8-1985

Cerebral Hemispheric Mechanisms in the Retrieval of Ambiguous Word Meanings

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Cerebral Hemispheric Mechanisms in the Retrieval of Ambiguous Word Meanings

A Thesis

Presented to the

Department of Psychology

and the

Faculty of the Graduate College

University of Nebraska

In Partial Fulfillment

of the Requirements for the Degree

Master of Arts

University of Nebraska at Omaha

by

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August 1985

THESIS ACCEPTANCE

Accepted for the faculty of the Graduate College, University of Nebraska, in partial fulfillment of the requirements for the degree Master of Arts, University of Nebraska at Omaha.

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ACKNOWLEDGMENTS

The person most prominent in my academic life has been my advisor, Dr. Greg Simpson. As an undergraduate, he encouraged me to become involved in research. He has unconditionally supported me throughout my career as a student at UNO. I feel privileged to be a Simpson Student (for almost 5 years) and pleased for that to have developed into a collegial relationship, as well as a friendship. It has been as a student with Greg that my interests evolved into what I consider to be my life's direction. I hope to repay this debt to Greg by sharing what he gave me with students of my own some day.

I have also worked with Dr. Frank Clark for over 4 years. Working with Frank has been an important relationship as well. Frank has provided me with ways of looking at problems that I would not have discovered in Psychology. I feel privileged to have worked with Frank at a major point in his career. He has provided me with considerable support and the means by which I could always be involved in research while in school. Frank's contribution to my productivity could not be overestimated.

I feel like the greatest share of my rich experience as a student is a direct result of working with Greg and

Frank. What has been conveyed to me through my association with them is the excitement of doing research. I wanted to be trained to be a researcher, with all other aspects of the educational process being secondary. They are among the very few teachers who really supported me in this respect. I have the deepest appreciation and admiration for them and hope to convey here how necessary their receptivity to my intellectual curiosity has been to my development. I have always felt like they were there when it was important.

Kristine Solomon has been a constant source of support to me during undergraduate and graduate school. She possesses an understanding of the needs of someone who pursues school with a passion. Her support, both personally and technically, has kept my spirits high at times when things were difficult.

A year ago I was overjoyed to finally know someone I considered to be a student colleague and peer. I will very much miss the company of Bob Peterson. Many experimental ideas have evolved from his company and he has always been a resource for me. Just so it can be in print somewhere:

"What's going on in the brain doesn't make any sense"

---Bob Peterson (March 1985)

I have appreciated the commitment of the members of my thesis committee. Dr. Ken Deffenbacher and Dr. Wayne Harrison provided many insights and suggestions that made the thesis a much better product and saved me from needlessly pursuing several aspects of my original idea. I asked them to be on my committee because I have respect for their research ability and because I have felt their support.

I also want to thank the computer network staff, particularly Frank Hartranft and Joyce Crockett. Each has extended themselves on my behalf many times. My neighbor, Carol Singer, has made a contribution to my graduate school that can not be underestimated -- she cared for my cat, Midnight, whenever I was late at school (which meant most every evening).

Oh -- I almost forgot, I HAVE to thank M.G. Krebes for his insight and even more so, Joel's friend, Miles for the best advice about graduate school (and life, really) one could get.

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ABSTRACT

Targets related to ambiguous primes were projected to the left and right visual fields in a lexical priming experiment with stimulus onset asynchronies (SOA) of 35ms and 750ms. Left hemisphere results were similar to earlier results with central projection (Simpson & Burgess, JEP:HPP, 1985). Facilitation across both SOAs for the more frequent meaning and a decrease in facilitation for the less frequent meaning at the longer SOA. In contrast, right hemisphere results indicated a decay of facilitation for the more frequent meaning at the longer SOA, while activation for the subordinate meaning increased. Results suggest that while automatic processing occurs in either hemisphere, only the left hemisphere engages in controlled processing of ambiguous word meanings. In addition, the present results support the idea that the right hemisphere lexicon possesses a richer endowment than earlier thought.

Cerebral Hemispheric Mechanisms in the Retrieval of Ambiguous Word Meanings

A central component of reading comprehension concerns the retrieval of word meanings. Only following such retrieval can the integrative process of understanding what is read occur. How these word meanings are stored and retrieved from the lexicon is a question that has received considerable attention in cognitive psychology (Krashen, 1976; Meyer & Schvaneveldt, 1971; Schvaneveldt, Meyer, & Becker, 1976 Searleman, 1977; Stanovich & West, 1979; Zaidel, 1978). Also, as the relationship between cognitive psychology and the neurosciences has grown closer in recent years, the representation of the lexicon in the cerebral hemispheres has been examined by cognitive psychologists and neuroscientists alike. It has been suggested that research in the neuropsychological underpinnings of word recognition could potentially tell us much about comprehension processes in general (see Posner, 1981, 1984; Posner, Pea & Volpe, 1982).

It is generally conceded that the association cortex of the left hemisphere is primarily responsible for language processes, at least in right handers (Kolb & Whishaw, 1980). At the same time, it is well-accepted that the right hemisphere can demonstrate language comprehension to a greater magnitude than earlier suspected (Krashen, 1976; Searleman, 1977; Zaidel, 1983; cf. Gazzaniga, 1983), and it has been argued that both hemispheres are involved in reading (Ingvar & Lassen, 1977). Zaidel (1977, 1983) has suggested that the lexicon of the right hemisphere appears to be diffuse with more imageable and concrete lexical items that constitute a subset of the left hemisphere lexicon.

A specific case of lexical retrieval involves the processing of ambiguous words, that is, words that have more than one meaning. Most words possess some indeterminacy in the representation of their meanings, so processing ambiguity may be seen as a general characteristic that pervades natural language processing (Swinney, 1982). Any complete language comprehension model, then, would need to account for lexical ambiguity. In fact, ambiguity can be such an obstacle in understanding the comprehension of language that it has been referred to as the "common cold" of language (Kaplan, 1955, p. 39).

This paper will review models of lexical ambiguity and the processes involved in the storage and retrieval of word meanings. The neuropsychological research will then be examined with regard to cerebral hemispheric processing differences (and similarities) in lexical memory. Hypotheses for this thesis will then be suggested from the theoretical convergence of these two research areas.

Lexical Ambiguity

Prior to discussing lexical ambiguity, it may be instructive to review a memory process called "spreading activation," a process that has been used to explain word retrieval. When a word is recognized, it's representation in memory is said to be "activated," and this activation may then spread to the representations of other words, partially activating them. A word recognition model relying on spreading activation assumes that related words are more closely linked in a semantic network than are unrelated words (Collins & Loftus, 1975; Meyer, Schvaneveldt & Ruddy, 1972; cf. Hardyck, 1983; Masson, 1984; Ratcliff & McKoon, 1981). Semantic facilitation (faster responses to words presented in context) is held to occur because activation spreads more rapidly among closely related words than more distantly related or unrelated words (Schvaneveldt & Meyer, 1973). Spreading activation is thought to be an automatic cognitive process (Neely, 1976). That is, activation spreads passively, requires no conscious control, and occurs without interfering with other cognitive processes and occurs very rapidly (see Posner & Snyder, 1975). Therefore, only benefits (and no costs) are derived from spreading activation.

Controlled processes have a role in word recognition as well. At some point in the spread of activation, the limited capacity attention mechanism may direct attention, e.g., to a particular word meaning (Neely, 1976; Posner & Snyder, 1975). Directing attention to a particular word meaning would allow the benefits of the spreading activation to be retained, but would also result in inhibition of word meanings that did not receive attention. Controlled processes are held to have slower onset than automatic processes, and to be sensitive to subject strategies. Word recognition can then be seen as a two-stage process that includes controlled as well as automatic cognitive processes.

One method used to investigate spreading activation is the lexical decision task. This task requires the subject to decide as quickly as possible if a visually presented string of letters is a word (DOCTOR) or a nonword (GLORB). The task assumes that the subject must retrieve the word from memory in order to make a lexical decision. A common finding in word recognition studies such as this is that subjects respond more quickly to a target (e.g., NURSE) when it is preceded by a related word (e.g., DOCTOR) than if it is preceded by an unrelated word (e.g., CHAIR) (Meyer & Schvaneveldt, 1971; Meyer, Schvaneveldt, & Ruddy, 1972).

Simpson (1984; also see Taft, 1984) recently reviewed the role of lexical ambiguity in word recognition, and suggested that three models of ambiguity processing have emerged from the research. A context-dependent model states that the meanings of ambiguous words are activated by the context of the sentences in which they occur. Accordingly, the contextually appropriate meaning of a word is the only meaning that is processed. This model (Glucksberg, 1984; Schvaneveldt, Meyer, & Becker, 1976; Simpson, 1981) is perhaps the most intuitively appealing but the least supported by the research (Simpson, 1984). In fact, there is research that shows activation for meanings that would not be appropriate for the sentence context (Onifer & Swinney, 1981; Seidenberg, Tanenhaus, Leiman, & Bienkowski, 1982; Tanenhaus, Leiman, & Seidenberg, 1979). The present study, however, will be constrained to ambiguity processing with words in isolation. In this respect, the ordered access model and the exhaustive access models are more relevant to the present discussion.

The ordered access model proposes that when an ambiguous word is encountered, retrieval of its meanings takes place in a serial fashion. According to this model, word meanings are selected by their frequency of occurrence (Forster & Bednall, 1976; Hogaboam & Perfetti, 1975). The most frequently occurring word meaning is retrieved first and the search stops if the meaning is appropriate in context. If the first meaning is not appropriate (MONEY in the case of the ambiguous word BANK), another meaning (viz., RIVER) is selected. This serial self-terminating search continues until a fit is made with context. In the absence of context, the dominant meaning would be retrieved (Simpson, 1981).

Alternatively, the exhaustive access model states that all word meanings are retrieved upon the presentation of an ambiguous word, after which context allows for the selection of the appropriate meaning (Holley-Wilcox & Blank, 1980; Lucas, 1984; Onifer & Swinney, 1981; Swinney, 1979). Context affects this selection process, but lexical activation occurs automatically and exhaustively (Onifer & Swinney, 1981; Seidenberg et al.

1982; Swinney, 1979; Tanenhaus et al. 1979). The exhaustive access model differs from the ordered access model in its predictions for retrieving word meanings that vary in frequency of use. While the ordered access model first selects the most frequently used meaning, the exhaustive access model would activate all the meanings in parallel. If all meanings are activated, there should be no retrieval advantage for the more frequent word meaning.

Recent research by Simpson and Burgess (1985) suggests that an ordered or exhaustive search model alone will not account for activation patterns in ambiguity processing. Reaction time (RT) to a lexical decision task was used as the dependent measure. The order of stimuli for each trial consisted of a fixation point (so subjects would know where on the CRT screen the prime and target would occur), a prime, and finally a target. The prime was either an ambiguous word (e.g., BANK) or a neutral stimulus (-----). The target was either a word related to one of the ambiguous word's meanings (e.g., MONEY or RIVER) or a nonword (e.g., GLORB). Subjects responded only to the target. The interval between the onset of the prime and the onset of the target (stimulus onset asynchrony, or SOA) varied from 16ms to 750ms. Simpson and Burgess included the neutral condition to serve as a baseline against which facilitation and inhibition could be computed (see Neely 1976, 1977; cf. Jonides & Mack, 1984). Facilitation is computed by subtracting the mean RT to the neutral prime condition from the mean RT to the related word target.

Inhibition is found by subtracting the mean RT to the neutral prime condition from the unrelated mean RT. Simpson and Burgess found that rate of semantic activation was a function of meaning frequency. Dominant meanings showed facilitation at all SOAs. The subordinate meanings showed no facilitation at the briefest SOA, but activation built as SOA increased, so that by 300ms the subordinate meaning showed the same level of facilitation as the dominant meaning. It would seem that access is exhaustive since both meanings were equally available by 300ms. However, the rate at which activation occurs differs with meaning frequency.

After 300ms, Simpson and Burgess (1985) found that facilitation for the subordinate meanings declined but that facilitation for the dominant meanings was maintained. These findings are suggestive of a two-process model of ambiguous word recognition, whereby word meanings are first activated automatically, followed by a stage in which attention is allocated to the dominant meaning (also see Inhoff, 1984). Once attention is directed to the dominant meaning, additional time is required to reallocate attention to the subordinate meaning. This difficulty in reallocating attention results in inhibition for responses to words related to the subordinate meaning. This suggests an active and capacity-limited process for the second stage of ambiguity processing, similar to the controlled processing described by Neely (1976, 1977) and Posner and Snyder (1975).

Hemisphere Asymmetries in Lexical Representation

The issues central to lexical ambiguity are also important in understanding neuropsychological models of word recognition. For example, Zurif (1980) has suggested that the semantic system for some dyslexics is the same as normals but without the peripheral lexical codes needed to comprehend semantically distant word meanings. Chiarello (1983, in press) has shown that lexical information is available for processing in each hemisphere, but that the hemispheres differ with respect to lexical organizational and retrieval processes. Chiarello (in press) investigated three kinds of lexical priming: orthographically related stimuli (BEAK-BEAR), phonologically related stimuli (JUICE-MOOSE), and semantically related stimuli (INCH-YARD). These stimuli were used in two series of experiments to ascertain the degree to which automatic or controlled word retrieval processes are responsible for lexical access in the two hemispheres. Chiarello (in press) manipulated probability of related word pairs. In one experiment, related trials occurred only 25% of the time, while in the other, they occur 75% of the time. In the latter case, but not in the former, subjects are encouraged to use controlled processes to facilitate word recognition. The two experiments, therefore, were held to tap automatic and controlled word recognition processes, respectively.

The results from her automatic priming experiments suggested that semantic priming occurred in both hemispheres, but that greater priming occurred in the right hemisphere. The retrieval process appeared to be quite different, however, in the controlled priming experiment. Chiarello (in press) found that controlled semantic priming still occurred in both hemispheres, but was now larger in the left hemisphere.

The distinction between automatic and controlled processing appears to be important, particularly as it concerns semantic or lexical memory. Chiarello (in press) found that semantic priming occurred in each hemisphere in both the controlled and the automatic priming conditions (cf. Zecker, Tanenhaus, Alderman, & Siqueland, 1984; Zecker & Zinner, 1984). In Chiarello's controlled processing experiment, greater facilitation was found for semantic priming in the left hemisphere. It is possible that the greater efficiency of the left hemisphere at attaining a preparatory state could affect performance on tasks requiring controlled processing (see Cohen, 1975). On the other hand, in the automatic processing experiment, there was greater facilitation in the right hemisphere for semantic priming. Intuitively, since the left hemisphere is more specialized for language function, one might expect greater facilitation in the left hemisphere for both automatic and controlled processing. However, Zaidel (1983) obtained results with commissurotomy patients consistent with those of Chiarello (in press), namely, greater facilitation with an automatic priming task in the right hemisphere. Chiarello (in press) explained the opposite hemispheric asymmetries for automatic and controlled semantic facilitation by making two assumptions. First, Zaidel (1978; also Ellis & Shepherd, 1974; Mannhaupt, 1983) argues that the right hemisphere lexicon consists of words that are of high frequency, concrete, and imageable (cf. Lambert, 1982a, 1982b; Moscovitch, 1981), and that these words are a subset of the words contained in the left hemisphere lexicon. Secondly, Chiarello draws from Anderson's (1976, see chp. 8) claim that an inverse relationship exists between the amount of activation spreading to a single network node and the extent of the semantic network. A richer semantic network in the left hemisphere, then, would lead to smaller spreading activation effects for any given node.

The idea that left hemisphere involvement is necessary for controlled semantic processing receives additional support from the work of Milberg and Blumstein (1981; Blumstein, Milberg & Shrier, 1982). A lexical decision task was used with patients with left hemisphere lesions. These patients showed no deficit with the automatic retrieval of word meanings (also see Sidtis, 1985), yet these same patients were unable to retrieve word meanings for use in a controlled semantic decision.

There has been one study that qualified the findings of Milberg and Blumstein (1981). Pierce (1984) concluded that aphasic subjects experienced a general deficit in retrieving meanings of ambiguous words. Pierce's subjects used a selection and decision procedure that allowed for a (relatively) long duration prior to the word decision, i.e., controlled processing. Simpson and Burgess (1985) have shown that only the dominant meanings show semantic facilitation at the longer durations for normal subjects, so Pierce's results may not reflect his subjects' actual ability to activate less frequent word meanings. A misleading picture can emerge if the distinction between automatic and controlled processing is not taken into account. That semantic processing can occur in either hemisphere is also supported by an evoked potential study by Roemer and Teyler (1977; Teyler, Roemer, Harrison & Thompson, 1973). They found that waveforms for particular stimulus word meanings were very similar in the right and left hemisphere.

The present experiment aims to extend our understanding concerning how speed of retrieval of dominant and subordinate meanings of ambiguous words (Simpson & Burgess, 1985) relates to the availability of these various meanings in the left and right cerebral hemispheres. As automatic processing is believed to operate before controlled processing can begin, the short SOA restricts the subjects processing capability. Two widely spaced SOAs (35ms and 750ms) were used that were similar to the shortest and longest SOA used by Simpson and Burgess (1985). The SOA manipulation was used to separate automatic and controlled processes in word recognition (Recall that Chiarello used probability of occurrence to elicit controlled processing). Because of the rapid onset of spreading activation, it is assumed that the short SOA will tap automatic processes only (Posner & Snyder, 1975; Hasher & Zacks, 1979; Simpson & Lorsbach, 1983). The 750ms SOA, on the other hand, is assumed to be long enough to allow controlled processing to occur, and, indeed, controlled processing of ambiguous words was demonstrated at this SOA by Simpson and Burgess (1985). Chiarello (in press) did not find controlled processing in the right hemisphere, although controlled processing occurred in the left hemisphere. At the 35ms SOA then, the automatic retrieval pattern of facilitation for the dominant meaning (but not for the subordinate meaning) is expected in both hemispheres. However, it is expected that controlled processing, namely inhibition of the subordinate meaning at the 750ms SOA, should be present in the left hemisphere, but not present in the right hemisphere. In both the automatic and controlled conditions, greater facilitation is expected in the right hemisphere due to the smaller set of lexical entries (see Anderson, 1976; Chiarello, in press).

Viewing the cerebral hemispheres as separate cognitive processing systems raises an interesting question concerning what should happen to the subordinate meaning in the right hemisphere at the 750ms SOA. As mentioned earlier, there should be inhibition for the subordinate meaning in the left hemisphere (i.e., controlled processing). It is not expected that controlled processing will occur in the right hemisphere (see Chiarello, 1985a).

It is not clear what to expect from the subordinate meaning. Lucas (1984) has suggested that activation for the inappropriate (subordinate) meaning decays. In general, this is probably not a preferred explanation over the notion of inhibition (see Simpson, 1984). However, in a cognitive system where inhibition may not occur (viz., the right hemisphere), the lack of facilitation would suggest that decay had occurred. Alternatively, if activation is maintained, one would expect to see equal facilitation for the dominant and subordinate meanings such as at the 300ms SOA in the Simpson and Burgess (1985) study.

Right-handed subjects will be used, and the hand used for the response in the lexical decision task will be varied between-subjects. Different patterns between response hand and hemispheric word recognition are possible if the memory retrieval processes and the processes involved in carrying out the motor response component of the lexical decision task compete for the same hemispheric resources (Chiarello, 1985b; Friedman, personal communication, November 1984; Friedman & Polson, 1981).

Method

Subjects. Subjects were 60 volunteers, University of Nebraska at psychology students, who agreed to participate for extra credit. English was their native language. All subjects had normal or corrected-to-normal vision and were right handed (with a non-inverted writing posture; see Levy & Reid, 1976, Levy, 1982) as verified when they signed the informed consent form. All relevant ethical guidelines were met.

Stimuli. One hundred twenty homographs were selected from the Nelson, McEvoy, Walling, and Wheeler (1980) norms. Two meanings were selected for each homograph. One associate was related to the homograph through its dominant meaning, and one through a subordinate meaning (see Table 1). Dominant and subordinate associates did not differ in length, $t(238) = 0.75$, $p > .05$, or in printed frequency, $t(238) = -1.41$, $p > .05$ (Kucera & Francis, 1967).

A second set of ambiguous primes was selected for nonword trials. Nonword targets were formed by replacing letters of words, maintaining pronounceability.

Apparatus. A Commodore Model 2001 Pet microcomputer underwent several modifications in order to present the stimuli as required. Subjects viewed the stimuli through a tachistoscope-like apparatus.

Table 1

Examples of Stimulus Items

Target Condition	Relatedness	Prime	Target
Subordinate	Unrelated	Riddle	River
	Neutral	------	River
	Related	Bank	River
Dominant	Unrelated	Riddle	Money
	Neutral	------	Money
	Related	Bank	Money
Nonword	Word	Bear	Glorb
	Neutral	------	Glorb

This apparatus consisted of a telescoping lightproof masonite box mounted on the CRT. A rubber facepiece was used so the subject's head could be comfortably placed against the apparatus.

The offset and onset ot the prime and target were controlled with a circuit that allowed the screen to be written by software while blank and then 'flashed' on (or off) within a single raster scan. This was necessary since the BASIC control program takes approximately 150ms to write a vertically presented letter string to the screen. Screen intensity was diminished to 50 per cent of the minimum factory capability by a special negative voltage power source that reduces the voltage of the video input transmission carrier signal. Attenuation of this intense phosphor persistence was necessary for stimulus masking. Stimulus masking could then be effective even with the additional contrast inherent with the use of the viewing hood.

Design and procedure. The experimental design for 48 right response hand subjects was a 2 x 2 x 2 x 3 mixed factorial, with the between-subjects factor corresponding to SOA. The within-subjects factors corresponded to visual hemifield, word dominance, and word relatedness. The experimental design for 12 left response hand subjects was a 2 x 2 x 3 mixed factorial, with the within-subjects factors corresponding to visual hemifield, word dominance, and word relatedness. The left response hand subjects only received the 35ms SOA.

Six word lists were formed so that, across lists, dominant and subordinate targets followed related, neutral, and unrelated primes an equal number of times and were presented to each visual hemifield an equal number of times. In the right response hand experiment, four subjects saw each of the six lists; two saw the stimuli in one order, and two in the reverse order. In the left response hand experiment, two subjects saw each of the six lists; one saw the stimuli in one order, and one in the reverse order.

Subjects participated in the experiment individually. Subjects were seated in front of the microcomputer and viewed the stimuli through the viewing hood. All stimuli were presented vertically to avoid directional scanning bias (see Bradshaw, Nettleton, & Taylor, 1981). The maximum vertical visual angle subtended by a word was 5.2 deg with 2.0 deg foveal eccentricity to the left or right. Responses were made by pressing one of two response buttons on a response box placed to the left or right of the computer. Responses were made with the index finger of either the left or right hand, depending upon the response condition to which the subject was assigned. Subjects were instructed to rest the index finger lightly between the two buttons and respond with the smallest possible excursion in order to keep the motor component of the response time at a minimum.

A trial consisted of the presentation of three events followed by a response. First, a fixation point (a period) appeared in the center of the screen. Two seconds later the prime was presented in the same location for 35ms, and was then masked for the duration of the SOA with a special graphics character (a filled circle in each letter location). Subjects were instructed not to respond to the prime, but that they should attend to it, as it would help them make the lexical decision to the target. The target followed, and was randomly presented 2 deg either to the left or right of fixation for 185ms and was then masked. The screen was blanked immediately following the 50ms presentation of the mask. Presentation of the target initiated a software millisecond timer, which stopped when the subject responded "WORD" (right button) or "NONWORD" (left button) with the designated index finger. If an error occurred the word "ERROR" was immediately presented in a vertical fashion on the far left side of the screen. The response began a 5-second intertrial interval. Stimulus presentation and all timing events were controlled by the computer. Before the experiment began, subjects were given three blocks of practice trials (20 trials per block). Subjects received reaction latency and error rate feedback after each block.

Results

Mean lexical decision latencies for correct word responses, along with corresponding error proportions, are shown in Table 2. To facilitate understanding of the results, it should be noted that faster responses to related than unrelated or neutral targets is an indication of meaning activation. If this relatedness effect is larger for dominant meaning trials, an ordered access view is supported. If access is exhaustive, however, no dominance x relatedness interaction is expected. Results for the left response hand subjects will be reported separately. The latencies for the right response hand subjects underwent a 2 (SOA) x 2 (hemifield) x 2 (dominant vs. subordinate) x 3 (related vs. unrelated vs. neutral) mixed analysis of variance, with the sole between-subjects factor corresponding to SOA (see Appendix A). A parallel analysis was carried out on the error proportions; however, the discussion will focus on the latency results.

Examination of Table 2 suggests that the neutral trials do not provide a reliable baseline against which to measure facilitation and inhibition. Indeed, the variability of response latencies to the neutral trials was <u>greater</u> than the range of either the related or unrelated trials, particularly at the 750ms SOA, where it is argued that attentional processing may be occurring. Chiarello (in press) noted a similar problem with neutral trials in a hemispheric asymmetry study. Jonides and Mack (1984) have

Table 2 -- Mean Lexical Decision Latencies (in ms) and Error Proportions for Each Target Condition

Target	Target Type: UNR	SD	NEU	SD	REL	SD	PRIM	FAC	INH
35ms									
R Hand									
L Hemisphere									
Sub	458(.21)	72	414(.16)	54	436(.17)	66	22	-22	44
Dom	416(.13)	62	392(.13)	58	376(.13)	62	40	12	28
R Hemisphere									
Sub	437(.23)	49	469(.18)	60	436(.20)	57	1	34	-33
Dom	459(.16)	64	440(.14)	67	410(.15)	59	49	34	19
750ms									
R Hand									
L Hemisphere									
Sub	440(.20)	82	428(.18)	71	486(.14)	82	-46	-58	12
Dom	442(.15)	80	511(.13)	97	397(.07)	84	45	114	-69
R Hemisphere									
Sub	476(.19)	84	518(.15)	105	442(.14)	78	34	76	-42
Dom	448(.18)	70	443(.17)	72	419(.10)	71	29	24	5
35ms									
L Hand									
L Hemisphere									
Sub	458(.19)	58	434(.17)	64	427(.19)	81	31	7	24
Dom	478(.13)	67	424(.14)	68	400(.17)	61	78	24	54
R Hemisphere									
Sub	460(.20)	53	458(.22)	63	447(.16)	69	13	35	2
Dom	425(.19)	47	444(.12)	72	409(.11)	60	16	35	-19

Note: Numbers in parenthesis are error proportions. Priming (PRIM) is the difference between related and unrelated conditions; Facilitation (FAC) is the difference between related and neutral conditions; Inhibition (INH) is the difference between unrelated and neutral conditions.

argued that specific attentional responses may develop to neutral trials, and in the present case this problem may be exacerbated with the use of vertical presentation. A test for homogeneity of variance was significant, $F_{max}(2, 47) = 3.27$, $p = .047$ indicating that this assumption of the ANOVA was violated. Furthermore, when the neutral trials were deleted, homogeneity of variance was restored $F_{max}(1, 47) = 1.66$, $p = .204$. Therefore, the data were analyzed without the neutral trials, in a 2 (SOA) x 2 (hemifield) x 2 (dominant vs. subordinate) x 2 (related vs. unrelated) analysis of variance (see Appendix B).

Responses were faster to targets presented to the right hemifield, to related targets, and to dominant targets. Visual hemifield and dominance also interacted, as did relatedness and dominance.

The interaction of most interest, however, is the SOA x hemifield x relatedness x dominance interaction, $F(1, 46) = 5.05$, $p = .029$. This four-way interaction was examined by testing the simple interaction effects for the SOA x dominance x relatedness interaction separately for each hemifield (hereafter referred to as hemisphere). This and all subsequent simple effects were calculated with the weighted average of the between-subjects error term and the error term for the four-way interaction (Kirk, 1982).

In the right hemisphere, the three-way interaction of SOA x relatedness x dominance was significant, $F(1, 46) = 4.45$, $p = .040$. Therefore, the dominance x relatedness simple effects were calculated for each SOA. Relatedness and dominance marginally interacted at the 35ms SOA, *F*(1, 46) = 4.01, *p* = .051. Simple main effects tests showed that priming occurred (49ms) at the 35ms SOA for the dominant target *F*(1,46) = 143.58, *p* < .001, but not for the subordinate target (only 1ms difference), *F*(1, 46) = .34. There was no interaction between relatedness and dominance at the 750ms SOA, *F*(1, 46) = 1.54, indicating an equal amount of priming for both the dominant and subordinate meaning. These results indicate that, in the right hemisphere, only the dominant meaning is activated at the short SOA, while both meanings are primed by 750ms.

In the left hemisphere, the three-way interaction of SOA x relatedness x dominance was again significant, *F*(1, 46) = 5.23, *p* = .027, so separate dominance x relatedness simple effects were again tested at each SOA. There was no interaction between relatedness and dominance, *F*(1, 46) = .94. A simple main effects test, however, revealed that related targets led to faster responses than unrelated, *F*(1, 46) = 5.84, *p* = .024, indicating that in the left hemisphere, both meanings are primed at 35ms. At the 750ms SOA, the interaction effect between relatedness and dominance was significant, *F*(1, 46) = 5.11, *p* = .028. Simple main effects tests showed that while priming occurred (45ms) for the dominant target *F*(1, 46) = 523.04, *p* < .001, subordinate targets led to slower responses than did unrelated words, *F*(1, 46) = 184.14, *p* < .001. By 750ms, then, only the dominant meaning is still active in the left hemisphere. These priming results (the difference between unrelated and related trials) are shown in Figure 1.

The analysis of error rates showed that fewer errors were made on related targets than unrelated targets, $F(1, 46) = 17.26$, $p < .001$, and also on dominant than subordinate targets, $F(1, 46) = 32.00$, $p < .001$. Relatedness and dominance interacted, $F(1,46) = 5.81$, $p = .020$, where fewer errors occurred with related targets in both the dominant condition, $t(47) = 3.44$, $p = .001$, and the subordinate condition, $t(47) = 2.77$, $p = .008$. The important point about these error proportions is that they do not suggest any speed-accuracy trade-off that would qualify the response latency findings, as can be seen in Table 2.

There were two marginal main effects for subjects responding with their left hand at the 35ms SOA; relatedness, $F(1, 13) = 3.95$, $p = .068$, and dominance, $F(1, 13) = 4.03$, $p = .066$. Hemisphere and dominance interacted marginally as well, $F(1, 13) = 3.66$, $p = .078$. The hemisphere x relatedness x dominance interaction was not significant, $F(1, 13) = .381$. There was a marginal main effect for dominance with error proportion, $F(1, 13) = 3.93$, $p = .069$, and the hemisphere x relatedness x dominance interaction was not significant, $F(1, 13) = .86$.

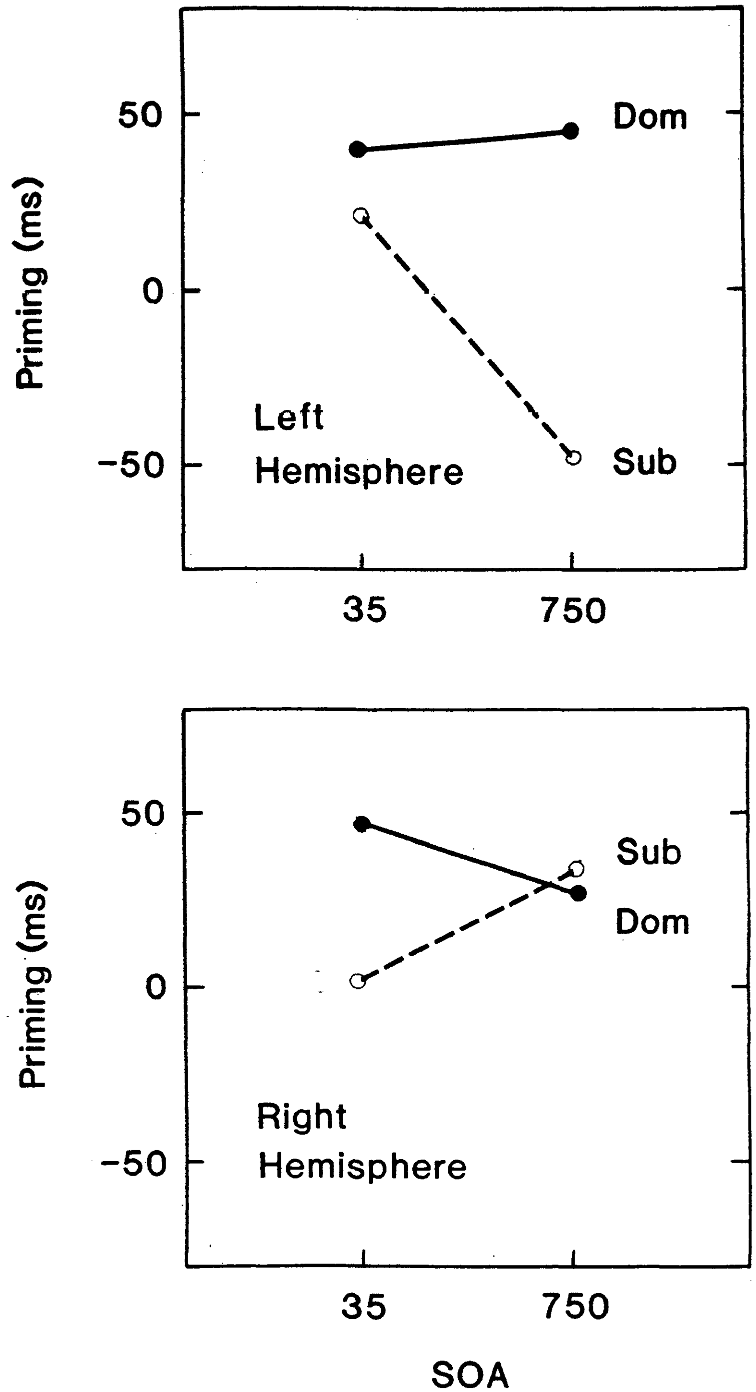

Figure 1. Mean priming of dominant (Dom) and subordinate (Sub) associates at 35ms and 750ms SOAs for the left and right hemisphere

However, examination of the reaction time latencies suggest that priming is probably occurring in the left hemisphere (see Table 2). There is the suggestion of priming for the dominant meaning (78ms) and also for the subordinate meaning (31ms). This pattern of greater priming for the dominant meaning than for the subordinate meaning is the same as the left hemisphere results for the right response hand subjects at this SOA. While a small amount of priming may be occurring for the targets in the right hemisphere, there appears to be no meaningful difference between the dominant targets (16ms) and the subordinate targets (13ms). In addition, the priming is small compared to any other condition. Curiously, targets presented to the right hemisphere and responded to with the left hand are the only ones for which the left hemisphere may not be involved. Further speculation on this point will follow in the discussion.

Discussion

The intent of this experiment was to extend our knowledge of the retrieval processes concerned with ambiguous word meanings as they relate to the availability of these meanings in the cerebral hemispheres. The retrieval patterns described in the present study for the left hemisphere are very similar to those described by Simpson and Burgess (1985), which did not consider hemispheric functioning. Both studies show greater facilitation for the dominant meaning than for the subordinate meaning at the brief SOA (35ms in the present experiment, 16ms in Simpson & Burgess). The facilitation for the dominant meaning is maintained at the longer SOA (750ms) just as Simpson and Burgess found. However, both experiments show a sharp decline in activation of the subordinate meaning by the longer SOA. Simpson and Burgess suggest that inhibition of the subordinate meaning occurs and accounts for the decline in activation. While the neutral trials necessary for a straightforward discussion of inhibition effects were not used in the analyses of the present data, the results are consistent with Simpson and Burgess' conclusion that of the allocation of attention to the dominant meaning results in inhibition of the subordinate meanings.

The right hemisphere results are in marked contrast to the left hemisphere findings (or those of Simpson and Burgess, 1985). Priming effects for the dominant meaning at the 35ms SOA are similar in the left and right hemisphere (40ms vs. 49ms, respectively). However, while by 750ms, activation for the dominant meaning declines in the right hemisphere, the subordinate meaning now shows priming (34ms).

These results support Chiarello's (in press) finding that controlled processing occurs in the left hemisphere, while the right hemisphere does not allocate attentional processes. The apparent controlled processing is represented by the sharp decline in priming for the subordinate meanings at the 750ms SOA in the left hemisphere. Such an effect is absent in the right hemisphere. The left hemisphere results are similar to those that Simpson and Burgess (1985) found in their Experiment 2. Simpson and Burgess confirmed in their Experiment 3 that this decline in performance for the subordinate meanings was due to inhibition of those meanings.

Greater priming was not found in the right hemisphere, contrary to Chiarello's (in press) results. In her automatic processing experiment, there was greater facilitation in the right hemisphere for semantic priming. The rationale for greater facilitation in the right hemisphere involves the notion that these words are a subset of the words contained in the left hemisphere lexicon (Zaidel, 1983). If an inverse relationship exists between the amount of activation spreading to a single network node and the extent of the semantic network

(Anderson, 1976), then the richer semantic network in the left hemisphere would lead to smaller spreading activation effects for any given node. One possibility for the discrepancy between the present findings and those of Chiarello (in press) and Zaidel (1983) may involve the nature of the stimuli. Chiarello (in press) used words that were imageable and concrete (e.g., JUICE, MOOSE, BEAK, BEAR, INCH, YARD), as did Zaidel (1983; e.g., DOG, APPLE). While some words in the present study were imageable and concrete (e.g., ROPE, HOUSE, CLUB), many others were not (e.g., NAME, UNION, NAG, WEIGH). The present findings compared to those of Chiarello (in press) suggest that the lexicon in the right hemisphere may be organized differently for imageable, concrete words than for more abstract or less frequently occurring words. In fact, Glanzer and Ehrenreich (1979) have proposed a model of the lexicon that is divided into one list of high frequency words and another list consisting of all entries. That the activation for the subordinate meanings (which are less concrete and imageable) increased by 750ms suggests that the right hemisphere lexicon may be more richly endowed that earlier thought (Zaidel, 1978). Replication of Chiarello's findings and well as the present findings are in order before further speculation on this type of model can be justified based on cognitive neuropsychological findings.

The results from subjects' left hand responses were not significant, although it is possible that low statistical power was involved. Only 14 subjects participated in this portion of the experiment. Main effects for relatedness and frequency (usually rather strong effects) approached significance ($p < .1$), as did the interaction between hemisphere and frequency. If the means for the left-hand subjects are reliable, these priming effects suggest some intriguing possibilities for additional research. The results in the left hemisphere, left response hand group were similar to the results of the left hemisphere, right response hand group, that is greater priming for the dominant than for the subordinate. However, response latencies do not differ for word dominance (nor is the magnitude of the priming great) when the targets are presented to the right hemisphere and subjects make a left hand response. What is potentially intriguing is that this is the only condition where the left hemisphere is not in the sequence of processing (see Zaidel, 1983). To elaborate, the target is presented to the left visual field and is received by the right hemisphere. The left hand is used for the lexical decision and is under right hemisphere control. At no point is the left hemisphere necessarily involved. Does this mean that some left hemisphere involvement is necessary for the meaning frequency effects to take place? Further experiments that do not suffer from the small sample size of the present study are needed.

The most important contribution of this study is the demonstration that left hemisphere results were consistent with the results with central projection reported in the cognition literature. At present it is unclear what implications should be drawn from the right hemisphere results that showed a decline of facilitation for the more frequent meaning at the longer SOA, while activation for the subordinate increased. One possibility is that right hemisphere processes temporally lag behind the processes of the left hemisphere. Another possibility is a model of hemispheric functioning in which the left hemisphere calls upon the right hemisphere to produce memory information as it is needed. An example of this would be the case where the need for a subordinate word meaning exists but sufficient time has elapsed and this meaning is currently inhibited in the left hemisphere. The present results suggest that this subordinate word meaning's activation is building in the right hemisphere and therefore available for use. A study using longer SOAs than used in the present study could clarify this issue.

Investigating an intermediate SOA (as did Simpson and Burgess, 1985) would further our understanding of how the subordinate meaning becomes available of use. As retrieval processes are more fully understood as they apply to ambiguous word meanings in isolation, attention can shift to the role of hemispheric retrieval mechanisms and sentential context.

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Appendix A

ANOVA Summary Table

SOURCE	SS	DF	MS	F	SIG
WITHIN CELLS	5545728.77	47	117994.22		
SOA	293998.42	1	293998.42	2.49	.121
WITHIN CELLS	279976.37	47	5956.94		
HEM	30831.17	1	30831.17	5.17	.028
SOA BY HEM	25685.65	1	25685.65	4.31	.043
WITHIN CELLS	355398.78	94	3780.84		
REL	77979.82	2	38989.90	10.31	.001
SOA BY REL	14008.37	2	7004.18	1.85	.171
WITHIN CELLS	129189.94	47	2748.72		
FRE	69688.89	1	69688.89	25.35	.001
SOA BY FRE	2222.22	1	2222.22	.80	.373
WITHIN CELLS	495273.48	94	5268.87		
HEM BY REL	31376.86	2	15688.43	2.98	.056
SOA BY HEM BY REL	19182.27	2	9591.13	1.82	.168
WITHIN CELLS	145601.48	47	3097.90		
HEM BY FRE	778.24	1	778.24	.25	.619
SOA BY HEM BY FRE	44664.91	1	44664.91	14.41	.000
WITHIN CELLS	275875.19	94	2934.84		
REL BY FRE	50027.78	2	25013.89	8.52	.001
SOA BY REL BY FRE	16309.91	2	8154.96	2.77	.067
WITHIN CELLS	348567.47	94	3708.16		
HEM BY REL BY FRE	19593.73	2	9796.86	2.64	.076
SOA BY HEM BY REL BY FRE	11697.34	2	5848.5	1.57	.213

Appendix B

ANOVA Summary Table

SOURCE	SS	DF	MS	F	SIG	ω^2
WITHIN CELLS	111292.14	46	2419.39			
SOA	353.71	1	353.71	.14	.705	
WITHIN CELLS	99460.06	46	2162.17			
HEM	9255.23	1	9255.23	4.28	.044	.01
SOA BY HEM	4350.64	1	4350.64	2.01	.162	
WITHIN CELLS	46622.73	46	1013.53			
REL	12461.16	1	12461.16	12.29	.001	.02
SOA BY REL	2205.18	1	2205.18	2.17	.144	
WITHIN CELLS	35033.55	46	761.59			
FRE	20678.54	1	20678.54	27.15	.001	.03
SOA BY FRE	1030.21	1	1030.21	1.35	.251	
WITHIN CELLS	102427.82	46	2226.69			
HEM BY REL	2848.56	1	2848.56	1.27	.265	
SOA BY HEM BY REL	2171.18	1	2171.18	0.97	.329	
WITHIN CELLS	65755.20	46	1429.46			
HEM BY FRE	11828.10	1	11828.10	8.27	.004	.01
SOA BY HEM BY FRE	3442.42	1	3442.42	2.40	.128	
WITHIN CELLS	48779.08	46	1060.41			
REL BY FRE	18731.06	1	18731.06	17.66	.001	.02
SOA BY REL BY FRE	2755.32	1	2755.32	2.59	.114	
WITHIN CELLS	65997.42	46	1434.72			
HEM BY REL BY FRE	11795.84	1	11795.84	8.22	.006	.01
SOA BY HEM BY REL BY FRE	7250.60	1	7250.60	5.05	.029	.01

Appendix C
INFORMED CONSENT

You are invited to participate in a study of word recognition, in which we are trying to learn about the information that people use in identifying words. You were selected because you submitted your name to the UNO Psychology Department as a volunteer.

You will be asked to participate in a single session of approximately 90 minutes. On each trial of this experiment you will see two stimuli. First, you will see a word or a set of dashes for a brief period. You do not have to respond to this word. Next you will see a string of letters that will spell either a common word or a nonword. You will be asked to indicate if this letter string is a word, as rapidly as you can. You will be provided the actual instructions for the experiment after completing this form.

There are no discomforts or dangers in this experiment, and no deception is involved. Please be assured that your name will not be involved in any way with the research findings. Please do not hesitate to ask any questions about the study, and remember that even if you initially agree to participate, you are free to withdraw your consent and discontinue participation at any time if you wish. Withdrawl will not in any way prejudice your relationship with the University of Nebraska.

If at any future time you have questions about the study, please feel free to call me at 554-2579.

We recommend that 90 minutes of extra credit (3 points) be given for an experiment of this length. Of course, participation in this particular experiment is not the only way to earn extra credit in psychology. Other experiments are available throughout the semester, and other opportunities for extra credit may be discussed with your instructor.

YOU ARE MAKING A DECISION WHETHER OR NOT TO PARTICIPATE. YOUR SIGNITURE INDICATES THAT YOU HAVE DECIDED TO PARTICIPATE, HAVING READ THE ABOVE INFORMATION. Thank you very much.

Sincerely,
Curt Burgess
Principal Investigator

Appendix D
SUBJECT INSTRUCTIONS

We are interested in how quickly people are able to recognize words. Vertical strings of letters (or dashes) will be presented to you on this computer screen. Your task is to decide as quickly as possible if the second of two stimuli is a word. On each experimental trial, you will see a fixation point for two seconds. It is important that you keep your eyes on the fixation point in order to make sure you have the best possible opportunity to see the stimuli. The point will then disappear and will shortly be followed by the first of two stimuli. Immediately following this first stimulus, the second stimulus will appear. As soon as each of these stimuli have been presented it will be covered by a mask. This mask will be a brief flash of light in the same location as the stimulus item.

The first stimulus will be a word or a string of dash marks. You do not have to respond to this first stimulus, but you should pay close attention to it, as it will often help you decide about the second letter string. The second letter string will be a word or a pronounceable nonword. For example:

g
l
o
r
b

The nonwords look as if they could be words, so it is important that you pay close attention.

If the second letter string is a word in the English language, you should press the right button (grey) on the response box with your right index finger. If the second letter string is a nonword (for example, glorb), you should press the left button (white) with your right index finger. The experimentor will show you how this should be done.

IT IS VERY IMPORTANT THAT YOU MAKE YOUR WORD/NONWORD RESPONSE AS RAPIDLY AS YOU CAN, BUT IT IS ALSO IMPORTANT THAT YOU NOT MAKE ERRORS!

<<<<<REMEMBER>>>>>

1. Be ready for each trial by keeping your eyes on the fixation point.

2. Pay close attention to the first stimulus, but do not respond to it.

3. If the second stimulus is a word in the English language, press the right button.

4. If the second stimulus is not a word, press the left button.

5. Respond AS RAPIDLY AS POSSIBLE, while still trying not to make errors.

We will have 60 practice trials before we begin. If you have any questions, please ask the experimenter.

Appendix E

LOAF	BREAD	89	LAZY	11	U
NOVEL	READ *	89	NEW	11	
DIVE	WATER	91	TAVERN	02	U
JAM	JELLY	74	STUCK	22	
TAG	LICENSE	78	TOUCH	22	
PITCH	THROW	67	SOUND	17	
FIX	REPAIR	72	DRUGS	17	
FAN	COOL	80	CLUB	17	
SPELL	WORDS	80	BOUND	17	U
GREEN	GRASS	85	YOUNG *	09	
LIE	TRUTH	80	SIT	20	U
TIRE	WHEEL	89	FATIGUE	11	U
LOT	HOUSE	76	LITTLE	22	
HEAD	HAIR	96	BATHROOM	02	
BUG	INSECT	83	BOTHER	13	U
STAKE	POST *	83	BET	04	U
STAMP	POSTAGE	83	OUT *	17	U
FAST	SLOW	89	EAT	07	U
DIAMOND	GEM *	93	BASEBALL	04	U
CHECK	CASH	65	LIST	26	
BLOW	AIR *	91	MISTAKE	07	U
NET	FISH	80	WORTH	20	
SWAMP	MUD *	87	WORK	11	U
GRAVE	DEAD	89	SERIOUS	11	U
STOCK	MARKET	78	BARREL	11	
CHARGE	ACCOUNT	76	FORCE	11	
STEER	COW	74	CAR	22	
ARM	LEG	93	WAR	2	
PAGE	PAPER	87	SERVANT	02	U
SWALLOW	THROAT	65	BIRD	33	
DECK	BOAT	63	CARDS	33	
COURT	JUDGE	72	YARD	17	U
POKER	CHIPS	93	FIREPLACE	07	U
STABLE	HORSE	78	FIRM	17	
STALK	HUNT	67	CORN	28	
RASH	RED	91	HARSH	09	U
LETTER	MAIL	91	ALPHABET	04	
SAP	PINE	83	DOPE	09	U
KIND	NICE	85	TYPE	09	
RAM	SHEEP	70	SHOVE	30	

FOIL	TIN	63	SWORD	22	
WATCH	TIME	61	LOOK *	33	
FOLD	BEND	91	FLOCK	04	U
STORY	TELL *	93	FLOORS *	04	U
STAPLE	GUN	63	FOOD	26	
SHELL	SEA	89	SHOCK *	07	U
CORD	ROPE	89	WOOD	07	U
RULER	MEASURE	78	KING	20	
PORT	HARBOR	65	WINE	20	
TIE	KNOW	98	WIN	02	
BALL	ROUND	91	DANCE	2	U
SOCK	SHOE	85	PUNCH	13	U
FLEET	SHIPS	85	RUN	13	U
CROOK	THIEF	91	FINGER *	04	U
WAX	SHINE *	85	WANE	15	U
STATE	CITY	80	CONDITION	15	
TRUST	FAITH *	65	FUND	26	
HABIT	BAD	85	NUN	09	U
HIDE	SEEK	91	TAN	09	U
GAME	PLAY	85	HUNTER *	09	U
GIN	TONIC	85	RUMMY	13	
BOLT	NUT	63	JUMP	15	
SIGN	STOP	63	NAME	37	
SLIDE	FALL	80	FILM *	20	
FIRE	HOT	89	HELP	02	U
RIDDLE	PUZZLE	85	HOLES	02	
VAULT	SAFE	78	POLE	22	
ROCK	STONE	63	ROLL	33	
HORN	HONK	91	BULL	04	U
YARN	KNIT	74	TALE	24	
FARE	MONEY	76	WELL	07	
COUNT	NUMBER *	85	DUKE *	11	U
RIB	CAGE	91	JOKE	04	U
FILE	CLERK	67	NAIL	20	
STILL	QUIET	74	WHISKEY	20	
BLUFF	FOOL	76	CLIFF	20	
STAFF	MEETING	67	STICK	22	
STRIKE	HIT	74	UNION	22	
RANK	ARMY *	80	STINK	13	U
PRUNE	JUICE	80	TRIM	13	
YELLOW	COLOR	96	CHICKEN	04	
SCALE	WEIGH	85	CLIMB	04	U
STALL	BARN	70	WAIT	26	
RACKET	TENNIS	89	NOISE	07	U

COAST	BEACH *	85	GLIDE *	09	U
TOAST	BUTTER *	89	DRINK	09	U
ROOT	PLANT	89	PIG	02	
HARP	MUSIC	78	NAG	15	

SCRAP	JUNK	89	FIGHT	07	U
FENCE	GATE	83	DUEL	11	U
STEEP	HILL	91	BREW	04	U
LEFT	RIGHT	93	OVER	04	
JERK	PULL	63	CREEP	35	
BARK	DOG	80	TREE	15	U
SAW	HAMMER	67	EYE	26	
GRILL	COOK *	87	QUESTION *	07	U

MIND	BRAIN	85	OBEY	07	U
POOL	SWIM	70	CUE	28	
MEAN	NASTY	70	AVERAGE	28	
HAM	BONE	91	RADIO	04	U
ORGAN	PIANO	63	BODY	37	
FIGURE	SHAPE *	76	ADD	17	
DUCK	GOOSE *	87	UNDER *	07	U
GRADE	MARK	89	INCLINE *	11	U

FOOT	TOE	96	INCH	02	U
KICK	HURT *	91	BACK	04	U
MUG	BEER	72	ROB	15	
SHIFT	CHANGE	65	JOB	17	
LEAF	MAPLE	89	TABLET *	07	U
KID	CHILD	63	GOAT	22	
PLAIN	FANCY	76	FLAT	22	
STIR	MIX	98	CRAZY	02	

JAR	LID *	83	SHAKE	13	
STAGE	FRIGHT	83	COACH	13	U
TRAIN	TRACKS	80	TEACH	15	U
MINE	YOURS	63	COAL	26	
WEAR	CLOTHES	78	TEAR	17	
LOG	CABIN	85	DIARY	09	U
LIGHT	DARK *	91	HEAVY	09	U
LIKE	HATE	89	AS	11	U

NONWORDS

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WASH     CORT    /   STEW    QUEN     /   DRIP   HOUME
TOOL     STAIT   /   YIELD   GLONCE   /   BLUE   BOTE
TAX      MAYE    /   BANK    SLIED    /   ROAD   HAPPE
SUIT     REMOLT  /   HOUND   GROMP    /   CRAB   EASH
CHEW     APIRT   /   ROSE    LOAR     /   COMB   NAOL
PLOT     GLANTS  /   DRESS   RAUND    /   SHARE  DED
FRONT    RUTE    /   CRUST   MINDOW   /   DIRT   BREAT
HEAT     ORN     /   LOCK    BRON     /   REEL   LOD
KERNEL   THARE   /   CALL    GURSE    /   EAR    PAUN
SACK     YALER   /   ROW     TRUCH    /   TAP    HOM
SPRING   FROT    /   QUACK   JIN      /   SOLE   HILB
POACH    GEARB   /   BASS    HUF      /   MINT   CHIEM
CELL     PACKLE  /   TRUNK   CIM      /   SINK   PASE
SHOT     SAB
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STRIP    CARRE   /   CAP     DUP      /   BOW    FRIKE
BEAM     AUN     /   PRESS   HANSY    /   SET    STOR
PUPIL    STAL    /   LITTER  NONT     /   TIP    FIW
PERCH    STEB    /   FINE    DOUN     /   DASH   THOB
GAG      ROAL    /   CHARM   LIBE     /   POUND  NARSE
SECOND   MIPE    /   SHED    THIAF    /   TICK   SHOOB
WAKE     TEY     /   BAT     BACE     /   DATE   MENT
HATCH    NORE    /   BOARD   DRITH    /   SOW    HIL
PANEL    NOMTH   /   MOLD    TROSH    /   CASE   SUGHT
CHOP     FULTER  /   POT     DALYE    /   CHUCK  LOTAL
SEAL     GORM    /   JOINT   FRINK    /   MATCH  QUEON
CHEST    SHOL    /   BOWL    SIE      /   DRAFT  HALD
LEAN     SKAPLE  /   DESERT  BOUNE    /   CHINA  THREAM
SPADE    FOT
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THIS BLOCK OF NONWORDS WERE PAIRED WITH THE NEUTRAL TRIAL

RAGE	MAGE	CRAIL	HAMED	LETUME	DORP	PARST
DADEL	THIEF	ALPLE	ALC	JIT	BIRM	WOMAL
KIY	TOBLE	SWEN	FLIDE	PERPER	DET	DERIKE
TILD	GREFT	NAIP	CHOAM	MOY	CETS	SOND
TOMP	MORFS	BURTER	DOOT	GINT	STO	FLATE
NOCE	GINTH	MESSLE	SPIR	TRIT		
