagates back to the letter recognition step.

Step 2, LVF-RH. The relayed letter image activates the lexicon in the same way as if the RVF had seen the letters, but activation is weaker or slower to build because interaction between the lexicon and the relayed visual image is delayed: the 6msec delay at each callosal transfer adds up when the stimulus is more than 3 letters long, and gets worse as length increases to the testable maximum of about 6 letters. (It might be well to postulate that there is also a serial interactive lexical access mode in the LH and that its contribution begins to dominates lexical arousal as the parallel interactive mode is slowed down.)

Insert Figure 9 about here

Rationale for Steps 1-2: Chiarello shows that the literature clearly supports a model in which the left hemisphere has access to a lexically-based processing mode, while the right hemisphere appears to process words letter-by letter. The absence or near-absence of an LVF word-superiority effect in letter identification (Krueger, 1975) follows directly from this model, since that effect comes from the top-down interaction of letter identification with lexical entries; in the unilateral lexicon model, this interaction is optimal in the LH, but hampered in LVF presentation, since it must then take place across the corpus callosum. (In the most recent work of Eviatar and Zaidel, a word length effect is found for the longest words - six letters - in the RVF. We would handle this with the serial mode mentioned above.)

We should note (P. Smolensky, personal communication) that there is as yet no evidence from computer modeling which demonstrates that a 6msec propagation delay would actually have this attenuating effect on activation; at the present writing, there are several opposing conjectures as to what would happen. Kosslyn (1987) hypothesizes a resource competition model to account for trans-callosal attentuation; both mechanisms might well be involved.

Step 3, RVF-LH (see Figure 10). The identity of the most highly activated lexical item ("apple") arouses its meaning above threshold. The activation of the word node stays strong for a relatively long time. The meaning also propagates to the RH, where an image of the object is aroused.

Step 3, LVF-RH. Same as step 3 for LH, but activation may be weaker since activation of the word node was weaker. After propagation to RH, an image is aroused.

Insert Figure 10 about here

Step 4, RVF-LH (see Figure 11). The meaning propagates to all receptive areas of the brain, arousing the associations of the word (the linguist's "encyclopedia entry"). The node for the word remains active long enough for propagation to take place interactively.

Step 4, LVF - RH. The image propagates to all receptive areas of the brain, arousing associations of the image - i.e. the 'encylopedia entry', although possibly a different pattern of arousal than if the activation had been via the word. The image fades slowly, allowing time for full interactive propagation.

Insert Figure 11 about here

Step 5, both hemifields/hemispheres. Sufficient information is now available to allow the stimulus information to interact with whatever stored knowledge is required for response to experimental tasks (lexical decision, word-naming, semantic or grammatical classification).

If the displayed lexical item was an abstract noun or other non-imageable word, steps 1 and 2 are the same as for concrete words, but after the RH gets the relayed meaning (step 3), no image is aroused, and so the RH cannot hold onto this meaning. The arousal of the RH associative network will therefore usually be indirect, entirely dependent on the LH. If the RVF-LH saw the word, the LH arousal will be strong; but if the LVF-RH saw the word, the LH arousal will probably be weaker (as above for concrete nouns), and the RH weaker still, making the LVF-RH response to non-imageable words the poorest of the six sections of Chart 1.

However, there is one well-documented condition under which abstract words are responded to about as well after LVF exposure as after RVF exposure: when the words are highly emotionally loaded. This effect is stronger for shorter words, and there are some gender differences as well; see Eviatar and Zaidel (submitted). The emotionality effect can of course be accounted for by assuming that the right hemisphere has such words in its lexicon. However, it can also be handled with the PDP Trans-hemispheric Interaction unilateral lexicon model. Note the qualifier in the statement above that "the arousal of the RH associative model will ... usually be indirect, entirely dependent on the LH." Suppose we assume that emotionally loaded words are powerful just because they activate their association networks very strongly and rapidly. Then the postulated inability of the RH to hold onto the meanings of words does not matter; when HATE or LOVE is momentarily aroused, the association network is activated before the stimulus meaning fades.

There is a potential difficulty here, since an association network arousal probably does not uniquely determine a word; knowledge of the word's form is necessary. One might argue that the RH still quickly loses exactly what the stimulus word meant even if the word's association network is fully activated, and by hypothesis only the LH can keep track of the word's form. Within the PDP unilateral lexicon model, how can the RH participate in lexical decision or naming?

The answer lies in assuming that the brain has a high degree of functional connectedness (note that this is opposite to the assumption made by the hemispheric independence model). The aroused RH part of the associative network interacts with the LH part, and this in turn keeps the word meaning and word form active, contributing to raising them above threshold. If the LH activation alone is sufficient to keep them above threshold, the RH contribution will be undetectable; but if the LH activation is weak, the RH contribution will be critical to all post-lexical processes.

The Trans-hemispheric Interaction model can also handle the data that Chiarello finds the most problematic in her review: the instability of the concreteness effect under minimal variation of experimental conditions, coupled with the absence of any concreteness effect in non-lateralized presentation paradigms. In addition, it can model the data that are often considered as the strongest argument for bilateral representation, namely, the appearance of different decision criteria in the two hemispheres. It does so by providing a variable to blame the mess on: the relative speed and strength of the contributions of the two hemispheres towards the final response. In Appendix Three, we work through explanations for some of the result configurations which have been reported.

Another constraint that must be satisfied by any model of laterality differences in reading is the differential sensitivity of RVF and LVH to stimulus degradation. In several paradigms (e.g. visual frequency filtering, Hardyck, in press; non-standard letter positions: Ellis, Young, & Anderson, 1988; Young & Ellis, 1985) the RVF advantage for word reading is sharply reduced or even eliminated, but it only becomes an LVF advantage in very-short-duration lexical decisions (not in naming) (Bradshaw & Nettleton, p. 90). Chiarello 1988 interprets the findings about the reduction in RVF advantage within the sequential-processing paradigm as indicating that (p. 48) "with vertical or other unfamiliar presentation, specialized LH lexical encoding mechanisms are not invoked, and the word will be processed serially, in a manner not qualitatively different from that used by the right hemisphere."

At first blush, these degradation/non-standard presentation data present a problem for the interactive unilateral lexicon model, whose only "specialized LH lexical encoding mechanism" is the interactive contact between letter-recognition and the lexicon. After all, in any combination bottom-up/top-down recognition model, as stimuli become noisy, the top-down component should make a larger and larger contribution to the recognition process. In the PDP unilateral lexicon model, by hypothesis, the top-down processing contribution of the lexicon is highly effective within the LH but hampered by callosal transfer. So the RVF advantage should increase with stimulus degradation.

However, this prediction ignores that fact the the RH is very good - better than the LH - at recognizing visual stimuli under degraded conditions of all sorts, including unfamiliar scripts and overlapping masking (Bradshaw & Nettleton, pp. 89-90). We can model the findings in the literature by assuming that this RH visual ability is strong enough to compensate for the loss of lexical interaction in degraded stimulus viewing. The finding that the RVF is always at least as good as the LVF at naming is compatible with the claim that letters must be relayed to the LH in order to access the lexicon - yielding the serial processing effects mentioned by Chiarello. The finding of an actual LVF advantage in speeded lexical decision (words presented at too short a duration for naming) is a genuine problem for the PDP model unless we allow the RH some ability to store whole-word visual patterns. This loosening may well be needed in any case to account for acquired dyslexia data and split-brain data (see below).

We now need to show that the Trans-hemispheric Interaction model can handle differences in response bias (beta) and similar hemispheric "personality" differences even though metaphors like "the right (or left) hemisphere makes decisions ..." have no role in it. Consider the specific example given by Chiarello (1988, p. 58): in lexical decision tasks, researchers find "a more stringent criterion (nonword response bias) in the LVF, and a more lax criterion (word bias) in the RVF." This is precisely what is to be expected if lexical access is optimal when the RVF receives the stimulus, but suboptimal when the LVF sees it. RVF exposure leads to rapid activation of corresponding lexical entries, and perhaps also to sufficient activation of "neighbors" of nonwords (see McClelland & Rumelhart, 1981) to raise "yes" responses above threshold, leading to more hits and more false positive acceptances of nonwords: a "word bias". LVF exposures lead to slower and weaker activation of the lexicon, and fewer occasions for reaching the threshold of the "yes" response. (The effect of slowed interaction on activation of neighbors will have to be worked out by running a simulation.)

So far, we have been modeling the intact brain. Now consider the implications of what is known about reading by the disconnected or isolated right hemisphere (excluding left infant hemispherectomy patients). Some isolated right hemispheres can read to some extent, and others cannot, regardless of the exact statistics of their distribution (Patterson & Besner, 1984; Patterson et al., 1989). Clearly, these right hemispheres have a lexicon, so the present unilateral-lexicon Trans-hemispheric Interaction model must be relaxed to permit them to store some kind of connection between word form and word meaning.

We observe that to a great extent, the contents of the studied RH lexicons are describable just in terms of the sort of things that the PDP model says that they have the best opportunity to learn: connections between visual letter configurations and the images associated with concrete objects. The usual RH reading performance consists of the recognition of concrete nouns, with semantic errors. The argument that the aphasic deep dyslexic is reading with the RH depends largely on the fact that the same general pattern of success and failure is observed, e.g. Patterson & Besner 1984 p. 317: "Deep dyslexic patients show a dramatic advantage in reading words which have concrete or imageable referents, as contrasted with abstract words of comparable length and familiarity." Elman, Takahashi, and Tohsaku (1981) demonstrated an RVF latency advantage for abstract kanji nouns but no hemifield difference for concrete kanji nouns. Schweiger, Zaidel, Field, and Dobkin (1989) say: "... as the semantic address provided by the RH is diffuse and unconstrained by phonology, the output (of an aphasic deep dyslexic) often consists of semantic paralexias". Even when the RH can speak, as is the case for some hemispherectomy patients, it has no access to internal phonological information about words, such as whether they rhyme (Patterson, Vargha-Khadem, & Polkey 1989; Zaidel & Peters, 1981). Therefore, to model general results about RH reading, we need only to add the assumption that people's right hemispheres vary on the ability to learn letter-configurations or connections between letter-configurations and object images.

What about emotional words in the RH? The Trans-hemispheric Ineraction model treats them differently from concrete nouns, claiming that the fact that the LVF can recognize them results from their "intensity" and the affect that they transmit across the callosum. At present, there appears to be no information available on the reading of emotional words by the disconnected LVF, but it seems that the present model could be modified fairly easily to fit with any future finding - a strength or a weakness, depending on how you look at it.

Verb-noun differences

Before concluding, we would like to discuss one more interesting result, for which we have no explanation. Pure verbs differ significantly from pure nouns on error type in the neutral xxx-cue condition and in the congruent-cue condition: verbs have more false alarms than nouns, while nouns have more misses than verbs. In the determining-cue condition, where the content words are ambiguously nouns or verbs, an excess of false alarms is found regardless of whether the cue indicates that the stimulus is to be read as a verb or a noun. This effect is thus clearly located in the content word. Thus, subjects have a greater disposition to push the response button when there is a verb stimulus than when there is a noun stimulus, independent of the question being asked ("Is it a noun?" or "Is it a verb?").

Babkoff et al., in what appears to be the only other published grammatical classification study, used a choice paradigm (one key for noun, one key for verb) rather than a go-nogo paradigm, so that all errors are "false alarms" and no error type analysis is possible. In their study, there were more errors to verbs than to nouns in all conditions, (a mean of 14% errors to verb stimuli vs. 10% errors to noun stimuli), indicating a greater disposition to respond "verb" in the noun condition than to respond "noun" in the verb condition. This agrees with our findings, to the extent that the two studies can be compared.

Psycholinguistic and neurolinguistic studies of differences between nouns and verbs (e.g. Gentner, 1981; Miceli, Silveri, Villa, & Caramazza, 1984; Zingeser, 1989) do not presently offer us a ready explanation for this phenomenon, nor is it easy to relate it to the available findings on verbs in lexical decision and naming tasks, which show responses to verbs as slower and less accurate than responses to nouns or to concrete nouns (Eviatar et al., submitted; Hines, 1976). This means that there are fewer button presses for verbs than for nouns in lexical decison. Studies using other classification tasks (such as semantic categorization) and other parts of speech, might prove fruitful in pursuing this matter.

Conclusion

The pattern of results obtained in this experiment do not allow one to discriminate between a unilateral left-hemisphere lexicon in a trans-hemispheric PDP model and a bilateral lexicon in an anatomical model. However, they do strongly indicate that the right hemisphere plays a role in this grammatical judgement task beyond that of passively relaying information from the RVF to the left hemisphere. A simple callosal relay model cannot account for the differential effects of concreteness on reaction times in the right and left visual fields. The strong effect of concreteness on LVF performance but not on RVF performance would be extremely difficult to explain if the right hemisphere's role were limited to receiving primary visual data and perhaps identifying letters and then relaying this lower-level information to the left hemisphere. Why should letters or sensory data from concrete words travel across the corpus callosum faster or more accurately than letters or sensory data from abstact words? This category difference does not exist until the word has been identified.

On the other hand, these results can be given a sensible interpretation if we assume that the right hemisphere is able to identify the word or to aid in some way in accessing its syntax or its meaning. The right hemisphere might make its contribution early in the task by identifying those words which are in its own lexicon (especially concrete nouns and emotional words), as in the anatomical model. Or its contribution might come later in the task, after initial word-identification by the left hemisphere; at this stage, its abilities to recall images and to respond emotionally could help to build up the subject's reaction to the level needed for conscious recognition and response, as in the trans-hemispheric interaction model. It is also quite possible that the right hemisphere operates in both of these ways, perhaps to varying extents across individuals.

At present, the unilateral lexicon/trans-hemispheric PDP model is loose enough and powerful enough to account for a large number, perhaps all, of the phenomena that Chiarello (1988) has described with the full bilateral lexicon/dual brain model. It therefore seems that real-time physiological data, especially evoked-potential and metabolic measures, will be important in deciding among our laterality models, at least until new experimental paradigms are developed.

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Appendix 1

Stimulus list with Francis-Kučera frequencies and Toglia-Battig or ISIB/Colorado concreteness ratings (if two sets are given, the first is T-B and the second ISIB)

Nouns

	Abstract			Concrete	
	frequency	concreteness/ imageability		frequency	concreteness/ imageabilty
death	274	-	town	281	5.52/5.47
mile	217	4.81/5.14	wife	265	5.76/5.31
growth	156	-	heart	199	6.05/6.11
truth	150	2.72/4.22 - 2.71/4.22	earth	167	5.81/5.61
threat	56	3.22/3.75 - 3.22/4.45	grass	55	6.02/5.73
mood	45	-	cloth	43	5.76/5.41 - 5.76/3.41
myth	41	3.30/3.53 - 3.35/3.57	coal	40	5.60/5.74
guilt	33	2.95/3.75 - 2.98/3.75	barn	33	-
noon	25	-	cheek	33	(cheeks, 5.98/5.59)
debt	25	4.12/3.78 - 4.18/3.92	pond	32	-
wealth	25	3.15/2.01	shirt	29	6.05/6.12

chore	23	-	blade	26	5.80/5.70
half	20	3.71/4.42	sheep	24	6.18/6.09
width	19	-	tray	21	5.95/5.60
cult	15	-	straw	18	5.91/5.60
gloom	14	3.95/4.45 - 4.00/4.45	sword	12	5.37/6.03

Verbs

speak	274	4.16/4.82
lose	274	-
learn	254	3.66/3.55
send	253	3.20/4.37
spend	194	-
seek	179	3.76/3.29
prove	156	-
teach	153	3.53/4.29
warn	62	3.15/3/53
shut	50	-
solve	49	-
thank	45	-
earn	45	3.45/4.31
dine	32	-
cease	32	-
cling	30	-
preach	26	-
lend	29	-
weep	28	4.38/5.07
greet	28	-
bathe	26	-

bless	26	-
plead	24	-
carve	23	-
kneel	21	-
merge	20	-
quit	20	-
tempt	18	2.79/4.32
strive	18	-
bake	15	-
drown	14	-
hurl	12	-

Category-ambiguous words

total freqency; verb use frequency-noun use frequency

ISIB/Colorado concreteness/imagery

balanced		verb dominant		noun dominant	
hope	300; 164-136	walk	327; 287-40	view	272; 55-217
	3.08/4.29		4.40/5.05		3.80/4.24
claim	223; 99-124	break	254; 228-26	land	270; 38-232
	-		3.60/4.10		5.64/5.98
share	205; 105-100	wish	195; 161-34	ship	154; 28-126
	-		2.69/4.16		6.26/5.75
gain	146; 77-69	ride	145; 121-21	farm	153; 16-137
	3.33/3.00		4.19/4.70		5.61/5.54
brush	74; 38-36	urge	74; 64-10	cloud	71; 7-69
	5.66/5.50		-		5.50/5.89
fish	63; 30-33	dare	50; 45-5	soil	76;9-67
	5.98/6.09		2.90/4.25		5.70/5.46
ease	55; 25-28	scream	48; 40-8	code	60; 5-55
	-		-		-
flash	52; 28-24	toss	46; 41-5	tour	58; 10-48
	4.82/5.37		-		-

pile	49; 26-23 5.00/5.07	yell	37; 31-6 4.35/4.95	prize	37; 3-34 5.02/5.29
cure	39; 20-19 3.57/3.91	spin	34; 31-3 -	storm	36; 5-31 4.98/5.60
stride	34; 15-19 -	**shine**	35; 32-3 -	drum	32; 6-26 6.02/5.93
drain	31; 16-15 -	bounce	32; 28-4 -	dawn	30; 4-26 4.98/5.29

Appendix 2

General assumptions of PDP models

1) A response occurs when activation levels of the nodes controlling that response increase above threshold. Processes take place as soon as a threshold amount of necessary information has been accumulated (pre- and post-lexical processes might therefore become difficult to distinguish, since 'later' processes can start off before logically prior ones have gone to completion).

2) Activation decays over time; decay rate and threshold level are both parameters which may vary across nodes.

3) Activation is interactive. This means that complex responses are not in general the result of a single unidirectional transfer of information (from one or many sources) to the responding unit, but result from a number of exchanges of activation back and forth which reinforce one another until the signals arriving at the responding unit finally reach its response threshold.

4) Other things being equal, responses are fastest when there is arousal from multiple sources, since these can combine to bring the response-triggering node above threshold. (An application of this principle: ambiguous and polysemous words are identified faster than words with few meanings [Gerratt & Jones, 1987; Millis & Button, 1989]; the faster response times associated with composite words such as nouns derived from verbs [Caplan, Holmes, & Marshall, 1975] can also be explained in this way.)

Appendix 3

Explaining the variability of visual field advantage findings with the Trans-hemispheric Interaction model

In all studies, whether or not they show concreteness or emotionality effects, the best performances include those of the RVF - LH on concrete nouns and emotional words (Cells 1 and 5 in Chart 1), and the poorest performances include that of the LVF - RH on abstract non-emotional words (Cell 4). If an emotionality effect is found, Cell 6 performance is as good as Cell 5 on some or all of the usual measures (reaction time, accuracy, or d'). The concreteness effect or lack of it seems to occur as one of the following cases:

A. Cells 1 = 3, both better than 2 = 4 (RVF superiority, no concreteness effect in either hemisphere).

B. Cells 1 = 2, both better than 3 = 4 (a non-lateralized concreteness effect, lateralized presentation, found in Eviatar et al.).

C. Cells 1 = 2 = 3, all better than 4 (found in the present study, reaction time data, and by Chiarello and Nuding).

D. Cell 1 better than 2; 2 better than or same as 3; 3 same as 4 (roughly equivalent to Bradley & Garrett findings).

E. Foveal presentation: no concreteness effect.

Consider Case A: RVF superiority with no word-class effect. Examine first the final step (step 5) in Cell 1 (RVF exposure, concrete word) and in Cell 3 (RVF abstract). When performance is equivalent in these two cells, then the weakness of the RH contribution must be irrelevant; the LH contribution plus perhaps a modest

RH contribution must be enough to get the responding nodes above threshold in good time.

When there is a concreteness effect, on the other hand, as in Case B - i.e. when performance in Cell 1 (concrete) is superior to performance in Cell 3, it must have been the case that the RH contribution to the final response was significant, and that the reduction of the RH contribution in Cell 3 (abstract) has therefore impaired the speed, accuracy, or sensitivity of the final response.

Returning to Case A for Cells 2 (LVF exposure, concrete word) and 4 (LVF exposure, abstract word), there are a number of possible ways to model the desired outcome, which is that Cell 2 is always superior to Cell 4. One is to say that the somewhat degraded (callosally transmitted) LH input still reaches threshold with essentially no help from the RH; another is to say that the difference between the amount of help from the RH in Cell 2 vs. in Cell 4 is not sufficient to affect the response because the LH input is so much stronger.

In Case B, by contrast, we can model the first part of the desired outcome (Cell 1 = Cell 2, i.e. concrete words are responded to equally well, regardless of visual field of input) if the RH contribution in Cell 2 (LVF exposure, concrete word) is strong enough so that it compensates for weakened LH input at step 5. We can also model it by adusting parameters so that after the RH network is aroused (in step 4), this activation spreads to the LH effectively enough to boost the LH arousal. We get the second part of the outcome (both Cell 1 and Cell 2 are better than Cell 3 = Cell 4, i.e. concrete words are better than abstract words, which are equally poor in both visual fields) as desired under these assumptions, too, since the RH contribution is weak or absent in Cells 3 and 4.

Now let us go on to check configurations of variables that might produce Cases C, D, and E. Case C is our present case, in which Cell 4 (LVF exposure, abstract words) is poorer (slower) than Cells 1, 2, and 3, all of which are approximately equal. This would occur if full arousal of at least one hemisphere, either the right or the left, is necessary and sufficient for good performance. Case D (Cell 1 best, i.e. concreteness effect in RVF - LH only) would occur if full arousal of both hemispheres gives an elevated performance, while all configurations of partial arousal of one of both hemispheres give equivalent performances at an inferior level.

Finally, there is Case E to explain away: why are concreteness effects not found in foveal stimulus presentation? According to the model, the concreteness effect will disappear if and only if the RH makes no significant contribution, as in Case A (ignoring the possible contribution of LH images). There seem to be two ways that this can happen: either 1) foveal presentation is effective enough so that the LH contribution alone will push the decision above threshold, rendering the RH contribution redundant, or 2) foveal presentation somehow interferes with RH processing - a speculation that appears to be without any foundation at the moment. Here we have a test of the model: if foveal-exposure experiments that fail to show a concreteness effect seem to show ceiling performance, 1) will work as an explanation. If, however, these experiments are not yielding ceiling performances, e.g. if they have used degraded stimuli so that performance has many errors and seems relatively slow, then the idea that the RH's contribution is redundant in foveal presentation experiments will be hard to maintain.

Chart 1: Summary of trans-hemispheric interaction unilateral lexicon model

[> below indicates trans-callosal relay; / indicates processes initiated separately and roughly simultaneously in the two hemispheres]

LH concrete - Cell 1	RH concrete - Cell 2
1) LH sees > RH gets relayed letter image	1) RH sees > LH gets relayed letter image
2) LH accesses lexicon; has continuing interaction from LH ltr. image	2) LH accesses lexicon; interaction with letter images is slowed by need for repeated trans-callosal transmission
3) LH meaning aroused > RH gets relayed meaning, object image aroused	3) LH meaning aroused > RH gets (less strongly) relayed meaning, object image aroused
4) LH accesses network/RH accesses via word network via image	4) LH accesses network/RH accesses (less effectively) network via image
5) both H's contribute to decision	5) both H's may contribute to decision
LH abstract - Cell 3	RH abstract - Cell 4
1) LH sees > RH gets relayed letter image	1) RH sees > LH gets relayed letter image
2) LH accesses lexicon; gets continuing input activation from LH ltr. im.	2) LH accesses lexicon; relayed ltr. im. gives little or no continuing input to LH
3) LH meaning aroused > RH gets relayed meaning, but cannot 'hold' it	3) LH meaning aroused > RH gets (less strongly) relayed meaning, but cannot 'hold' it
4) LH accesses network> RH network aroused (less effectively)	4) LH accesses network > RH network aroused (somewhat)

5) both H's may contribute to decision	5) both H's may contribute to decision, but neither H is as fully aroused
<u>LH abstract, emotional - Cell 5</u>	<u>RH abstract, emotional - Cell 6</u>
1) LH sees > RH gets relayed ltr. im.	1) RH sees > LH gets relayed ltr. im.
2) LH accesses lexicon; gets continuing input activation from LH ltr. im.	2) LH accesses lexicon; relayed ltr. im. gives little or no continuing input to LH
3) LH meaning aroused > RH gets relayed meaning, cannot 'hold' it, but arouses network very swiftly.	3) LH meaning aroused (less strongly) > RH gets relayed meaning, cannot 'hold' it, but arouses network very swiftly.
4) LH accesses network; network also gets input from RH network arousal	4) LH accesses network, partly from input lexicon, partly due to RH network arousal.
5) both H's contribute to decision	5) both H's may contribute to decision

Table 1

<u>Reaction times as a function of visual field, cue type, and part of speech*</u>

Right-handed native English speaking subjects only N=48

	Category-unambiguous Words				Category-ambiguous Words		
	LVF		RVF			LVF	RVF
cue:	xxx	congruent	xxx	congruent			
nouns	913	952	925	918	noun cue	944	975
verbs	898	867	911	869	verb cue	901	913

*(reaction times in milliseconds)

Table 2

Error Rates as a function of visual field, cue type, error type, and part of speech

Misses

Right-handed native English speaking subjects only N=48

	Category-unambiguous words				Category-ambiguous words		
	LVF		RVF			LVF	RVF
cue:	xxx	congruent	xxx	congruent			
nouns	.234	.177	.182	.177	noun cue	.346	.327
verbs	.229	.151	.161	.120	verb cue	.267	.258

False alarms

Right-handed native English speaking subjects only N=48

	Category-unambiguous words				Category-ambiguous words		
	LVF		RVF			LVF	RVF
cue:	xxx	congruent	xxx	congruent			
nouns	.188	.099	.135	.125	noun cue	.472	.441
verbs	.203	.182	.250	.167	verb cue	.434	.441

Figure and Table Captions

Table 1. Reaction time results.

Table 2. Error analysis.

Figure 1. Response latency, part-of-speech by cue type.

Figure 2. Error rate and types.

Figure 3. Error rate by cue and part of speech.

Figure 4. Response latency, visual field by abstract/concrete.

Figure 5. Error rate, visual field by abstract/concrete.

Figure 6. Error rate, visual field by cue type, concrete only.

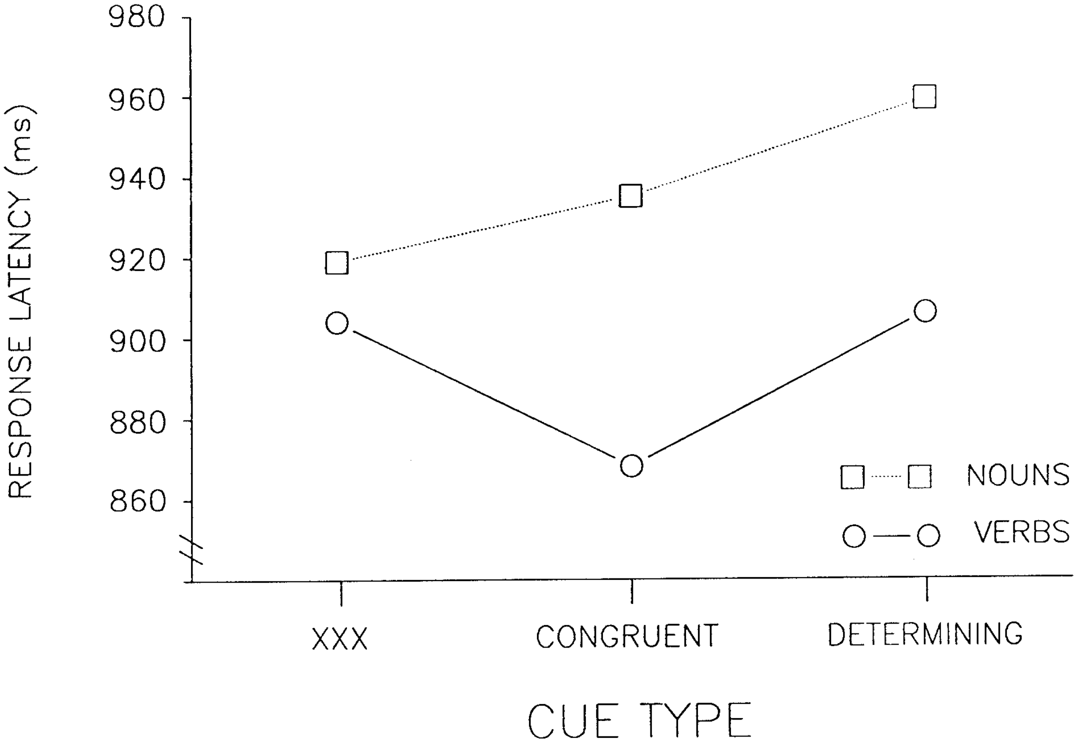
Figure 7. Patterns of possible interactions between visual hemifield of stimulus presentation and an experimental variable with two levels (I and II). The column on the left plots the pattern with hemifield on the Y-axis; the column on the right plots the same data with the experimental variable on the X-axis. * = a statistically significant difference in a planned comparison..

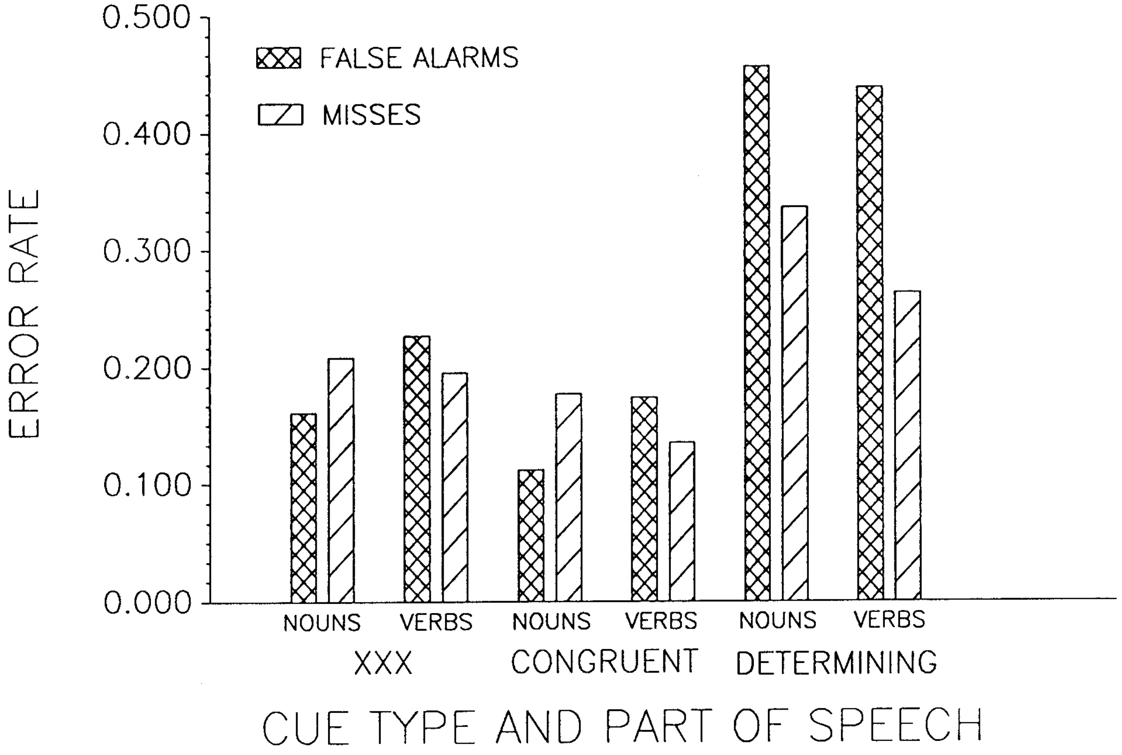
Figure 8. Word recognition, Step 1

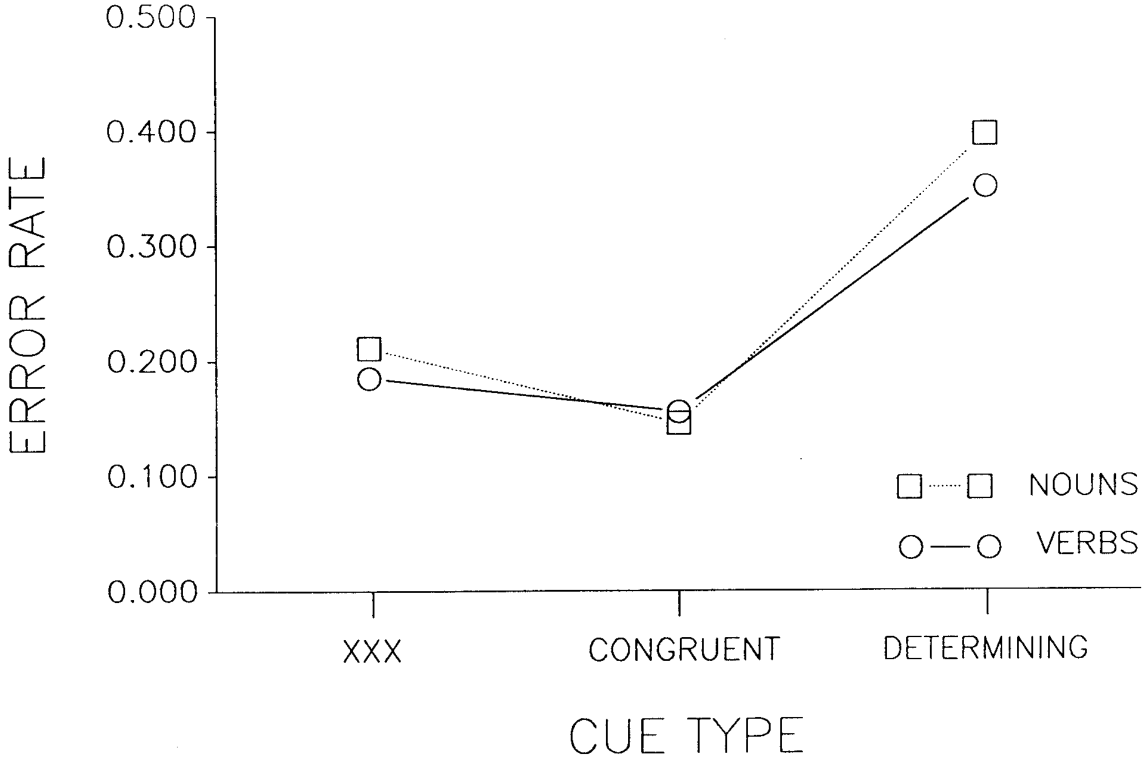
Figure 9. Word recognition, Step 2.

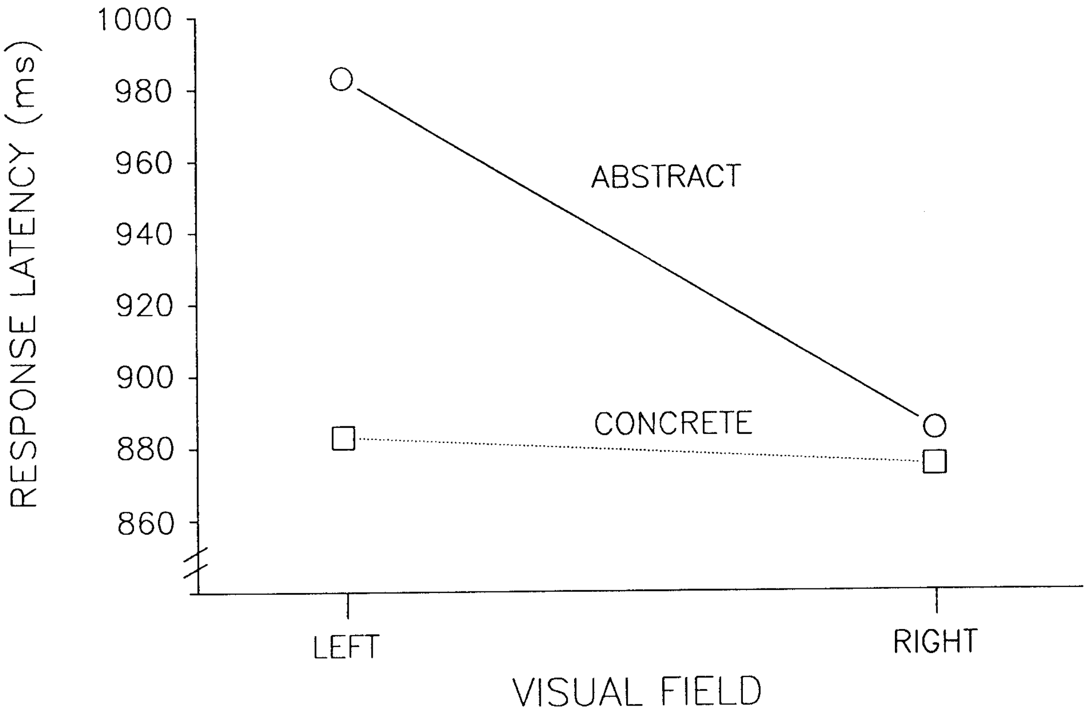
Figure 10. Word recognition, Step 3.

Figure 11. Word recognition, Steps 4 and 5.

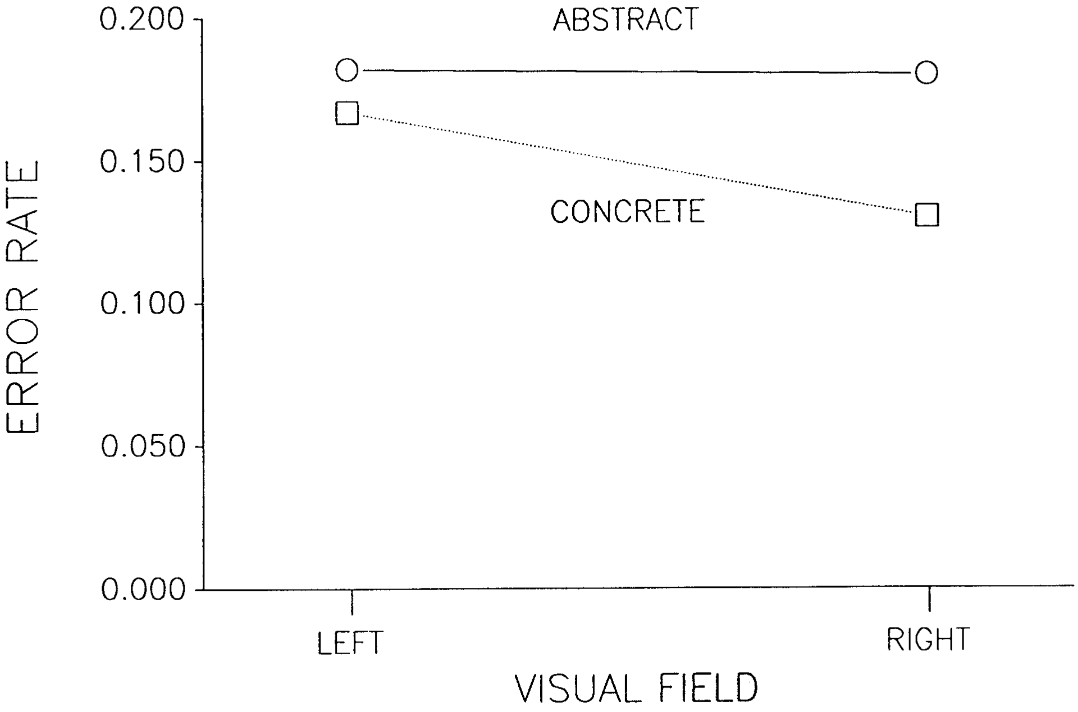

980
960
940
920
900
880
860
RESPONSE LATENCY (ms)
NOUNS
VERBS
XXX
CONGRUENT
DETERMINING
CUE TYPE

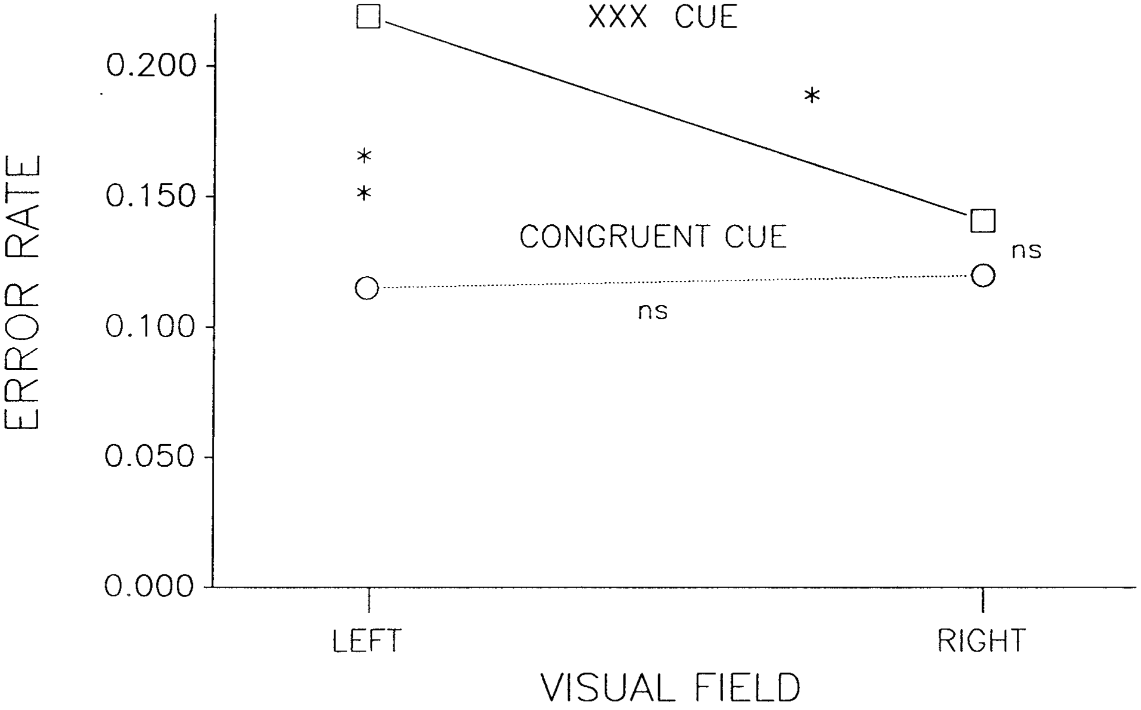

0.500
0.400
0.300
0.200
0.100
0.000
ERROR RATE
FALSE ALARMS
MISSES
NOUNS
VERBS
NOUNS
VERBS
NOUNS
VERBS
XXX
CONGRUENT
DETERMINING
CUE TYPE AND PART OF SPEECH


0.500
0.400
0.300
0.200
0.100
0.000
ERROR RATE
XXX
CONGRUENT
DETERMINING
CUE TYPE
NOUNS
VERBS



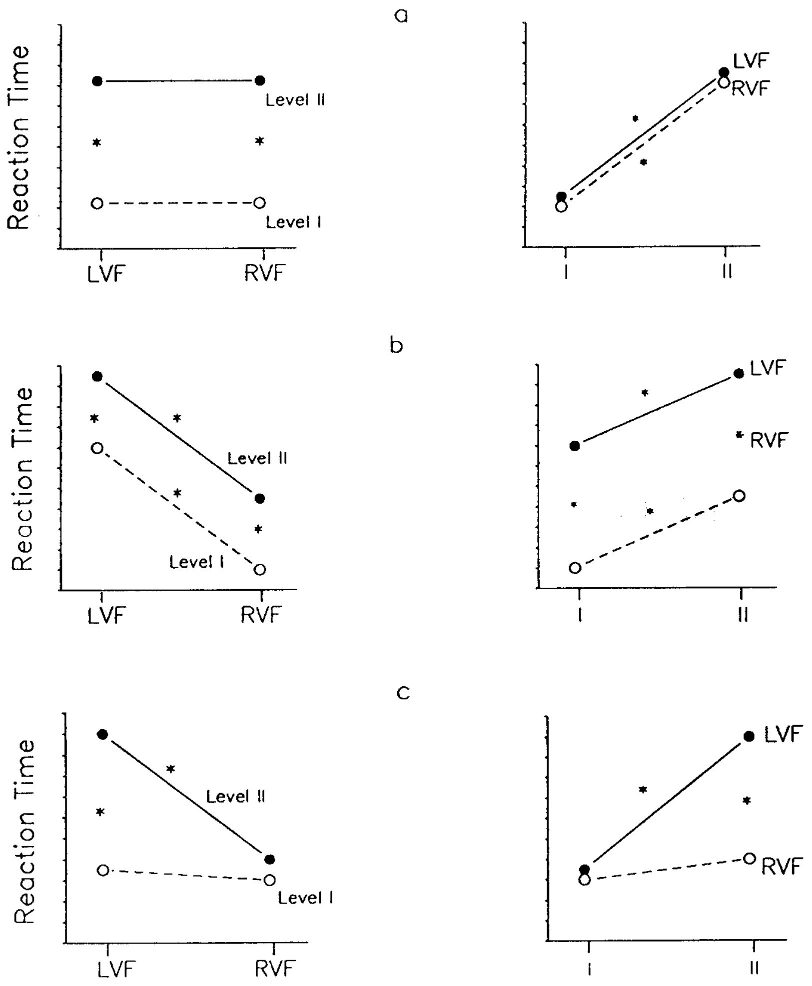
RESPONSE LATENCY (ms)
1000
980
960
940
920
900
880
860
ABSTRACT
CONCRETE
LEFT
RIGHT
VISUAL FIELD


0.200
0.150
0.100
0.050
0.000
ERROR RATE
ABSTRACT
CONCRETE
LEFT
RIGHT
VISUAL FIELD

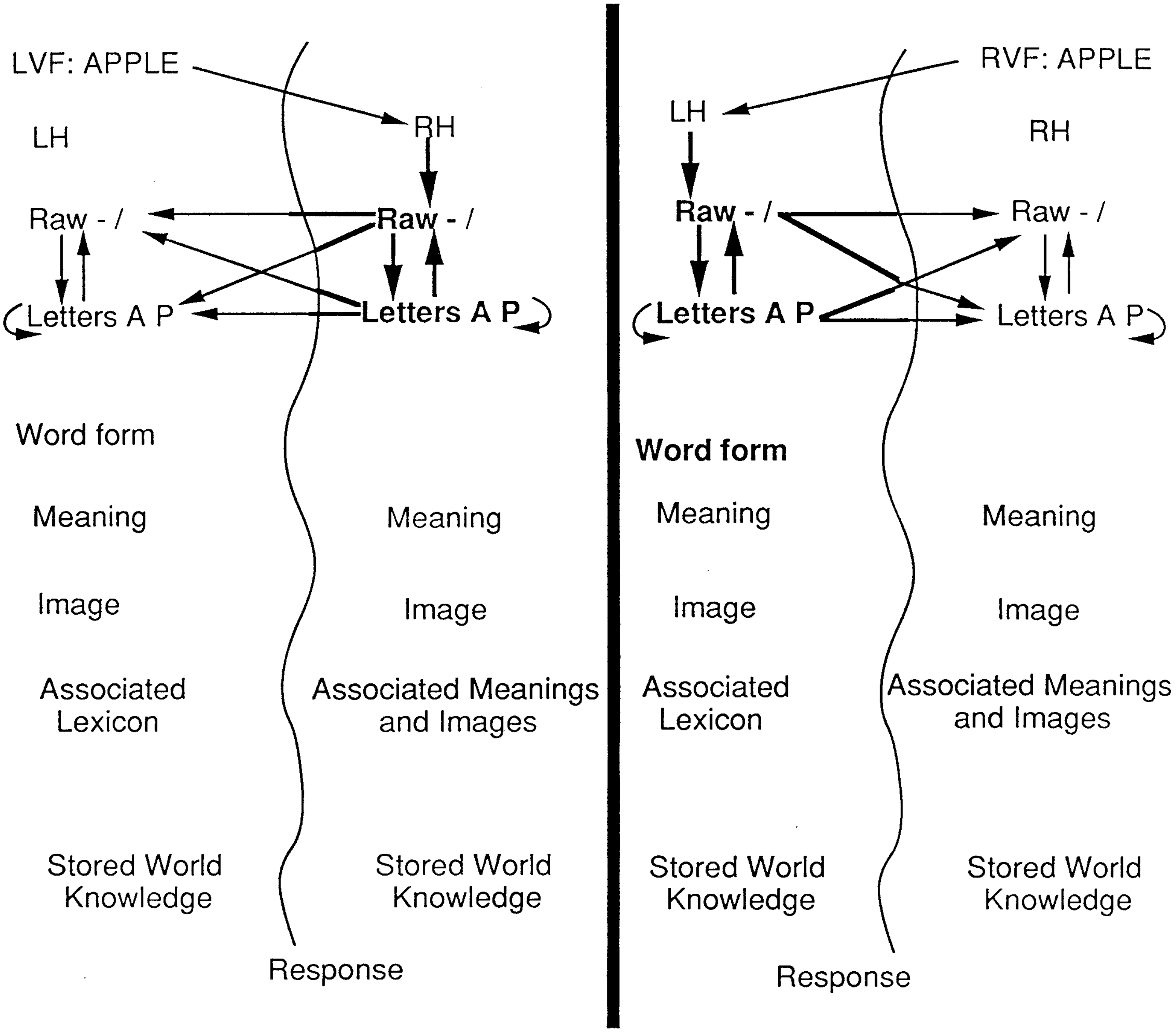

XXX CUE
CONGRUENT CUE
*
*
*
ns
ns
0.200
0.150
0.100
0.050
0.000
ERROR RATE
LEFT
RIGHT
VISUAL FIELD

---

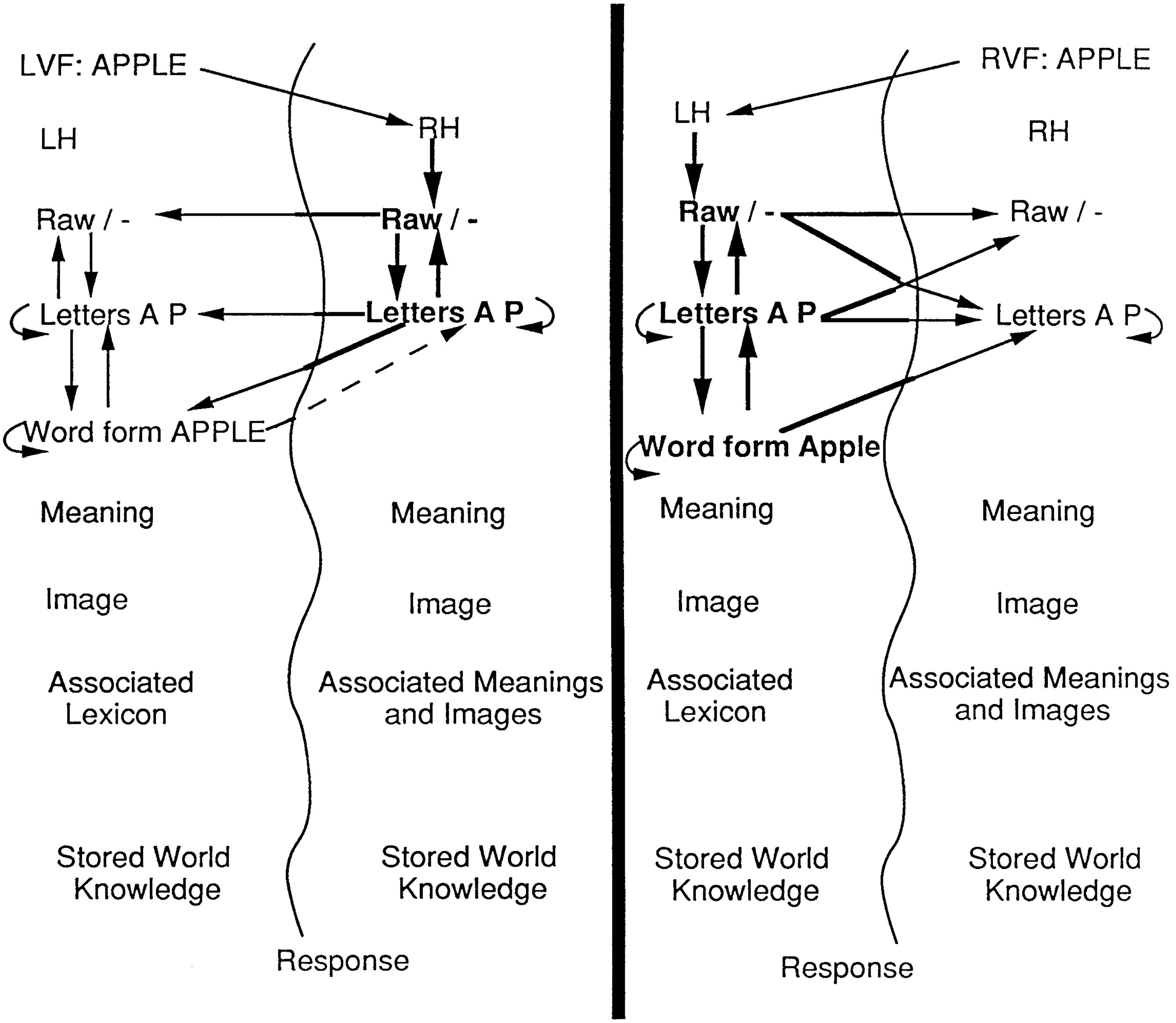
* $p < .01$
** $p < .001$


a
Reaction Time
Level II
Level I
LVF
RVF
LVF
RVF
I
II
b
Reaction Time
Level II
Level I
LVF
RVF
LVF
RVF
I
II
c
Reaction Time
Level II
Level I
LVF
RVF
LVF
RVF
I
II

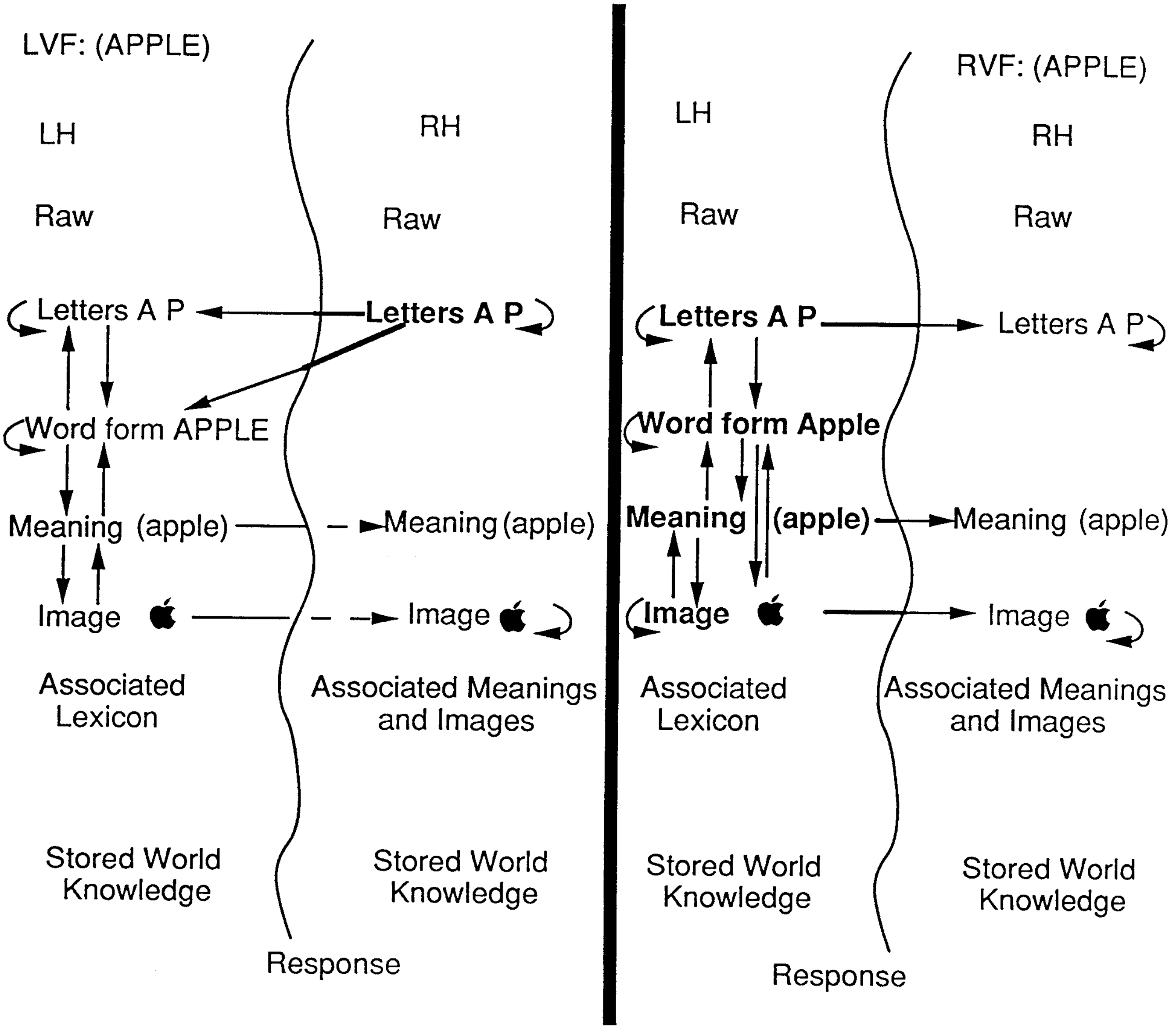
Step 1 - Concrete Noun
Initial Visual Activation



Step 2 - Concrete Noun Word Activation



Step 3 - Concrete Noun
Retrival of Meaning and Image



Steps 4 & 5 - Concrete Noun
Accessing Network & Responding