HEMISPHERIC DIFFERENCE IN SEMANTIC

PRIMING FOR EARLY AND LATE AGE OF

ACQUISTION WORDS

By

JERALD MICHAEL BOWERS

Bachelor of Science in Psychology
Oklahoma State University
Stillwater, Oklahoma
1997

Master of Science in Psychology
Oklahoma State University
Stillwater, Oklahoma
2006

Submitted to the Faculty of the
Graduate College of the
Oklahoma State University
in partial fulfillment of
the requirements for
the Degree of
DOCTOR OF PHILOSOPHY
July, 2008

HEMISPHERIC DIFFERENCE IN SEMANTIC

PRIMING FOR EARLY AND LATE AGE OF

ACQUISTION WORDS

Dissertation Approved:

Dr. Shelia Kennison
Dissertation Adviser

Dr. David Thomas

Dr. Celinda Reese

Dr. John Deveny

Dr. A. Gordon Emslie
Dean of the Graduate College

ACKNOWLEDGMENTS

I would like to thank my committee members, Drs. David Thomas, Cindy Reese, and John Deveny, for their thoughtful contributions not only to this project but also to my education. All of you have been extremely instrumental to my development as a scientist. I will always be thankful for the privilege it has been to learn from each of you.

I would especially like to thank my advisor and mentor Dr. Shelia Kennison. There are no words to express my enduring appreciation and gratitude for everything you have done for me. You are a brilliant scientist and I enthusiastically look forward to all of the work that we will be conducting together in the future.

Finally, I would like to dedicate this project to my darling wife Mary Jean Bowers. Without the support and encouragement of you Mary, none of this would be possible. Mary, you are my guiding light, my soul mate, my one and only love. You have sacrificed many things for me so that I could obtain my goal of becoming a Ph.D. This degree is yours as much as it is mine. You are my world and I will forever be in your debt. Many of the trials and tribulations that we have both endured throughout this process will never be known to outsiders. Our road to success is only beginning. I just want you to know that you will always be my DG. I love you with all of my heart!

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

Semantic Priming and Hemispheric Processing Differences

For almost two centuries, it has been known that there are hemispheric differences in language processing. One of the most intriguing details about the human brain is the fact that there are two hemispheres, each of which is dedicated to specialized processing. At one point, it was believed that only the left hemisphere was specialized for language processing. However, recent research, using a variety of techniques, has shown that the right hemisphere is also involved (Beeman, 2005; Beeman & Chiarello, 1998; Bogen & Gazzaniga, 1965; Bradshaw & Nettleton, 1983; Bryden, 1982; Chiarello & Church, 1986; Chiarello et al., 1990; 1992; 2001; 2003; 2005; Gazzaniga & Sperry, 1967; Hellige, 1993; Kimura; 1967; Sperry, 1964; Sperry & Gazzaniga, 1967; Sperry, Gazzaniga, & Bogen, 1969; Zaidel, 1978; Zaidel & Peters, 1981). Therefore, the objective of the present research was to investigate further the extent of differences in hemispheric processing for language using semantic priming.

Semantic priming is a common method used to investigate the lexical-semantic processes involved in memory. The process of semantic priming functions under the principle that semantically related concepts are closely linked in a network, whereas distantly related concepts are either connected indirectly or not at all (Collins & Loftus, 1975; Meyer & Schvaneveldt, 1971; Schvaneveldt & Meyer, 1973; Neely, 1977).

1

Therefore, when a word is recognized, its representation is triggered, (i.e., made more available for processing), and this activation spreads through the network to other semantically related words. This triggering of activation serves to facilitate the subsequent recognition of other semantically related items. Consequently, a priming effect occurs if a target stimulus is processed faster or more accurately when it is preceded by a semantically related prime stimulus, (e.g., *apple-orange*), as compared to a semantically unrelated prime-target pair, (e.g., *apple-car*) (for review see Neely, 1977; 1991).

Neely (1977) identified two different types of priming (i.e., automatic and controlled). Both types of priming depend on varying the stimulus onset asynchrony (SOA) (i.e., length of time between the onset of the prime stimulus and the onset of the target stimulus). Automatic priming occurs under conditions when the prime-target interval is shorter than 400 ms or when a small number of related primes and targets are used in the experiment (Fischler, 1977; Fischler & Goodman, 1978; Neely, 1977). Automatic priming prevents or discourages the participant from actively using the prime word as an "aid" for lexical access and thus, is believed to be an unconscious process (Neely, 1977). In contrast, controlled priming occurs under conditions when the prime-target interval is longer than 400 ms or when a larger number of related primes and targets are used in the experiment (Fischler, 1977; Fischler & Goodman, 1978; Neely, 1977). Controlled priming allows the participant to use the prime word as a "clue" which directs attention and thus, is believed to be a conscious process (Neely, 1977).

Automatic and controlled priming provide an elegant and flexible technique for investigating hemisphere asymmetries, because short SOAs serve as a method for tracing how words are linked/stored, whereas long SOAs serve as a method for investigating lexical processing strategies.

Among the most prominent researchers to investigate lexical-semantic processing within the brain's two hemispheres are Chiarello and colleagues (Beeman & Chiarello, 1998; Chiarello, 1985; Chiarello & Church, 1986; Chiarello et al., 1990; 1992; 2001; 2003; 2005). Chiarello's research has shown that both hemispheres do not process lexical-semantic information in the same manner. Chiarello's conclusions have come from combining semantic priming with one of the most widely used behavioral methods for testing hemispheric processing, the divided visual field (DVF) technique (Beaumont, 1982, Fassbinder & Tompkins, 2006). The DVF technique involves the presentation of a stimulus either to the left or the right visual field. Since each visual field is processed by the contralateral hemisphere, stimuli presented in the left visual field (LVF) are processed by the right hemisphere (RH), and stimuli presented in the right visual field (RVF) are processed by the left hemisphere (LH). Subsequently, any visual field effects are interpreted as reflecting differences in hemispheric processing (Beaumont, 1982; Beeman & Chiarello, 1998).

Using both semantic priming and the DVF technique, Chiarello (1985) tested the hypothesis that when a long SOA is used, (i.e., *controlled priming*), the left hemisphere would show greater priming for both semantically and phonologically related prime-

target word pairs. Chiarello also hypothesized that when a short SOA is used, (i.e.,

automatic priming), the right hemisphere would show greater priming for both

semantically and orthographically related word pairs. In the experiment, the relationship

between the prime and target words was varied. There was either a semantic relationship

(e.g., *inch-yard*), phonological relationship (*juice-moose*), or orthographic relationship

(e.g., *beak-bear*). The results of the study showed that when a long SOA was used,

semantically similar words produced higher degrees of priming in the RVF/LH;

phonologically similar words produced equivalent priming in both visual fields; and

orthographically similar words produced greater LVF/RH priming. In contrast, the

results for the set of experiments using a short SOA showed equivalent priming effects in

both visual fields for semantically similar words; phonologically similar words showed

greater RVF/LH priming; and orthographically similar words showed greater LVF/RH

priming. Chiarello suggested that because semantic priming occurred in both visual

fields in the short SOA condition, the right hemisphere has access to semantic

information, but only under automatic priming conditions. Chiarello further suggested

that, because of the equivalent priming in both visual fields for phonologically similar

words, but only in the long SOA condition, phonological processing necessitates inter-

hemispheric transfer of LVF/RH stimuli to the left hemisphere. The results also showed

the right hemisphere to be superior to the left hemisphere for tasks involving visual-

orthographic processing of letters and words. Other studies using similar methods and

contrasting long and short SOAs have found similar results (Beeman et al., 1994; Burgess

& Simpson, 1988; Michimata, 1987; Nakagawa, 1991).

Chiarello, Senehi, and Nuding (1987) investigated whether the semantic networks

of the two hemispheres have shared or independent access to concrete and abstract words.

It was hypothesized that because concrete words contain higher amounts of associated

imagery features than abstract words, the right hemisphere's superiority for imagery

processing would bias it and result in greater priming for concrete words. Therefore, if

the right hemisphere's semantic network consists only of concrete words, then semantic

priming should be smaller in the LVF/RH vs. the RVF/LH. The results of a lexical

decision task supported the hypothesis by showing that in the long SOA condition, (i.e.,

controlled priming condition), abstract prime words produced less priming for target

stimuli presented to the LVF/RH than to the RVF/LH. Conversely, in the short SOA

condition, (i.e., automatic priming condition), equivalent priming in both visual fields

was found for both word types. Chiarello et al. argued that, because controlled priming is

a consciously directed process, it is a predominant processing function of the left and not

the right hemisphere. This argument is based on the fact that, in the long SOA condition,

abstract prime words facilitated performance in the RVF, but inhibited performance in

the LVF. Chiarello et al. further argue that, because automatic priming is an unconscious

process it is a processing function common to both hemispheres. This argument is based

on the fact that both concrete and abstract prime words showed equivalent visual field

priming effects in the short SOA condition. Additional studies investigating the how

different classes of words are accessed within each hemisphere, (e.g., nouns vs. verbs and high frequency words vs. low frequency words), have found comparable results (Abernethy & Coney, 1993; Burgess & Simpson, 1988; Chiarello, Richards, & Pollock, 1992).

Chiarello, Burgess, Richards, and Pollock (1990) hypothesized that location of the prime word would influence processing speed such that laterally displayed prime words would influence both hemispheres independently. They hypothesized that centrally displayed prime words would induce a sharing of information between hemispheres and therefore, result in a classic RVF/LH processing advantage. It was also hypothesized that the degree of semantic relationship shared between the prime and target words would influence processing. In their first experiment, using a lexical decisions task, they varied the location of prime word presentation (i.e., central or lateral) as well as varying the degree of semantic relatedness of the prime and target words (e.g., similar only, *deer-pony*, associated only, *bee-honey*, and both similar and associated, *doctor-nurse*). The results showed that an overall RVF/LH processing advantage was not observed. However, when the prime words were centrally located, a RVF/LH advantage was obtained. Thus, activation initiated by a single hemisphere is not immediately shared. Chiarello et al. (1990) suggested that the use of centrally located prime words allows the inferior hemisphere to recruit assistance in processing from the superior hemisphere. Furthermore, the processing differences between the left and right hemisphere indicated that the left hemisphere is faster at responding to highly associated word pairs, (e.g.,

doctor-nurse), whereas more distantly related word pairs, (e.g., *deer-pony*), only showed priming in the right hemisphere. Chiarello et al. further suggested that the semantic processing abilities of the left hemisphere operate in a focal manner with rapid selection of one meaning and suppression of other potential candidates. In contrast, the semantic processing in the right hemisphere involves more diffuse activation spreading to a broader range of semantic candidates over an extended time course. These conclusions were supported in a second experiment in which prime words were either dominant or non-dominant category exemplars. The results from Experiment 2 showed that the right hemisphere was more sensitive to distant relationships than was the left hemisphere. Additional studies contrasting degree of word relatedness and prime-target location have found comparable results (Chiarello & Richards, 1992; Chiarello, Maxfield, & Kahan, 1995; Richards & Chiarello, 1995).

In summary, both semantic priming and the DVF technique have contributed towards our understanding of how lexical-semantic memory is processed by the left and right hemisphere. As a result, this research has led to the development of two behaviorally based viewpoints. However, only a few studies have attempted to connect together the two behavioral perspectives (e.g., Chiarello, Liu, Shears, Quan & Kacinik, 2003; Koivisto, 1997, 1999; Koivisto & Laine, 2000; Richards & Chiarello, 1995; Shears & Chiarello, 2003). Therefore, the purpose of the present research was to bridge the gap between the two theoretical viewpoints, by investigating the strong possibility that there

are hemispheric differences in semantic priming for words learned early in childhood and

words learned later in life.

CHAPTER II

REVIEW OF LITERATURE

BEHAVIROAL PROCESSING THEORIES

There are two prominent behavioral theories used to explain hemispheric processing: 1) the depth of processing approach and 2) the inhibitory time course approach (e.g., Beeman, 2005; Cohen, 1973; Efron, 1990; Kimura, 1973; Kinsbourne, 1975; Moscovitch, 1979; Semmes, 1968). Behavioral theories, which take the depth of processing perspective, suggest that the left and right hemisphere process information in distinctly different ways. The depth of processing approach views the left hemisphere as being a focal, analytically based serial processor, whereas the right hemisphere is viewed as being a holistically based, parallel processor (Beeman, 2005; Efron, 1990; Kimura, 1973; Semmes, 1968). It has been argued, by Chiarello et al. (2005), that the differential specialization within each hemisphere is advantageous for the maintenance and control of each hemisphere's respective functions. Thus, with regards to language processing, the left hemisphere is specialized for performing functions that require fine discrimination and the temporal sequencing of stimuli, (i.e., syntax). In comparison, the right hemisphere is specialized for the processing of the emotional and visual features of language, (i.e., orthography).

In contrast to the depth of processing theory, the inhibitory time course perspective suggests that both hemispheres have the capacity to perform identical processing functions, although they do not (Cohen, 1973; Fassbinder & Tompkins, 2006;

9

Kinsbourne, 1975). According to this perspective, the two hemispheres process information simultaneously. The simultaneous processing is performed by each hemisphere as a result of one hemisphere, (i.e., the language dominant hemisphere) inhibiting the activity of the opposite hemisphere and by both hemispheres processing different characteristics of the same stimulus (Kinsbourne, 1975; Moscovitch, 1973). Moreover, the inhibitory time course view predicts that after initial broad activation of a word's features or meanings by the left hemisphere, the left hemisphere then focuses processing on the core meaning of a word through inhibition or decay of less related or inconsistent features and/or interpretations of the word. As a result, only strongly related meanings are maintained for further processing in the left hemisphere. During this early phase of language processing, the left hemisphere initiates processing, but at the same time the left hemisphere is actively inhibiting the right hemisphere from performing any processing. After the left hemisphere shifts its processing strategy from the initial broad approach to the more focalized approach, it releases the right hemisphere from its inhibitory state. Once released from its inhibitory state, the right hemisphere begins the processing of weakly related features or meanings of words in order to keep them available for possible processing later on (Cohen, 1973; Fassbinder & Tompkins, 2006). The prolonged activation of word meanings in the right hemisphere is thought to facilitate the processing of unexpected interpretations or metaphors (Anaki, Faust, & Kravetz, 1998; Kacinik & Chiarello, 2007).

STUDIES TESTING THE BEHAVIORAL PROCESSING THEORIES

Even though several features of the two behavioral theories have been widely accepted, there have been no satisfactory explanations suggested. Fassbinder and Tompkins (2006) addressed the unsatisfactory explanations for the two accounts as resulting from: 1) a lack of evidence indicating how the information is combined in order to provide a single percept (i.e., depth of processing approach) and 2) how the brain's physiology functions with regards to inhibiting hemispheric activity in order to process different characteristics of the same stimulus (i.e., inhibitory time course approach).

Studies that have directly tested the predictions of the two alternative behavioral perspectives have produced mixed results. For instance, Richards and Chiarello (1995), using a pronunciation task, compared the visual field priming patterns across different SOAs (i.e., less than 250 ms and more than 750 ms), for directly associated (e.g., *wine-grape*) and indirectly associated (e.g., *beer-grape)* word pairs. The comparison of different SOAs was done in order to determine whether the hemispheric activation is differentially modulated over time. It was hypothesized that if the left hemisphere only activates a small set of highly related information, whereas the right hemisphere activates a wider set of associated information, (i.e., depth of processing approach), then at all SOAs, priming for both types of word pairs in the LVF/RH would occur, although priming for the directly associated word pairs would occur only in the RVF/LH. Moreover, no priming for indirectly associated word pairs would be observed in the RVF/LH, regardless of SOA. It was further hypothesized that if the left hemisphere initially activates distant relations, but over time, inhibits such irrelevant information

from being processed, (i.e., inhibitory time course view), then priming for the indirectly associated words pairs would occur at the shortest SOA, but not at the longest SOA in the RVF/LH. Moreover, no priming would occur for the directly associated word pairs in the LVF/RH, regardless of SOA. The results showed no support for either hypothesis, because priming was found for both directly and indirectly associated word pairs at both short and long SOAs. Richards and Chiarello suggested that the right hemisphere appears to activate associated information as rapidly and for the same duration as the left hemisphere (C.F., Chiarello et al., 2003; Shears & Chiarello, 2003).

In contrast, Koivisto (1997) reported evidence supporting the inhibitory time course approach. Koivisto, using similar methods and stimuli as Richards and Chiarello (1995), found that in the shortest SOA condition, (i.e., 165 ms), priming effects occurred in the RVF/LH, but not in the LVF/RH. However, at the longest SOA, (i.e., 750 ms), there was no priming in the RVF/LH, whereas a priming effect was found in the LVF/RH. As a consequence, Koivisto concluded that initial priming occurs in the left hemisphere whereas over time, priming in this hemisphere decreases or becomes reduced. Meanwhile, priming in the right hemisphere was absent initially, but increased over time or became uninhibited. Therefore, because this pattern is incongruent with the predictions of the depth of processing view, Koivisto suggests that the processing activity of both hemispheres operates according to the inhibitory time course processing view. Subsequent studies have reported finding similar results (Koivisto, 1999; Koivisto & Laine, 2000).

GAZZANIGA'S LANGUAGE LATERALIZATION HYPOTHESIS

The approach of the present research was not only influenced by the two behavioral explanations, but also by anatomically based theories. Anatomical theories of lateralization are primarily supported by the physiological developmental of the brain (Gazzaniga, 1974; Geschwind & Behan, 1982; Geschwind & Galaburda, 1985; Ringo et al., 1994). One of the most prominent lateralization theories was proposed by Gazzaniga (1974).

Gazzaniga's lateralization hypothesis is based on the physiological development of the corpus callosum. Gazzaniga suggests that, because the corpus callosum is not fully mature during early development, infants and young children will only establish hemispheric dominance for language after the age of 4. Therefore, prior to the age of 4, both hemispheres would function as two independent parallel decision systems, both of which have language processing capabilities. According to Gazzaniga, the dual language processing capabilities established in both hemispheres are a manifestation of two things: 1) the slow maturation of the corpus callosum and 2) the rapid maturation of the language areas in both the left and right hemisphere. The combination of these two developmental patterns would essentially cause the young language learner to have two equally functioning brains (Gazzaniga, 1974; 1983). Based on his anatomical study of postmortem brains, Gazzaniga proposed that a hemispheric specialization for language would not begin to develop until the corpus callosum begins to fully myelinate, starting after the age of 4. Gazzaniga further proposed that, because there is a lack of lateralized specialization between the left and right hemisphere, words acquired early in life, (i.e., prior to the age of 4), would be bilaterally represented in the brain. Subsequently,

because the left hemisphere specialization for language would have begun to be established, words learned after the age of 4 would be represented in the left hemisphere.

BEHAVIORAL STUDIES TESTING GAZZANIGA'S HYPOTHESIS

Gazzaniga's hypothesis has been supported by numerous physiological studies focusing on brain development and the corpus callosum (Brizzolara, et al., 1994; Chi, Dooling, & Gilles, 1977; Dehaene-Lambertz, Hertz-Pannier, & Dubois, 2006; de Schonen & Mathivet, 1989; Dorsain-Pierre et al., 2006; Geschwind & Levitsky, 1968; Paus, et al., 1999; Pujol et al., 2002; Pujol et al., 2006; Turkewitz, 1988;). However to date, only two behavioral studies have directly tested Gazzaniga's hypothesis (i.e., Bowers & Kennison, 2008; Ellis & Young, 1977).

In a DVF experiment, Ellis and Young (1977) compared processing for words learned early in life, (i.e., prior to the age of 4) and words learned later in life, (i.e., after the age of 7). All words were balanced across the variables of word frequency, imageability, and familiarity. According to Gazzaniga's hypothesis, one would expect to find only a RVF/LH processing advantage for words learned later in life. In contrast, it is expected that an equivalent visual field processing advantage would be found for words learned early life. The results of the study showed that overall, words were named more accurately when presented to the RVF/LH than the LVF/RH. More importantly, Ellis and Young did not find any hemispheric differences for the processing of words learned either early or later in life.

Since 1977, numerous studies have shown that age of acquisition (AoA) is an important variable in language processing (for a review see Juhasz, 2005). Research on

14

AoA began in the early 1970s with the seminal work of Carroll and White (1973). These researchers showed that based on self-report ratings, the approximate age at which specific words were learned influenced the processing of those words later in life. In order to determine this finding, participants were shown pictures and instructed to name them as quickly as possible. The results showed that AoA was a stronger predictor of naming times for pictures than word frequency. In a later study, Gilhooly and Gilhooly (1979) extended the interest in AoA research by showing how early acquired words were produced more often than late acquired words in a lexical memory tasks. More recent studies have found AoA effects in a variety of language processing tasks, including lexical decision (Gilhooly & Gilhooly, 1979; Morrison & Ellis, A. W., 2000; 1995; Stadthagen-Gonzalez, Bowers, & Damian, 2004), semantic categorization (Brysbaert et al., 2000; Ghyselinck, Custer, & Brysbaert, 2004), picture naming (Ellis, A. W., & Morrison, 1998; Morrison, Ellis, A. W. & Quinlan, 1992), word naming (Brown & Watson, 1987; Morrison & Ellis, 2000; 1995), bilingual word translation (Bowers & Kennison, 2006; Hirsh, Morrison, Gaset, & Carnicer, 2003; Izura & Ellis, 2004), and fixation durations during sentence processing (Juhasz & Rayner, 2003).

Because of the large numbers of studies that have shown AoA effects, Bowers and Kennison (2008) revisited the Ellis and Young's (1977) findings. Bowers and Kennison identified three areas in which the methodology used by Ellis and Young (1977) could be improved. First, Bowers and Kennison measured both accuracy and reaction time, whereas Ellis and Young (1977) measured only word recognition (percent accuracy in reporting the word). Second, Bowers and Kennison tested a larger number of participants (i.e., 64) than Ellis and Young (1977) (i.e., 20). Lastly, Bowers and

Kennison used a larger set of materials than Ellis and Young (1977). Bowers and Kennison used 80 words, (i.e., 40 early AoA words and 40 late AoA words), whereas Ellis and Young used a total of 40 words, (i.e., 20 early AoA words and 20 late AoA words). In accordance with Gazzaniga's (1974) proposal, Bowers and Kennison hypothesized that there would be hemispheric differences for early and late AoA words such that there would be greater right hemisphere involvement for early AoA words than late AoA words. The result of the accuracy measurements replicated the findings from Ellis and Young (1977) such that no differences in visual field processing were found for either early or later AoA words. However, the results from the reaction time measurements showed significant hemispheric differences for the processing of early and late AoA words. For early AoA words, the mean reaction time was faster in LVF/RH, but only when stimulus items were not blocked by semantic categories, (i.e., when items were randomly selected from one of four semantic categories and presented). Moreover, the mean reaction time was faster in RVF/LH, but only when stimulus items were blocked by semantic categories, (i.e., when items were presented in groups based on semantic category). For late AoA words, the mean reaction time was faster in RVF/LH when the stimulus items were not blocked by semantic categories, whereas no significant difference in the mean reaction time was found for either visual field in the semantically blocked condition. As a result, the overall findings were not consistent with Gazzaniga's (1974) hypothesis, because early AoA words showed processing effects in the LVF/RH, but only when presented randomly. It was only after manipulating the context of presentation that early AoA words were found to be processed faster in the RVF/LH. Likewise, late AoA words exhibited faster processing in the RVF/LH, but only when

16

presented in the random condition, whereas when these same words were blocked by semantic category, they showed no visual field processing advantages.

RESEARCH HYPOTHESIS

The purpose of the present experiment was to determine whether there are hemispheric differences in semantic priming for the processing of early and late AoA words. Using a DVF task, participants viewed letter sequences presented either to the left or right visual field. The experimental task consisted of participants performing lexical decision judgments. In this study, two hypotheses were tested using a short SOA condition of 250 ms, (i.e., automatic priming), and a long SOA condition of 750 ms, (i.e., controlled priming). It was hypothesized that semantic priming in the left and right hemisphere would be different for early and late AoA words. Three outcomes were possible. One possibility, as suggested by Gazzaniga (1974), predicts that early AoA words would show equivalent semantic priming in the two hemispheres, whereas, semantic priming would occur only for late AoA words when they were presented to the left hemisphere. A second possibility, as suggested by Bowers and Kennison (2008), predicts that early AoA words would show greater semantic priming in the right hemisphere, while late AoA words would show greater semantic priming in the left hemisphere[1]. A final possibility is that the pattern of semantic priming in the left and right hemisphere would not differ for early and late AoA words over both SOAs. The second hypothesis compared the depth of processing hypothesis and the inhibitory time course hypothesis. Therefore, if support was found for the depth of processing hypothesis, then one would expect to find that the pattern of semantic priming in the left

and right hemisphere would be similar, regardless of SOAs. In contrast, if support was found for the inhibitory time course hypothesis, then one would expect to find that priming would occur only in the left hemisphere for the short SOA condition. Moreover, in the long SOA condition, the priming effect would shift and occur only in the right hemisphere.

CHAPTER III

METHODOLOGY

PARTICIPANTS

Sixty-four undergraduates (32 men and 32 women) enrolled in psychology courses at Oklahoma State University participated in exchange for course credit. The mean age of the participants was 22.7 years (*SD*= 4.1). All participants were native speakers of American English and right-handed, (as assessed by the Edinburgh Handedness Inventory, Oldfield, 1971).

MATERIALS

Forty-eight target words (24 early AoA and 24 late AoA) were selected for the experiment. The AoA ratings for these words were obtained from Bowers and Kennison (2006) or from the MRC psycholinguistic database (Wilson, 1988). The overall mean AoA for words in the early AoA condition was 2.24 (*SD*= .34), which corresponds to an actual age of 3 to 4 years of age. Likewise, the mean AoA for words in the late AoA condition was 4.13 (*SD*= .51), which corresponds to an actual age of 7 to 8 years old. In addition, all words were matched on number of letters and printed word frequency (Francis & Kucera, 1982), familiarity (Gilhooly & Logie, 1980; Toglia & Battig, 1978), imageability, (Chiarello, Shears, & Lund, 1999), as well as number of orthographic neighbors (Medler, & Binder, 2005). A summary of these characteristics for target words is displayed in Table 1.

For each target word, related and unrelated prime words were selected. These words were matched on number of letters and printed word frequency (Francis & Kucera, 1982), familiarity (Gilhooly & Logie, 1980; Toglia & Battig, 1978), imageability, (Chiarello, Shears, & Lund, 1999), as well as number of orthographic neighbors (Medler, & Binder, 2005). Ratings for the semantic relatedness of these prime words to the target words were obtained from a rating study which involved 15 undergraduate participants. The participants provided semantic ratings for a list of 140 prime-target word pairs. For each word pair, participants rated on a scale from 1 to 7, the degree of relationship that existed between the word pairs. On this scale, "1" indicated the word pairs were not related (e.g., *apple* and *car*) and "7" indicated the word pairs were highly related (e.g., *sugar* and *salt*). The related prime-target pairs had a mean rating above 5, whereas the unrelated prime-target pairs had a mean rating below 2. A summary of these characteristics for the prime words is displayed in Table 2. The appendix contains a list of target and prime words used in the experiments.

Because prime and target words appeared in the same visual field, filler words were used to ensure that half of the trials involve successive trials in the opposite visual field. Forty-eight word pairs, (i.e., 96 words), appeared in the opposite visual field, half in the left and half in the right. The ninety-six filler words were randomly intermixed with the experimental items. Furthermore, in order to ensure that half of the trials should involved a "no" response; 192 nonword fillers were used. The nonword fillers were pronounceable and orthographically legal nonwords, created by changing a single letter of a word that was not part of the experimental list. All words and non-words were within the range of three to six letters in length.

APPARATUS AND PROCEDURES

Stimulus presentation was performed on a computer with a 15 inch viewing screen. The collection of responses was controlled by E-Prime (version 2.0 Beta 1.0, Schneider, Eschmann, & Zuccolotto, 2002). All stimuli were presented horizontally in uppercase characters using Courier New 18-point font. When displayed, the stimuli subtended .8° vertical visual angle, while the innermost letters were displayed 2.2°- 3.1° of horizontal visual angle. Participants were seated 60 cm in front of the computer screen and instructed to place their heads comfortably into a headrest, which was used to stabilize their head position. Participants were instructed to focus on a cross whenever it appeared on the screen. Participants were also instructed to respond as quickly and accurately as possibly to whether the presented letter strings formed a legitimate word in the English language. Participants responded by depressing the "A" or "L" key on a standard computer keyboard. For half, the "A" key indicated a word response, and for the other half this response was reversed.

Participants were tested in a single session. Participants first completed a practice block of 20 trials in order to become familiar with the task. The experimental procedure involved participants viewing 384 experimental trials. The 384 trials were subdivided into two experimental test lists consisting of 192 trials. Each of the test lists contained an equivalent number of "yes" word "no" nonword responses. To counterbalance for relatedness, the two test lists included 24 related, (i.e., 12 in each visual field), and 24 unrelated word pairs, (i.e., 12 in each visual field). Within the test lists, half of the critical prime-target pairs were presented to the LVF and half to the RVF. Every prime-target pair was unique and no stimuli were repeated within the test lists. The primes and

targets for the critical pairs always appeared in the same visual field, (i.e., LVF related prime-target and LVF unrelated prime-target). Likewise, half of the word-nonword trials and all of the filler word pairs were displayed in the opposite visual field, (e.g., LVF prime and RVF target word or nonword). This was done in order to ensure that target location could not be predicted on the basis of the prime location. The order of stimulus presentation was independently randomized for each participant. Eight counterbalancing lists, (i.e., four for the short SOA condition and four for the long SOA condition), were used in order to ensure that each prime and target word appears equally often in the LVF and RVF. Participants were randomly assigned to one of the eight counterbalancing lists. All counterbalancing lists contained an equal number of participants.

Each trial began with a central presentation of a black fixation cross for 400 ms. After a 50 ms blank interval, the fixation cross was displayed in red for 50 ms then after another 50 ms blank interval the cross reappeared in black for 400 ms. The use of these steps served to draw the attention of the participant to the center of the display screen at the onset of each trial, because this progression sequence gives the appearance of a flickering fixation cross. The prime word was displayed for 100 ms. Following the presentation of the prime word, the central fixation cross reappeared either for 150 ms, (for the short SOA condition), or 650 ms, (for the long SOA condition). Subsequently, a target was displayed for 150 ms. Following the presentation of the target, the fixation cross would reappear and remain on the screen for 125 ms.

CHAPTER IV

FINDINGS

Accuracy for participants' responses was calculated. Participants were incorrect about 14.4 percent of the time in the short SOA condition and 20.9 percent of the time in the long SOA condition; error rates did not differ significantly across conditions for either SOA, $Fs < 1$. All incorrect response times were removed from the dataset. Data trimming was performed on all correct response trials in which reaction times were three standard deviations from the participants' mean response time. This trimming eliminated 5.3 percent of the total dataset, (i.e., 3.2 percent of the dataset in the short SOA condition and 2.1 percent of the dataset in the long SOA condition). The percentage of trimmed trials did not differ significantly across conditions for either SOA, $Fs < 1$. Mean reaction times and standard errors for correct responses are displayed by condition in Table 3, along with the priming effect observed in each condition. In all analyses to be reported, participants were treated as the only random factor. Stimulus items were treated as fixed effects, because the stimuli were restricted and did not constitute a random sample of words (Clark, 1973). Participants' mean reaction times for correct responses were analyzed using an analysis of variance (ANOVA). A 2 x 2 x 2 x 2 split-plot ANOVA was conducted with three within-participant factors, each having two levels: AoA (early vs. late), visual field (left vs. right), and target (unrelated to the prime vs. related to the

prime) along with one between-participant factor having two levels: SOA (short vs. long)[2].

The results indicated that there were differences in hemispheric processing for early and late AoA words. This analysis found that participants were faster to judge words in the early AoA condition than words in the late AoA word condition, resulting in a significant main effect of AoA (849 ms vs. 870 ms, respectively), $F(1,62)= 4.69$, $p =.03$, $\eta^2= .07$. There was a trend toward the classic right visual field advantage (848 ms vs. 871 ms, respectively); however, the effect of visual field was not significant $F(1,62)= 3.16$, $p = .08$, $\eta^2= .05$. The main effect for target (i.e., related vs. unrelated) was not significant, $F < 1.30$. More importantly, the four-way interaction involving AoA x visual field x target x SOA was significant, $F(1,62)= 4.06$, $p = .04$, $\eta^2= .06$. On the other hand, the three-way interaction of AoA x visual field x target was not significant, $F < 1.60$, which suggests that the four-way interaction was due to the changes occurring over time.

Due to the theoretical significance of the time-course manipulation, planned comparisons were conducted on the priming effects for both within as well as across each SOA condition. Moreover, priming effects were calculated for each condition by subtracting the response times for unrelated prime-target word pairs from the response times for related prime-target word pairs. These results are displayed in Figure 1. For the short SOA condition, there were no significant contrasts, Fs < 1.90. For the long SOA condition, significant differences in priming strength were found to occur between the conditions in which early AoA words were presented in the LVF/RH and late AoA

words presented in the LVF/RH, (85 ms vs. -34 ms, respectively), $F(1,31) = 4.11$, $p =$ .05, $\eta^2 = .12$. This pattern suggests that the priming effects occurred in the right hemisphere for early AoA words, but not for late AoA words. Furthermore, within the long SOA condition, significant differences in priming strength were found to occur between the conditions in which early AoA words were presented in the LVF/RH and early AoA words presented in the RVF/LH, (85 ms vs. -57 ms, respectively), $F(1,31) = 5.92$, $p = .02$, $\eta^2 = .16$. This pattern suggests that in the right hemisphere, there is greater priming for early AoA words than for early AoA words in the left hemisphere. No other comparisons approached significance, ps > .05.

CHAPTER V

CONCLUSION

The purpose of the present study was to investigate the hypothesis that there are hemispheric differences in semantic priming for early and late AoA words. The results supported this hypothesis by demonstrating that in the short SOA condition there were no statistically significant priming effects observed for early or late AoA words in either hemisphere. In contrast, at the long SOA condition, early AoA words showed priming effects only in the LVF/RH, whereas late AoA words were found to show priming effects in no other experimental condition except for in the RVF/LH. Overall, these results suggested that the two hemispheres process early and late AoA words differently over time.

The results of the present study differ from the results obtained by other studies that have directly examined the two prominent behavioral theories used to explain hemispheric processing of language (Richards & Chiarello, 1995; Chiarello et al., 2003; Shears & Chiarello, 2003; Koivisto, 1997, 1999). Chiarello and colleagues found similar priming patterns taking place in both visual fields and in both the short and the long SOA conditions (Chiarello et al., 2003; Richards & Chiarello, 1995; Shears & Chiarello, 2003). Comparable results were found in the present study, because nearly equivalent priming patterns were observed to occur in both visual fields in the long SOA condition. However, in contrast to Chiarello's findings, the present study did not find significant

priming effects occurring in any visual field at the short SOA condition. Moreover, the present study did not observe identical priming patterns for early and late AoA words in the long SOA conditions. Even though priming was found to occur in both visual fields in the long SOA condition; priming was only found to occur for early AoA words in the LVF/RH and late AoA words in the RVF/LH. Therefore, the results from the present study, similar to the conclusions by Chiarello and colleagues, demonstrate no irrefutable support for the inhibitory time course approach.

The present study's results also differed from those results observed by Koivisto, (1997, 1999). Unlike Chiarello and colleagues, Koivisto found that in the short SOA condition, priming effects occurred in the RVF/LH, but not in the LVF/RH. However, in the long SOA condition, no priming was found in the RVF/LH, whereas a robust priming effect was found in the LVF/RH. Comparable results were found in the present study because, in the long SOA condition, a robust priming effect occurred in the LVF/RH, for early AoA words. However, in contrast to Koivisto's findings, the present study did not find significant priming effects in the RVF/LH, at the short SOA condition. Moreover, in the long SOA condition, the present study found priming effects occurring in the RVF/LH, for late AoA words. As a consequence, the results from the present study, similar to the conclusions by Koivisto, demonstrate no irrefutable support for the depth of processing approach.

The failure to find statistically significant priming effects in the present study's short SOA condition may be due to differences in experimental designs. Studies by

Chiarello and colleges as well as Koivisto repeated prime words such that related prime-target items were re-paired to create unrelated critical trials. In the present study, no prime words were repeated such that the prime words for related target items were different than the prime words used for the unrelated critical trials. It is plausible that priming asymmetries vary with procedure changes.

Overall, the results from the present study do not unanimously support either the depth of processing approach or the inhibitory time course approach. Consequently, because prior research by Chiarello and colleagues as well as Koivisto has not co-varied words based on AoA, one could easily posit that the prior findings, along with their conclusions, must be cautiously considered. More importantly, the main effect of AoA found in the present study and the prior work of Bowers and Kennison (2008) both provide support for the idea that there are hemispheric differences for the processing of early and late AoA words. Together, the findings from these two studies have important implications. First, the results from both studies are of key importance because they show hemispheric processing differences for early and late AoA words. This finding is a major step towards proposing a hypothesis which is designed to bridge together the physiological and behavioral explanations for language lateralization. Second, the results from both studies provide new insights into the overwhelming importance that not all types of words are processed similarly by both hemispheres and that AoA is a significantly influential variable.

One way to conceptualize early and late AoA words would be to view these two word categories as representing semantic concepts arranged within a connectionist network. In this connectionist framework, early AoA words would constitute the base foundation level of semantic knowledge, because these words are learned first, (i.e., prior to the age of 4), and therefore encompass a broad range of semantic information. The reduced specificity of early AoA words would make them a lower order of processing function within the semantic network and as a consequence, early AoA words would be easier to activate. In connectionist terms, excessive ease could decrease the time required for the semantic system to settle into a stable pattern of activation, and this could facilitate the onset of priming under some conditions. Similarly, late AoA words would constitute the top level of semantic knowledge, because these words are learned later in life and as a result are comprised of a more concentrated and a more narrowly focused core of semantic information. The increased specificity of late AoA words would make them a higher order of processing function within the semantic network, which in turn would cause these words to be more difficult to activate. Hence, with late AoA word pairs, considerably more time will be required for the system to settle into a stable pattern of activation. Thus, when there is a great deal of semantic overlap between successive words, such as with the early AoA word pairs, the semantic "signal" is particularly strong and could be hypothesized to functionally minimize hemisphere differences in the onset of meaning activation relative to situations in which there is considerably less meaning overlap between prime and target words, such as occurs with the late AoA associate word

pairs. Taking this proposed view of early and late AoA into consideration, there are aspects of the present study's findings that can be explained in terms of both behavioral processing hypotheses.

According to the depth of processing approach, when the right hemisphere processes a lexical item it weakly activates a larger semantic field, as compared to the left hemisphere, which activates a stronger, but more focalized core within the semantic field. The activation of a larger semantic field allows the right hemisphere to activate more distantly related semantic associates, which makes the right hemisphere more sensitive to these weaker relationships, as compared to the left hemisphere. As a consequence, the depth of processing approach would predict that, because of the broad array of semantic features associated with early AoA words, greater priming would occur in right hemisphere, as opposed to the left hemisphere. Moreover, because of the more concentrated and more narrowly focused core of semantic information that exists between late AoA words, less priming would occur in the right hemisphere, as opposed to the left hemisphere.

As predicted by the depth of processing approach, the present results showed an increased priming effect, which was found to occur at the long SOA for early AoA words in the LVF/RH and not in the RVF/LH. Likewise, the results also showed increased priming occurring for late AoA words in the RVF/LH and not in the LVF/RH. However, in contrast to the predictions made by the depth of processing approach, the present results found no priming effects in either the LVF/RH or the RVF/LH, at the short SOA

condition. The results from the short SOA condition are not predicted outcomes by the depth of processing approach, because the left and right hemisphere are not viewed as having identical processing specialties.

In contrast to the predictions made by the depth of processing approach, the inhibitory time course approach makes different predictions. According to the inhibitory time course approach, both hemispheres process information simultaneously, although, harmonized processing is performed as a result of the language dominant hemisphere (i.e., left hemisphere) inhibiting the activity of the opposite hemisphere. Thus, after initial broad activation of distantly associated semantic features, (i.e., early AoA words), by the left hemisphere, the left hemisphere then shifts its processing approach towards the processing of word meanings which have a more concentrated and highly focused core set of semantic features, (i.e., late AoA words). As a result, early AoA words would show priming effects in the left hemisphere at the short SOA condition, but at the long SOA condition, only late AoA words would show priming in this hemisphere. After the left hemisphere shifts its processing strategy, it releases the right hemisphere from its inhibitory state. Once released from its inhibitory state, the right hemisphere begins the processing of word meanings that consist of weakly related or distantly associated semantic features of words, (i.e., early AoA words). This shift in processing patterns results in the RVF/LH showing a reduced priming effect at the long SOA condition for early AoA words, as compared to the robust priming effect in the LVF/RH, for early AoA words at the long SOA condition.

As predicted by the inhibitory time course approach, the present study found priming, at the long SOA condition, for early AoA words in the LVF/RH. In addition, priming was found to occur for late AoA words in the RVF/LH, but only in the long SOA condition. However in the short SOA condition, the present study found no significant difference in priming for early AoA words in the RVF/LH than in the LVF/RH. This pattern is not a predicted outcome of this approach, because the left hemisphere is perceived to be initiator of word processing, focusing on broad meanings. Consequently, in the short SOA condition, the left hemisphere is thought to inhibit the right hemisphere from performing any initial processing. Hence, the lack of priming observed to occur for early AoA words in the left hemisphere is not a plausible effect. In addition, the near equivalent priming, observed to occur in the long SOA condition, for early AoA words in the right hemisphere and late AoA words in the left hemisphere are not predicted outcomes. According to this approach, once the right hemisphere is released from inhibition, it begins to process the broad meaning of words, which results in greater amounts of priming, as compared to the left hemisphere, which has been processing word meanings the entire time.

The results of this study confirmed the hypothesis that the prior conflicting results were related to differences in AoA. Nevertheless, in order to accommodate the non-predicted outcomes of the present study, both behavioral explanations require a minimal revision. The revision involves taking features from both hypotheses and combining them into one explanation. The new explanation would view the processing capacities of

the two hemispheres similar to the way the depth of processing approach proposes. Therefore, the left hemisphere is viewed as being a focal, analytically based serial processor, whereas the right hemisphere is viewed as being a holistically broad based, parallel processor. However, instead of both hemispheres maintaining these separate processing strategies throughout the entire process; this new explanation suggests that in the initial stages of processing, both hemispheres will process words using a broad based approach. A subsequent switch in processing strategies would take place after initial processing is complete, through which both hemispheres would use separate processing strategies. Furthermore, this new explanation would incorporate the view of the inhibitory time course approach such that both hemispheres would process information simultaneously. However, instead of inhibition from the language dominant left hemisphere being initiated at the beginning stages of word processing; this new explanation suggests that the inhibition would be a delayed processing strategy instituted later on.

As a result, this new explanation would predict that in the initial stage of word processing, both hemispheres will begin processing by activating the broad based meanings of words, (i.e., early AoA words). After processing has been initiated, the left hemisphere would then shift its processing focus towards the processing of the core meanings of words. This shift is a result of the left hemisphere moving from a broad based approach towards a focal based, serial processing approach. In addition to this shift in processing strategies by the left hemisphere, the left hemisphere will actively

inhibit the right hemisphere from changing its processing strategy. As a result, only late AoA words are maintained for further processing in the left hemisphere. At the same time, the right hemisphere maintains and enhances the processing of weakly related, broad based meanings of words, (i.e., early AoA words). By the right hemisphere maintaining and enhancing early AoA words, this allows the meanings associated with these words to be quickly accessed and processed, by the left hemisphere, if a reinterpretation is required, (e.g., in metaphors or unexpected interpretations). Therefore, in the long SOA condition, this processing shift will result in early AoA words only being primed in the LVF/RH and late AoA words only being primed in the RVF/LH.

The next step in this program of research will be an attempt to replicate these findings in an experiment using the same materials and design. However, unlike the present study, which used prime and target words that appeared in the same visual field, this next experiment will present prime words in the opposite visual field to their respective target words. The results are expected to show that in the short SOA condition, early AoA words displayed in the LVF will prime early AoA words displayed in the RVF and vice versa, but no priming will be observed for late AoA word in any order. In contrast, in the long SOA condition, no priming is expected to be found. This replication would demonstrate that the present results in the short SOA condition are reflective of how words are linked/stored in the two hemispheres and that the results in the long SOA are reflective of the lexical processing strategies used by both hemispheres.

In sum, the present results showed that AoA influences the semantic processing of the left and right hemisphere. Specifically, in the short SOA condition, priming was found to occur for early AoA words in both visual fields. Moreover, no priming effects were found to occur, in either visual field, for late AoA words. Conversely, in the long SOA condition, early AoA words showed priming in the LVF/RH, whereas late AoA words showed priming in the RVF/LH. These results support the view that an asymmetry exists between how early and late AoA words are processed in the brain. Therefore, this study can be a springboard for guiding our understanding of how AoA works in formulating memory representations for concepts and lexical items. Understanding the nature of how memory representations function in the left and right hemisphere is important to the development of future theories which address hemispheric processing of language. Therefore, the results of this study have the potential to motivate the direction of future investigations and add to our knowledge of hemispheres processing. Obtaining such detailed knowledge may, in turn, contribute to our understanding of developmental disorders, the influence of early brain development and the consequence that aging has on our brains.

REFERENCES

Abernethy, M. & Coney, J. (1993). Associative priming in the hemispheres as a function of SOA. *Neurospychologia, 31,* 1397-1410.

Anaki, D., Faust, M., & Kravetz, S. (1998). Cerebral hemispheric asymmetries in processing lexical metaphors. *Neuropsychologia, 36*, 353-362.

Beaumont, J. G. (1982). *Divided visual field studies of cerebral organization.* New York: Academic Press.

Beeman, M. & Chiarello, C. (1998). *Right Hemisphere Language Comprehension: Perspectives from Cognitive Neuroscience.* Mahwah, NJ: Erlbaum.

Beeman, M., et al., (1994). Summation priming and course semantic coding in the right hemisphere. *Journal of Cognitive Neurosciences, 6,* 26-45.

Beeman, M., (2005). Bilateral brain processes for comprehending natural language. *Trends in Cognitive Sciences, 9,* 512-518.

Bogen, J. E. & Gazzaniga, M. (1965). Cerebral commissurotomy in man. Minor hemisphere dominance for certain visuospatial functions. *Journal of Neurosurgery*, 394-399.

Bowers, J. M., & Kennison, S.M. (2006 under revision). Age of acquisition effects in bilingual word translation. *Memory and Cognition.*

Bowers, J. M. & Kennison, S. M. (2007 under revision). Hemispheric Differences in the Processing of   Words Learned Early Versus Later in Childhood. *Brain and Language.*

Bradshaw, J. & Nettleton, N. C. (1983). *Human cerebral asymmetry.* Englewood Cliffs, NJ: Prentice-Hall.

Brizzolara, et al. (1994). Is interhemispheric transfer time related to age? A developmental study. *Behavioural Brain Research, 64,* 179-184.

Brown, G., & Watson, F. (1987). First in, first out: Word learning age and spoken word

    frequency as predictors of word familiarity and word naming latency. *Memory and*

    Cognition, 15, 208-216.

Bryden, M. P. (1982). *Laterality: Functional asymmetry in the intact brain.* NewYork:

    Academic Press.

Brysbaert, M., Van Wijnendaele, I. & De Deyne, S. (2000). Age of acquisition effects in

    semantic processing tasks. *Acta Psychologica, 104*, 215-226.

Burgess, C. & Simpson, G. (1988). Cerebral hemispheric mechanisms in the retrieval of

    ambiguous word meanings. *Brain and Language, 33,* 86-103

Carroll, J. & White, M. (1973). Word frequency and age of acquisition as determiners of picture

    naming latency. *Quarterly Journal of Experimental Psychology, 25,* 85-95.

Chi, J., Dooling, E. & Gilles, F. (1977). Gyral development of the human brain. *Annual of*

    Neurology, 1, 86-93.

Chiarello, C. (1985). Hemisphere dynamics in lexical access: Automatic and controlled priming.

    Brain and Language, 26, 146-172.

Chiarello, C. & Church, K. (1986). Lexical judgments after right or left hemisphere injury.

    Neuropsychologia, 24, 623-630.

Chiarello, C., Senehi, J. & Nuding, S. (1987). Semantic priming with abstract and concrete

    words: differential asymmetry may be postlexical. *Brain and Language, 31,* 43-60.

Chiarello, C., Burgess, C., Richards, L., & Pollock, A. (1990). Semantic and associative priming

    in the cerebral hemispheres: Some words do, some words don't…sometimes, some

    places. *Brain and Language, 38,* 75-104.

Chiarello, C., Richards, L., & Pollock, A. (1992). Semantic additivity and semantic

    inhibition: Dissociable processes in the cerebral hemispheres? *Brain and Language, 42,*

    52-76.

Chiarello, C., Maxfield, L., & Kahan, T. (1995). Initial right hemisphere activation of

    subordinate word meanings is not due to homotopic callosal inhibition. *Psychonomic*

    Bulletin & Review, 2, 375-380.

Chiarello, C., Shears, C., & Lund, K. (1999). Imageability and distributional typicality measures

    of nouns and verbs in contemporary English. *Behavior Research Methods, Instruments &*

    Computers, 31, 603-637.

Chiarello, C., Liu, S., Shears, C. (2001). Does Global Context Modulate Cerebral Asymmetries?

    A Review and New Evidence on Word Imageability Effects. *Brain and Language, 70,*

    360-378.

Chiarello, C., Liu, S., Shear, C., Quan, N., & Kacinik, N. (2003). Priming of strong semantic

    relations in the left and right visual fields: A time-Course investigation.

    Neuropsychologia, 41, 721-732

Chiarello, C., Shears, C., Liu, S., & Kacinik, N. (2005). Influence of word class proportion on

    cerebral asymmetries for high and low imagery words. *Brain and Cognition, 57,* 35-38.

Clark, H. H. (1973). The language-as-fixed-effect fallacy: A critique of language statistics in

    psychological research. *Journal of Verbal Learning and Verbal Behavior, 12*, 335-359.

Cohen, G. (1973). Hemispheric differences in serial versus parallel processing. *Journal of*

    Experimental Psychology, 97, 349-356.

Collins, A. M., & Loftus, E. F. (1975). A spreading-activation theory of semantic processing.

    Psychological Review, 82, 407-428.

De Schonen, S. & Mathivet, E. (1989). First come first served: A scenario about the

    development of hemispheric specialization in face recognition during infancy. *European*

    Bulletin of Cognitive Psychology, 9, 3-44.

Dehaene-Lambertz, G., Hertz-Pannier, L., & Dubois, J. (2006). Nature and nurture in language

    acquisition: Anatomical and functional brain-imaging studies in infants. Special issue:

Nature and nurture in brain development and neurological disorders. *Trends in Neurosciences, 29,* 367-373.

Dorsaint-Pierre, R., Penhune, V., & Watkins, K. (2006). Asymmetries of the planum temporale and Heschl's gyrus: Relationship to language lateralization. *Brain: A Journal of Neurology, 129,* 1164-1176.

Efron, R. (1990). *The Decline and Fall of Hemispheric Specialization*. Hillsdale, NJ, England: Lawrence Erlbaum Associates.

Ellis, A. W., & Morrison, C. M. (1998). Real age of acquisition effects in lexical retrieval. *Journal of Experimental Psychology: Learning, Memory, & Cognition, 24*, 515-523

Ellis, H. D. & Young, A. (1977). Age of acquisition and recognition of nouns presented in the left and right visual fields: a failed hypothesis. *Neuropsychologia, 15,* 825-828.

Francis, W. N., & Kučera, H. (1982). *Frequency analysis of English usage: Lexicon and Grammar*. Boston: Houghton Mifflin

Fassbinder, W. & Tompkins, C. (2006). Hemispheric differences in word-meaning processing: Alternative interpretations of current evidence. *Aphasiology, 20,* 110-122.

Gazzaniga, M. (1974). Cerebral dominance viewed as a decisions system. In S. Diamond & J. Beaumont (eds.) Hemisphere Function in the Human Brain. (pp. 367-382) New York. John Wiley & Sons.

Gazzaniga, M. (1983). Lateralization and specialization of human language. *In. Issues in cognition: proceedings from a joint conference in psychology*. National Academy of Sciences; Washington, DC, US, 407-429.

Gazzaniga, M. S. & Sperry, R. W. (1967). Language after section of the cerebral commissures. *Brain*, 90, 131-148.

Geschwind, N. & Behan, P. (1982). Left-handedness; Association with immune disease, migraine, and developmental learning disorder. *Proceedings of the National Academy of Sciences, 79,* 5097-5100.

Geschwind, N. & Levitsky, W. (1968). Human brain: Left-Right asymmetries in temporal speech

region. *Science, 161,* 186-187.

Geschwind, N., & Galaburda, A. M. (1985). Cerebral lateralization: Biological mechanisms,

associations, and pathology: A hypothesis and a program for research. *Archives of

Neurology*, *42*, 428–459.

Ghyselinck, M., Custer, R., & Brysbaert, M. (2004). The effect of age of acquisition in visual

word processing: Further evidence for the semantic hypothesis. *Journal of

Experimental Psychology: Learning, Memory, and Cognition, 30,* 550-554.

Gilhooly, K. & Gilhooly, M. (1979). Age of acquisition effects in lexical decision and

episodic memory tasks. *Memory and Cognition, 7*, 214-223.

Gilhooly, K., & Logie, R., (1980). Age of acquisition, imagery, concreteness, familiarity,

and ambiguity measures for 1,944 words. *Behavior, Research Methods, and

Instrumentation, 12,* 395-427.

Hellige, J. B. (1993). *Hemispheric asymmetry: What's right and what's left*. Cambridge, MA:

Harvard University Press.

Hirsh, K., Morrison, C., Gaset, S., & Carnicer, E. (2003). Age of acquisition and speech

production in L2. *Bilingualism: Language and Cognition, 6*, 117-128.

Izura, C. & Ellis, A. (2004). Age of acquisition effects in translation judgment tasks. *Journal of

Memory and Language, 50,* 165-181.

Juhasz, B. & Rayner, K. (2003). Investigating the effects of a set of intercorrelated

variables on eye fixation durations in reading. *Journal of Experimental Psychology:

Learning, Memory, and Cognition, 29,* 1312-1318.

Juhasz, B. (2005). Age-of-Acquisition Effects in Word and Picture Identification.

Psychological Bulletin, 131, 684-712.

Kacinik, N. & Chiarello, C. (2007). Understanding metaphors: Is the right hemisphere uniquely

involved? *Brain and Language, 100,* 188-207.

Kimura, D. (1967). Functional asymmetry of the brain in dichotic listening. *Cortex, 3,* 163-178.

Kimura, D. (1973). The asymmetry of the human brain. *Scientific American, 228,* 70-78.

Kinsbourne, M. (1975). The mechanism of hemispheric control of the lateral gradient of

    attention. In *Attention and Performance.* P. Rabbitt & S. Dornic (eds.), *(*pp. 81-97).

    Academic Press, New York.

Koivisto, M. (1997). Time course of semantic activation in the cerebral hemispheres.

    Neuropsychologia, 35, 497-504.

Koivisto, M. (1999). Hemispheric dissociations in controlled lexical-semantic processing.

    Neuropsychology, 13, 488-497.

Koivisto, M., & Laine, M. (2000). Hemispheric asymmetries in activation and integration of

    categorical information. *Laterality*, *5*, 1-21.

Medler, D.A., & Binder, J.R. (2005). MCWord: An On-Line Orthographic Database of the

    English Language. http://www.neuro.mcw.edu/mcword/

Meyer, D. E. & Schvaneveldt, R. W. (1971). Facilitation in recognizing pairs of words:

    Evidence of a dependence between retrieval operation. *Journal of Experimental*

    Psychology, 90, 227-234.

Michimata, C. (1987). Lateralized effects of semantic priming in lexical decision tasks:

    Examinations for the time course of semantic activation build-up in the left and right

    cerebral hemispheres. PhD dissertation, University of Southern California

Morrison, C. & Ellis, A. (1995). Roles of word frequency and age of acquisition in word naming

    and lexical decision. *Journal of Experimental Psychology: Learning Memory, and*

    Cognition, 21, 116-133.

Morrison, C. M., & Ellis, A. W. (2000). Real age of acquisition effects in word naming and

    lexical decision. *British Journal of Psychology, 91*, 167-180

Morrison, C. M., Ellis, A. W., & Quinlan, P. T. (1992). Age of acquisition, not word frequency,

    affect object naming, not object recognition. *Memory and Cognition, 20*, 705-714.

Moscovitch, M. (1979). Information processing and the cerebral hemispheres. In. M. Gazzaniga (ed). *Handbook of Behavioral neurobiology, vol 2: Neuropsychology.* (pp. 379-446). Plenum Press, New York.

Nakagava, A. (1991). Role of anterior and posterior attention networks in hemispheric asymmetries during lexical decisions. *Journal of Cognitive Neuroscience, 3,* 314-321.

Neely, J. H. (1977). Semantic priming and retrieval form lexical memory: Roles of inhibitionless spreading activation and limited-capacity attention. *Journal of Experimental Psychology: General, 106,* 226-254.

Neely, J. H. (1991). Semantic priming effect in visual word recognition: A selective review of current finding and theory. In *Basic Processes in Reading. Visual Word Recognition.* D. Besner & G.W. Humphreys (eds.), (pp. 264-336). Lawrence Erlbaum, Hillsdale, NJ.

Paus, T. et al., (1999). Structural maturation of neural pathways in children and adolescents: Invivo study. *Science, 283,* 1908-1911

Pujol, J. et al. (2006). Myelination of language related areas in the developing brain. *Neurology, 66,* 339-343.

Pujol, J., et al., (2002). The lateral asymmetry of the human brain studied by volumetric magnetic resonance imaging. *NeuroImage, 17,* 670-679.

Richards, L. & Chiarello, C. (1995). Depth of associated activation in the cerebral hemispheres: Mediated versus direct priming. *Neuropsychologia, 33,* 171-197.

Ringo, J. et al., (1994). Time is of the essence: A Conjecture that hemispheric specialization arises from interhemispheric conduction delay. *Cerebral Cortex, 4,* 331-343.

Schneidner, W., Eschman, A., & Zuccolotto, A. (2002). *E-Prime User's Guide.* Pittsburg, Psychology Software Tools, Inc.

Schvaneveldt, R. W. & Meyer, D.E. (1973). Retrieval and comparison processes in semantic memory. In S. Kornblum (ed.), *Attention and Performance IV.* New Yourk: Academic Press.

Semmes, J. (1968). Hemispheric specialization: A Possible clue to mechanism. *Neuropsychologia, 6,* 11-26.

Sperry, R. W. (1964). The great cerebral commissure. *Scientific American, 210,* 42-52.

Sperry, R. W., Gazzaniga, M. S. & Bogen, J. E. (1969). Interhemispheric relationships: the neocortical commissures; syndromes of hemisphere disconnection. In: P. J. Vinken & G. W. Bruyn (Eds.), *Handbook of Clinical Neurology,* (pp. 177-184). Amsterdam: North-Holland Publishing Company,

Sperry, R.W. & Gazzaniga, M.S. (1967). Language following surgical disconnection of the commissures. In: F. Darley,(ed). *Brain Mechanisms Underlying Speech and Language*, (pp. 147-168). Grune & Stratton, New York.

Stadthagen-Gonzalez, H. Bowers, J. & Damian, M. (2004). Age of acquisition effects in visual words recognition: Evidence from expert vocabularies. *Cognition, 93*, B11-B26.

Turkewitz, G. (1988). A prenatal source for the development of hemispheric specialization. In D. Molfese & S. Segalowitz, (eds.), *Brain Lateralization in children: Developmental Implications,* (pp. 73-81). New York: Guilford Press.

Wilson, M.D. (1988). The MRC Psycholinguistic Database: Machine Readable Dictionary, Version 2. *Behavioural Research Methods, Instruments and Computers*, 20, 6-11. http://www.psy.uwa.edu.au/MRCDataBase/uwa_mrc.htm

Zaidel, E. & Peters, A. (1981). Phonological encoding and ideographic reading by the disconnected right hemisphere: Two case studies. *Brain and Language, 14,* 205-234.

Zaidel. E. (1978). Concepts of cerebral dominance in the split brain In: P. Buser and A. Rougeul-Buser (Eds.) *Cerebral Correlates of Conscious Experience*. (pp. 177-197). Elsevier North-Holland Biomedical Press, Amsterdam.

APPENDIX

	Early AoA			Late AoA	
Prime	Target	Unrelated Prime	Prime	Target	Unrelated Prime
tree	leaf	doll	brook	creek	blade
cheek	chin	dress	elm	cedar	avenue
butter	cheese	bath	reef	coral	tool
coat	glove	sauce	copper	rust	joy
dog	puppy	bubble	jaw	skull	cherry
knee	elbow	bell	lead	steal	bonnet
apple	grape	chair	minnow	trout	essay
rabbit	frog	gravy	mist	liquid	scroll
egg	bacon	nail	olive	lime	brain
smoke	cloud	nose	otter	ferret	banker
corn	carrot	pillow	wheat	rye	beaver
dirt	mud	rattle	shrub	vine	fawn
deer	goat	stool	soil	turf	lens

	Early AoA			Late AoA	
Prime	Target	Unrelated Prime	Prime	Target	Unrelated Prime
plate	bowl	thumb	willow	reed	tomb
sheep	lamb	needle	disk	record	herb
shoe	boot	ocean	wine	beer	seal
salt	sugar	leg	breast	lung	gang
toilet	sink	ear	planet	comet	nozzle
orange	lemon	pond	dome	tower	drug
kitten	lion	finger	kidney	liver	male
duck	bird	sand	spine	pelvis	leek
fork	spoon	pig	dusk	dawn	nipple
shirt	pants	robin	silk	fleece	lawyer
milk	juice	skirt	shawl	veil	cider

Footnotes

[1] The second predicted result is based on the results found to occur in the random condition of the Bowers and Kennison (2008) study.

[2]Preliminary analyses investigated the possibility of significant interactions involving either sex differences, counterbalancing lists, or response hand. Since none were found, these variables were not considered any further.

Table 1

Summary of Mean and Standard Deviation (SD) Characteristics for Target Words in Early and Late AoA Conditions.

	Early AoA Target	Late AoA Target
AoA	2.30 (.29)	4.12 (.59)
F & K Word Frequency	17.25 (15.84)	17.29 (29.00)
Imageability	5.95 (.21)	5.84 (.38)
Familiarity	5.55 (.35)	5.57 (.47)
Neighborhood Size	6.00 (5.24)	6.08 (5.72)
Letters	4.54 (.78)	4.87 (.90)

Table 2

Summary of Mean and Standard Deviation (SD) Characteristics for Related and Unrelated Prime Words in the Early and Late AoA Conditions.

	Early AoA		Late AoA	
	Prime	Unrelated Prime	Prime	Unrelated Prime
AoA	2.16 (.38)	2.27 (.40)	4.15 (.43)	4.07 (.62)
Word Frequency	24.79 (15.67)	24.16 (20.30)	18.12 (28.75)	16.67 (16.40)
Imageability	5.98 (.24)	5.93 (.33)	5.91 (.39)	5.71 (.33)
Familiarity	5.68 (.37)	5.47 (.44)	5.56 (.50)	5.40 (.44)
Neighborhood	6.13 (4.04)	6.17 (5.04)	6.00 (5.57)	6.45 (6.17)
Letters	4.63 (.88)	4.67 (.96)	4.71 (.95)	4.88 (.99)

Table 3

Mean Response Times (and Standard Error) by Visual Field, SOA, and Relatedness Condition.

		Short SOA (250 ms)		Long SOA (750 ms)	
		Early AoA	Late AoA	Early AoA	Late AoA
LVF					
	Related	780 (24)	806 (37)	887 (24)	978 (37)
	Unrelated	796 (30)	808 (28)	972 (30)	944 (28)
	Priming	+16 (18)	+2 (26)	+85 (32)	-34 (42)
RVF					
	Related	735 (45)	784 (27)	965 (45)	906 (27)
	Unrelated	751 (30)	759 (45)	908 (30)	974 (45)
	Priming	+16 (22)	-25 (23)	-57 (37)	+68 (53)
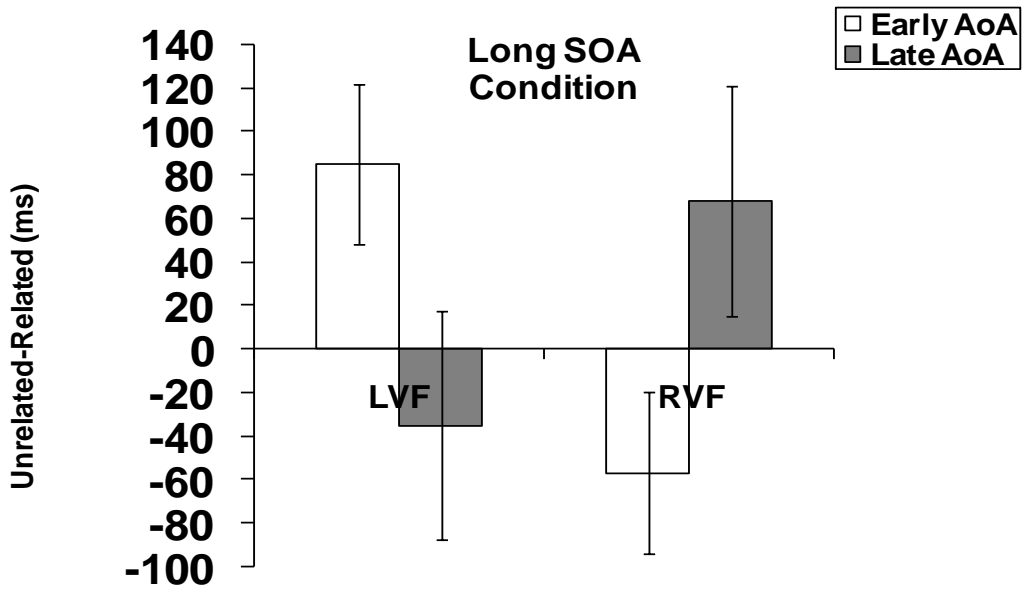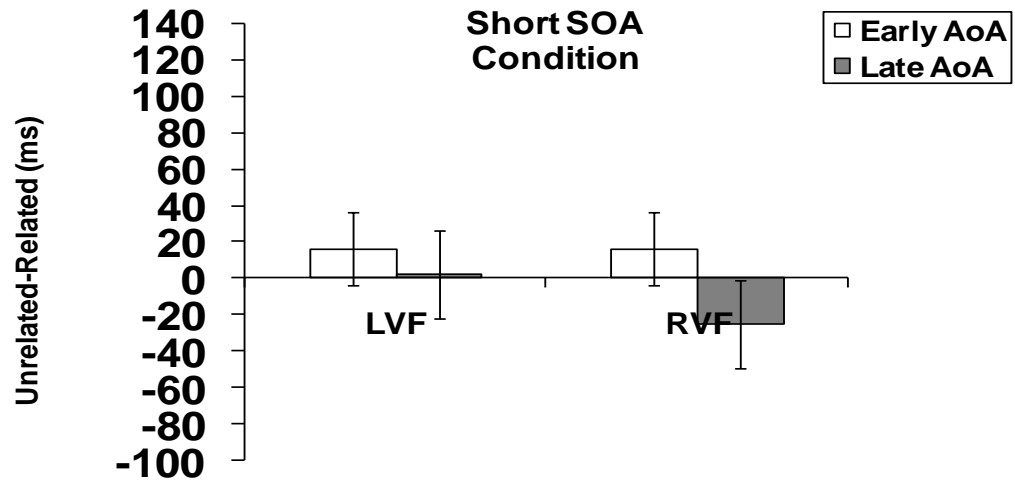
<center>CONSENT FORM</center>

GENERAL DESCRIPTION

The project title is *Word Relationships and Hemispheric Processing*. It is being conducted by J. Michael Bowers, a doctoral student in the Department of Psychology at Oklahoma State University and Dr. Shelia Kennison, Ph.D., a faculty member in the Department of Psychology at Oklahoma State University. The purpose of the research is to understand how words are processed visually. We are interested in the process of word identification, which will enable us to identify how the brain's two hemispheres access words.

PROCEDURES

If you choose to volunteer today, your session will last about 45 minutes. You will view words briefly presented on a computer screen which will be followed by a brief presentation of a series of letters. Both words and the letter strings will be presented either at the left or right of the computer screen, while you are looking straight ahead. You will press one key to indicate that the letters make up a real word in English and another key to indicate that the letters do not make up a word. After the computer tasks, you will complete a short questionnaire about which hand you use for most tasks and which hand your relatives use for most tasks.

STATEMENT OF RISKS

We would like you to know that we are not aware of any risks associated with this procedure, beyond the risks we all face in everyday life.

STATEMENT OF BENEFITS

We would like you to know that those who participate in this study are not expected to benefit, except for the course credit that you may be receiving from one of your college courses. For your participation in this study, you will receive one credit/unit of participation. We would like you to know that for college courses, there are alternative means to receive similar credit. You may contact your instructor to learn about these alternatives. Nevertheless, your participation today may result in a benefit to society, if our research leads to a better understanding of how language is processed. Our research may help us identify individuals who have reading problems.

CONFIDENTIALITY ISSUES

Your data will be recorded by the computer anonymously. You will be assigned an arbitrary number, which will be entered into the computer at the time of your participation. This anonymous data will be used for research purposes only. We follow guidelines established by the American Psychological Association in keeping our data for a minimum of five years after the research report has been published. When the anonymous data is destroyed, the file will be purged from the computer using special software that will prevent future retrieval of the data.

CONTACT INFORMATION

If you have any questions regarding this study, you can direct them to J. Michael Bowers (jmikebowers1@cox.net) or Dr. Shelia Kennison (shelia.kennison@okstate.edu), in the Department of Psychology, 116 North Murray, Oklahoma State University, Stillwater, OK 74078. Phone: 405-744-7335. If you have questions about your rights as a research volunteer, you may contact Beth McTernan, IRB manager, 219 Cordell North, Stillwater, OK 74078. Phone: 744-5700.

WITHRDRAWAL INFORMATION

We want you to know that your participation is voluntary and that you will not be penalized if you choose not to participate. You are free to withdraw at any time and you will not experience any penalty.

CONSENT

If you feel you have read this statement and fully understand it and now wish to participate, please sign on the line below: We will provide you with a copy of this form for your personal records.

Signed: _____Date: _____ Time: _____(a.m./p.m.)

I certify that I have personally explained all elements of this form to the subject or his/her representative before requesting the subject or his/her representative to sign it.

Signed: _____Date: _____ Time: _____(a.m./p.m.)

<center>Project director or authorized representatives</center>

Okla. State Univ.
IRB
Approved 3/11/08
Expires 3/10/09
IRB# AS0818
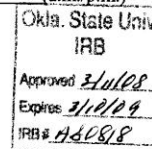
VITA

Jerald Michael Bowers

Candidate for the Degree of

Doctor of Philosophy or Other

Thesis: HEMISPHERIC DIFFERENCE IN SEMANTIC PRIMING FOR EARLY AND

LATE AGE OF ACQUISTION WORDS

Major Field: Psychology

Biographical:

Personal Data:

Education:
    Completed the requirements for the Doctor of Philosophy Psychology at
    Oklahoma State University, Stillwater, Oklahoma in July, 2008.

Experience:
    Research assistant supported by a National Science Foundation (BCS
    0446998) grant
    Graduate Instructor, Oklahoma State University, 2003-present
    High School Biology Instructor, Santa Cruz Valley High School, Eloy,
    Arizona, 2001-2003
    Graduate ESL Instructor, University of New Mexico, 2000-2001

Professional Memberships:
     Sigma XI
     Oklahoma Network for Teaching of Psychology
     Southwestern Psychological Association

Name: Jerald Michael Bowers   Date of Degree: July, 2008

Institution: Oklahoma State University   Location: Stillwater, Oklahoma

Title of Study: HEMISPHERIC DIFFERENCE IN SEMANTIC PRIMING FOR EARLY
             AND LATE AGE OF ACQUISTION WORDS

Pages in Study: 50   Candidate for the Degree of Doctor of Philosophy

Major Field: Psychology

Scope and Method of Study: Empirical Research

Findings and Conclusions:

The present research investigated the hypothesis that there are hemispheric differences in

semantic priming for early and late age of acquisition (AoA) words. To test this

hypothesis, semantic priming effects were measured in the left and the right hemisphere

using the divided visual field technique. The stimulus onset asynchrony (SOA) was

varied. A short SOA of 250 ms and a long SOA of 750 ms were used. The results

demonstrated that in the short SOA condition there were no differences in the priming

effects observed for early or late AoA words in either hemisphere. However, in the long

SOA condition, early AoA words showed priming effects only in the LVF/RH, whereas

the late AoA words showed priming effects only in the RVF/LH. Overall, the results

suggested that the two hemispheres process early and late AoA words differently.

Implications for current models of hemispheric processing are discussed.

ADVISER'S APPROVAL: Dr. Shelia Kennison