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Individual differences in hemispheric lateralization of language processing

Sarah Ann Van Dyke
Wayne State University,

INDIVIDUAL DIFFERENCES IN HEMISPHERIC LATERALIZATION OF LANGUAGE PROCESSING

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SARAH A. VAN DYKE

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CHAPTER 1 BACKGROUND

Introduction

An extensive body of literature has examined the differences between men and women in functional brain laterality. Although many studies report sex differences in lateralized cognitive processing using various methodologies, the research remains inconclusive with other studies reporting no sex differences. Inconsistent findings may suggest that sex differences in laterality are domain-specific, or it may suggest that sex differences are moderated or mediated by other variables, or a combination of both.

Typically, significant sex difference findings in laterality studies suggest that women utilize both cerebral hemispheres in processing verbal, visual-spatial, and emotional information, whereas men process the same information more asymmetrically in a “dominant” or “specialized” hemisphere. Specifically, it is often proposed that men process verbal material dominantly in the left hemisphere and process non-verbal information dominantly in the right hemisphere. However, in broadening the scope of literature examining sex differences in cognition and individual differences in brain laterality, a more complex picture is revealed.

For example, a substantial body of literature suggests that men outperform women in spatial tasks, whereas women outperform men in verbal tasks (e.g., McGlone & Kertesz, 1973). Furthermore, studies have found that pre- and post-natal androgen exposure is positively related to spatial skills and negatively related to verbal skills (e.g., Cohen-Bendahan, van de Beek & Berenbaum, 2005; McKeever, 1995). For instance, in a dichotic listening study of young people, testosterone exposure was positively related to left-hemisphere lateralization of language in girls, and positively related to right-hemisphere lateralization of emotion recognition in boys (Cohen & Forget, 1995). These findings lead to the interpretation that androgen levels lead to greater cerebral lateralization in both sexes. In support of this, Weekes, Zaidel and Zaidel (1995), reported that lateralization on a dichotic listening task was positively related to masculinity scores on a measure of gender role identity. And not surprisingly, gender role identity is related to biological sex (Bem, 1974).

In short, previous research suggests that sex is related to verbal and spatial skills, verbal and spatial skills are related to sex hormones, sex hormones are related to measures of laterality, measures of laterality are related to gender identity, and gender identity is related to sex. Considering this complex web of related factors, one might suspect that biological and skill-specific moderators might explain some sex and laterality findings. Understanding predictors of lateralization is important not only from a theoretical standpoint, but also a practical standpoint. For example, understanding if verbal or visual-spatial skills are positively or negatively related to the degree of lateralization of language may aid in interpreting assessment results of individuals with lesions that require surgery. Predicting whether individuals process language bilaterally or dominantly in the left hemisphere could have implications for preservation of function following surgical interventions.

Unfortunately, previous studies of sex and laterality have not adequately examined the role of these potentially related factors in predicting the degree to which individuals process information bilaterally or asymmetrically. Therefore, the current study examined multiple domains related to both sex and laterality in men and women from a diverse range of ability levels that are both prototypical and non-prototypical of their respective sexes. Using a laterality index based upon dichotic listening and lateralized semantic priming, this study examined the relative contributions and potential moderating or mediating roles of verbal ability, visual-spatial ability, gender identity, prenatal hormone exposure and trait personality characteristics in predicting laterality.

Sex Differences in Laterality

Researchers have found sex differences in functional laterality using various methodologies in both clinical and normal populations. Examining a clinical population, McGlone (1980) investigated cognitive differences on the Wechsler Adult Intelligence Scale (WAIS; Wechsler, 1955) between men and women who sustained either right- or left-hemisphere lesions. The results indicated that men exhibited more severe and more specific cognitive deficits than women. Specifically, men with left-hemisphere lesions showed specific verbal deficits and men with right-hemisphere lesions showed specific non-verbal deficits. However, women with either left- or right-hemisphere lesions exhibited less specific cognitive deficits compared to men. McGlone concluded that men exhibit more functional asymmetry than women for both verbal and nonverbal processes.

The findings demonstrated by McGlone (1980) were also extended to normal populations. For instance, Cowell and Hugdahl (2000) conducted a dichotic listening experiment to examine the effect of individual differences in hemispheric functioning. The experimenters presented consonant-vowel pairs, one stimulus to each ear simultaneously, to neurologically intact men and women of various ages. In a free recall task, participants were first instructed to report stimuli irrespective of ear, and then participants were instructed to attend to either the left- or right-ear specifically. Men showed a significantly larger right-ear advantage compared to women in all test conditions, which the authors interpreted as suggesting that men processed the language more dominantly in the left hemisphere in comparison to women.

In addition to dichotic listening among normal populations, sex differences in laterality have been found in lateralized semantic priming. Van Dyke et al. (2009) instructed participants to determine whether the stimuli presented was a real word or a pseudoword in a lexical decision task. Real words were strongly related, weakly related, or unrelated to the prime word. Reaction time and accuracy were measured, and priming was calculated by subtracting reaction times to related trials from reaction times to unrelated trials. Women showed greater priming to contralaterally presented stimuli than did men. In addition, women did not show a difference in reaction times to right or left visual field presentations of ipsilateral stimuli, whereas men showed an advantage to right visual field presentations of ipsilateral stimuli. This supported the contention that men process language dominantly in the left hemisphere, whereas women process language bilaterally.

In one of the early studies of sex and non-verbal processing, Witelson (1976) investigated differences in spatial processing between boys and girls between the ages of 6 and 13. Participants engaged in a dihaptic task involving tactually manipulating two different shapes out of view simultaneously with right and left hands and then choosing the two shapes from a visual display. Boys showed a left-hand advantage, suggesting greater right hemisphere involvement in spatial processing, whereas girls showed no lateralized advantage. Witelson proposed that girls might have greater brain plasticity, for a longer period time than boys, as suggested by greater bilateral processing.

In addition to behavioral methods, imaging studies confirm sex differences in lateral asymmetry. Kansaku, Yamaura and Kitazawa (2000) compared regional cortical activation using fMRI while men and women listened to stories forward and then in reverse. The imaging revealed that men showed significant activation in superior and middle temporal regions in the left hemisphere compared to the right hemisphere, whereas women did not show a significant difference between left and right hemispheres. The authors posited that women process linguistic material more bilaterally than men. Despite strong support for the conclusion that men are more lateralized than women, many of these studies do not consider possible mediating or moderating characteristics, such as visual-spatial and verbal skills, gender identity, trait personality characteristics, and hormone exposure. In examining other characteristics that are related to both sex and laterality, the plausibility of interactions increases.

Verbal and Visual-Spatial Skills and Laterality

The evidence that men and women show differences in verbal and non-verbal laterality measures becomes difficult to interpret, considering the evidence of sex differences in verbal and non-verbal ability. Hyde and Linn (1988) conducted an extensive meta-analysis that included various age groups and various verbal tasks. They found that adult women (older than 26 years of age) tended to outperform men across all verbal tasks. Although these authors reported a small effect (d = .20), it is consistent with the trend that observed sex differences in verbal ability tend to be in favor of women. In addition to observing sex differences in normal adult populations, researchers have found discrepancies between younger boys and girls with learning and speech impairments. For instance, researchers have found that boys are much more likely than girls to have problems with fluent speech production marked by stuttering (Skinner & Shelton, 1985; Andrews, Morris-Yates, Howie & Martin, 1991) and are more likely to have problems with dyslexia (Vandenberg, 1987).

Although the differences are often not statistically significant, the predominant trends in the literature conclude that men outperform women on visual-spatial tasks and women outperform men on verbal tasks. Voyer, Voyer and Brydan (1995) conducted a meta-analysis of 286 studies examining differences in performance between men and women on visual-spatial tasks. They found that men tended to outperform women on visual-spatial skills, but the effect was small (d = .37). However, according to a fail-safe analysis, 178,205 studies with non-significant findings would be required to offset the effect; thus, although the size of the effect is modest, it appears to be highly reliable. Geary, Saults, Liu and Hoard (2000) administered arithmetic computation and reasoning tests, a spatial cognition test, and an IQ test to men and women to detect sex differences using structural equation modeling (SEM). The authors found that men performed better than women on the arithmetic and spatial cognition tests, but the two groups were similar on the test of IQ. Based on SEM, the authors suggested that men tend to perform well on tests of three-dimensional ability, regardless of their IQ, whereas women might require a higher IQ to perform at a similar level.

With interactions between verbal and visual-spatial abilities and sex, in addition to interactions between sex and laterality, it is possible that ability scores could moderate or mediate the effect of sex on laterality, or vice versa. A lateralized semantic priming study by Van Dyke et al. (2009) found that visual-spatial ability significantly predicted semantic priming in women, such that visual-spatial performance was inversely related to priming. This pattern was not demonstrated in men. Similar to Johnson and Harley's (1980) findings, visual-spatial skills appear to mediate strength of lateralization, assuming that greater priming is indicative of utilizing bilateral resources than in lower levels of priming.

In addition, Saucier and Elias (2002) conducted a lateralized visual field study testing working memory for between sexes. In this experiment, participants were asked to recall either numbers or letters in high or low memory load conditions. The results indicated that men exhibited greater left-hemisphere lateralization than women in recalling letters, whereas women exhibited greater right-hemisphere lateralization in recalling numbers. The authors concluded that working memory tasks of recalling letters lateralizes differently than tasks of recalling numbers and is also dependent on sex. These results suggest that men demonstrated asymmetrical organization only for letters, whereas women demonstrated asymmetrical organization only for numbers. These findings contradict the previous evidence that men process information asymmetrically whereas women process information bilaterally; in fact, it suggests that functional laterality depends on an interaction between sex and type of information (i.e., verbal or non-verbal).

Johnson and Harley (1980) provided further support for the role of visual-spatial skills in functional laterality. The researchers conducted a study comparing verbal and visual-spatial abilities between sexes and hand dominance. The experimenters administered Vocabulary, Arithmetic, Block Design, and Picture Arrangement subtests of the WAIS and found that both left-handed men and women demonstrated higher verbal scores than visual-spatial scores. Considering previous studies that suggest weak lateralization in left-handed individuals, the authors concluded that poorer spatial ability is indicative of weaker functional lateralization. According to this hypothesis, the interaction between sex and laterality might be moderated by visual-spatial skills. This is a viable hypothesis, as men typically outperform women on visual-spatial tasks (Vandenberg & Kuse, 1978; Voyer, Voyer & Bryden, 1995), just as men have been found to have stronger functional lateralization than women. In short, evidence suggests that verbal and spatial ability play roles in the interaction between sex and laterality.

Gender Identity and Laterality

Although gender identity is related to biological sex, the two constructs are conceptually distinct. Constantinople (1973) asserted that all individuals possess psychological traits that are stereotypically associated with masculinity and femininity to different degrees, despite their biological sex. Rather than conceptualizing gender as a mutually exclusive dichotomy, individuals could possess both masculine and feminine psychological traits. Similar levels of masculine and feminine traits that are relatively high were subsequently termed “androgyny,” whereas relatively low levels of the traits were termed “undifferentiated.” Based on this conceptualization of psychological gender traits, Bem (1974) developed the Bem Sex Role Inventory (BSRI) to measure masculine and feminine traits and determine whether an individual can be categorized as masculine, feminine, androgynous, or undifferentiated.

In time, researchers incorporated gender traits as a continuous variable in laterality research. For instance, Weekes, Zaidel and Zaidel (1995) conducted an experiment examining gender identity as measured by the Bem Sex Role Inventory (BSRI) and its effect on laterality measured by a dichotic listening task. The authors attempted to differentiate between “polar sex” (male vs. female) and “spectral sex” (masculinity vs. femininity) in lateralization of function. The results indicated that women had a smaller right ear advantage then men, suggesting that they were less lateralized. In addition, men who had lower masculinity scores on the BSRI had smaller right ear advantages than men who had higher masculinity scores in the BSRI. This suggests that although the “spectral sex” construct may overlap with the “polar sex” construct, the two are not the same. Govier and Bobby (1994) compared men and women within occupations that are stereotypically held by either men or women. Results suggested that both men and women in occupations stereotypically held by men produced a right ear advantage on a dichotic listening test, whereas both men and women in occupations stereotypically held by women showed a smaller right ear advantage, suggesting less hemispheric asymmetry. In summary, sex differences in laterality have been found to be influenced by “femininity” and “masculinity”, or the extent to which an individual represents a prototypical man or woman based upon his or her identification with a particular gender identity or role.

Personality and Laterality

Another area of emerging research is that of biological correlates of cognitive style and personality. Kozhevnikov (2007) reviewed modern cognitive style research, including methodologies that incorporate neuroscience techniques. Although research has progressed in this area, Kozhevinikov noted that few modern studies have examined the role of five factor personality traits in cognitive style, warranting further research. The five factor personality traits were initially developed through the lexical approach of compiling all words that represent personality characteristics within the English language. In its initial form, the list contained nearly 18,000 words that were eventually whittled into a five-factor structure dubbed the “Big Five” (Goldberg, 1981) as they are reliably replicated yet extremely broad. The factors include extraversion (e.g., assertive, talkative), agreeableness (e.g., cooperative, trusting), conscientiousness (e.g., responsible, orderly), neuroticism (e.g., easily upset), and openness (e.g., intellectual, independent-minded) (John & Srivastava, 1999).

Compton and Weissman (2002) investigated the role of neuroticism on laterality, arguing that the findings would promote neuropsychological understanding of mood and anxiety disorders. The experimenters administered the NEO five-factor personality questionnaire (Costa & McCrae, 1992) in addition to a global-local laterality task. The stimuli were creating by manipulating the letters T, O and A. The global stimuli were large letters formed by smaller, local letters. For instance, small T’s might be placed in a way that forms a letter A. Trials were comprised of a probe at the bottom of the screen on either the right or the left side as well as two target stimuli presented at the top of the screen. The probe and targets were presented simultaneously and participants were to decide if the probe matched one of the top two targets on either the global level or the local level, depending on the condition. The researchers used a median split to divide participants into High and Low groups based on neuroticism scores. There was an equal distribution of men and women between the two groups. The results indicated that individuals in the High group did not show a significant left-hemisphere advantage when processing local targets, suggesting that individuals with relatively high trait neuroticism process information in a bilateral fashion. Conversely, individuals in the Low group showed significant left-hemisphere advantage, suggesting that individuals with relatively low trait neuroticism process information in a lateralized fashion. In short, individuals with low neuroticism showed greater left-hemisphere lateralization for local stimuli than individuals with high neuroticism, with control for sex effects. It should be considered, however, that the researchers' use of a median split likely compromised statistical variance. It is possible that the distribution of neuroticism was not equivalent between men and women (e.g., it is possible that the women fell at the low ends of the both the low group and the high group, relative to men, thus yielding different means).

Similarly, Schmidtke and Heller (2004) theorized that basic personality traits have an effect on patterns of neural activity. They argued that extraversion and neuroticism, components of the five factor personality traits, are typically related to pleasant and unpleasant affective states, which have been found to be associated with different patterns of brain activity. The experiment entailed an EEG measuring resting regional brain activity of participants, in addition to five factor personality traits being measured by the NEO-PI-R. Although sex analyses were not included in the a priori hypotheses, they investigated possible sex effects and found null effects. The results offered partial support to Schmidtke and Heller's theory, where levels of neuroticism were positively related to increased activity in the right posterior hemisphere. In sum, Compton and Weissman (2002) and Schmidtke and Heller (2004) found evidence that linked neuroticism with either decreased processing in the left hemisphere or increased processing in the right hemisphere. Arguably, this pattern of processing may be more bilateral in nature in comparison to the leftward lateralization in individuals with low levels of neuroticism.

Considering the link between personality traits and laterality, a compelling link can be drawn between personality traits, laterality, and sex. Previous studies have found significant relationships between sex and ratings on Big Five measures. Lippa (2006) found significant relationships between participants' biological sex and their self-ratings on measures of five-factor personality traits, with the strongest relationship suggesting that women score higher on neuroticism than men. Furthermore, Costa, Terracciano and McCrae (2001) conducted an examination of sex differences on the NEO-PI among 26 cultures and found that women were more likely to endorse items consistent with higher levels of neuroticism, agreeableness, warmth and openness to feelings in comparison to men, who tended to endorse items consistent with higher levels of assertiveness and openness to ideas in comparison to women. The authors noted that individual differences were relatively small within sex groups. To recapitulate, neuroticism has been linked to both bilateral processing and to women. Therefore, it is possible that personality, especially neuroticism, could play a role in influencing the interaction between sex and laterality.

Hormone Exposure and Laterality

Prenatal hormone exposure has also been hypothesized to influence hemispheric lateralization (Jackson, 2008). One prominent theory suggests that the growth of certain regions of the left hemisphere slow in growth when exposed to high levels of testosterone, thus resulting in higher incidences of right-hemisphere language dominance and left-handedness (Geschwind & Galaburda, 1987). Prenatal exposure to testosterone arises from structures within the mother, adrenal glands in both male and female fetuses, and developing testes in male fetuses. Therefore, all fetuses are exposed to some level of testosterone, but male fetuses are likely to be exposed to more testosterone than female fetuses. A second theory posited by Witelson and Nowakowski (1991) suggests that naturally occurring axonal loss in each side of the corpus callosum may be influenced by androgens, explaining prenatal development of hand preference. Although support for this theory was shown in males, the authors note that neither the total volume of the corpus callosum nor any of its sub-regions are related to handedness in females, which suggests that callosal axon loss during prenatal development may not play a role in lateralization in females. Since different neurobiological factors may predict hand preference in each sex, Witelson and Nowakowski posited that different mechanisms might lead to structural and functional asymmetries in each sex. As correlations between callosal size and handedness have been found in males only, the authors argue that axon loss related to lateralization could be related to a sex-linked hormonal or genetic factor.

To examine the effect of hormones on laterality, researchers have utilized populations with sex-atypical hormone levels. Cohen and Forget (1995) compared men who were transsexual or were undergoing hormone treatment to groups of normal men and women. Using verbal and nonverbal dichotic listening tasks to determine lateralization of function, normal men showed a significant left-ear advantage with non-speech sounds, whereas women and transsexual men did not show this advantage, suggesting less lateralization. Differences were primarily found between men who were normal and men who were transsexual, and between men who were normal and women who were normal, on nonverbal tasks. No significant differences were found between men who were transsexual and women who were normal on the nonverbal task.

Additionally, Hausmann, Güntürkün and Corballis (2003) compared younger and older people for differences in laterality on a figural comparison task. Results indicated that left visual field advantages decreased slightly with age in men, but increased significantly with age in women. The authors posited that this was due to age related changes in hormone levels, which tends to be more marked in women. These results suggest that hormones are involved in hemispheric dominance.

Relatively recently, research has suggested that the ratio between the length of the second finger and fourth finger (i.e. 2D:4D ratio) is an indicator of prenatal sex hormone exposure, with the second finger length being positively related to estrogen exposure and the fourth finger being positively related to testosterone exposure (Manning, Scutt, Wilson & Lewis-Jones, 1998). Clusters of the *Hox* gene are responsible for growth of digits and differentiation of genitalia (Kondo, Zakany, Innis, & Duboule, 1997). Based upon this finding, Manning et al. hypothesized that patterns of digit growth may be related to sex hormones and fertility. In a series of studies, the researchers measured digit ratios of 800 boys, girls, women and men ages 2-25 in the general population, as well as 131 men and women attending a reproductive medicine unit. Blood and sperm samples were collected from the individuals at the fertility unit to measure sperm count and testosterone concentrations in men and luteinizing hormone, follicle stimulating hormone, estrogen and prolactin concentrations in both men and women. The findings from the general population suggest that digit ratios are established in early development, likely before 2 years of age. The findings from the fertility clinic sample yielded that a high 2D:4D ratio in men was negatively related to sperm count and testosterone concentration. In addition, luteinizing hormone, estrogen, and prolactin ratios were positively correlated with 2D:4D in both women and men. Lutchmaya, Baron-Cohen, Raggat, Knickmeyer and Manning (2004) conducted a study in which fetal testosterone and estradiol levels were measured from amniotic fluid obtained from amniocentesis during the second trimester of pregnancy. Two years postnatal, the children returned to have their digit ratios measured. The results indicated that low 2D:4D ratios were related to high fetal testosterone levels in comparison to fetal estradiol levels, and high 2D:4D ratios were related to low fetal testosterone levels in comparison to fetal estradiol levels.

Hormone exposure has been hypothesized to also influence sex roles. Weis, Firker and Hennig (2007) conducted a study in which they measured digit ratios as well as career interests between men and women. Results indicated that a low 2D:4D ratio, which is indicative of high levels of prenatal testosterone, was related to male-typical career interests in both men and women. The researchers interpreted these findings as providing evidence that prenatal androgens their influence on brain development may partially explain sex differences in career interests.

Interrelated factors

As discussed, various factors have been found to predict the strength of lateralization in information processing. Verbal and visual-spatial abilities, gender identity, personality, and hormone exposure are related to the direction and strength of hemispheric asymmetry. These findings are difficult to interpret, however, as all of these factors have also been found to be related to sex and as well as to each other.

Previous studies have primarily focused on the predictive power of one or two of these factors on laterality, resulting in a limited knowledge base regarding which predictor accounts for more variance in laterality than others. Additionally, previous studies typically do not select a sample with sex-atypical attributes. For instance, a study that does not control for the distribution of verbal and spatial skills between sexes will likely obtain a "sex typical" sample (i.e., men have better spatial skills than women, and women have better verbal skills than men). With systematic confounding of variables, it would be difficult to determine if sex differences predicted differences in laterality, or if verbal and visual-spatial skills predicted differences in laterality. Therefore, the current study aimed to collect a broad range of verbal and visual-spatial abilities between sexes.

Methods of Assessing Laterality

Since Mishkin and Forgays' (1952) study sparked interest in the sub-field of cerebral dominance (White, 1967), several methodologies have been developed to assess laterality. One of the most classic methods is dichotic listening, initially developed by Broadbent (1954) in an effort to understand speech recognition and discrimination. In its initial form, the methodology consisted of presenting different messages to each ear simultaneously and the participant was asked to recall as much of the message as possible. Kimura (1961) noted that the right ear produced greater accuracy than the left ear, which was coined a "right ear advantage" (REA). The right ear advantage was found as evidence of left hemisphere dominance for language

(Kimura, 1967), as the right ear corresponds to the left hemisphere and the left ear corresponds to the right hemisphere, and this was confirmed with the later used Wada technique. Furthermore, left ear advantage (LEA) provides evidence of right hemisphere dominance, and a lack of ear advantage provides evidence of weak or absent hemisphere dominance. Since the development of the dichotic listening methodologies, technology has evolved from tape reels to digital manipulation; yet, the initial findings of ear advantage remains relevant in modern replications.

Cowell and Hugdahl (2000) conducted a study investigating individual differences in laterality utilizing a consonant-vowel dichotic listening task. The participants were presented with 36 syllable pairs (e.g., /ba/, /ka/), one syllable per ear, per trial. They were then asked to report which syllable they heard on each trial. In the second condition, they were instructed to attend to and report from attention to their right ear, and in the third condition, they were instructed to attend and report from the left ear. In all three conditions, men showed greater REA for accuracy than women, suggesting possible asymmetry in auditory processing. Cowell and Hugdahl’s finding of sex differences suggests that the consonant-vowel dichotic listening task effectively detects individual differences in laterality.

A second, more recent, approach to determining hemispheric asymmetry employs lateralized semantic priming within a lexical decision task. The rationale behind this methodology is based upon the theory of spreading activation, which was initiated by Quillian (1962) and elaborated by Collins and Loftus (1975). According to this theory, words are arranged in a theoretical semantic network with the distance between words representing semantic associations. Accordingly, words that are close in proximity are closely related in meaning, whereas words that are far in proximity are weakly related. When a word or concept, or “node”, is activated, or processed, activation spreads across the network of related concepts. Activation first spreads from the original activated node to strongly related concepts first and then moves to progressively less related concepts. As the activation spreads from closely related concepts to weakly related concepts, arousal of the network weakens.

The lexical decision task capitalizes upon this theory by assuming that if an individual is presented with a “prime” word and then presented with a “target” word and asked to determine if the target is a real word or a pseudoword, performance will be enhanced if the two words are closely related within the semantic network. Traditionally, researchers have used this method to measure laterality by using a visual half-field technique, in which the prime word is presented to the participant’s central visual field and the target is presented to either the right or the left visual field. Because stimuli presented in the right visual field are processed by the left hemisphere, and stimuli presented in the left visual field are processed by the right hemisphere, differences between stimuli presented to either visual field are presumed to offer information about laterality. However, this methodology assumes that the location of the initial simulation does not matter and that the hemispheres do not interact between the centrally presented prime and the laterally presented target.

In an attempt to remedy this methodological flaw, our lab has utilized both lateralized primes and targets. By presenting prime words to either the right or the left visual fields, we are able to isolate the initial stimulation of a single hemisphere and its respective semantic network. The differences between centralized and lateralized prime methodologies were investigated by Chiarello et al. (1990). The researchers found that centralized primes produced similar priming in both right and left visual fields, whereas lateralized primes produced similar priming in right and left hemispheres if they were strongly related to the target word, but greater right hemisphere priming than left hemisphere priming if they were weakly related to the target word. Lateralized priming allows us to compare priming with right visual field presentations and left visual field presentations, and also allows us to assess cross-hemispheric priming (contralateral presentation) in comparison to within-hemispheric priming (ipsilateral presentation). In essence, we are able to assess how the stimulation of one hemisphere affects the arousal in another hemisphere.

In addition to utilizing lateralized primes and targets, our lab has investigated the role in time delay between the presentation of prime and target. Abeare, Raiter, Hutchinson, Moss and Whitman (2003) used six different stimulus onset asynchronies (SOA) at 35 ms, 50 ms, 200 ms, 400 ms, and 750 ms and found reciprocal arousal between hemispheres across time and eventual convergence of activation. This finding reinforces that the right and left hemispheres interact over time, and that spreading activation is a rapid process. The methodological implications are that results from a single SOA may not be generalizable to all priming; therefore, sampling two or more SOAs may enhance reliability general findings, as well as yielding information about the effect of different latencies on priming.

Van Dyke et al. (2009) used the lateralized semantic priming methodology to investigate lateralized differences between sexes. The results indicated that women had significantly more priming in contralateral conditions than ipsilateral conditions, whereas men did not show this difference. This suggests that women benefited from bilateral hemispheric priming, whereas men did not. This offers support to the theory that women process information bilaterally, whereas men process information asymmetrically. In addition, with ipsilateral presentations, men produced faster reaction times to stimuli presented to the left hemisphere in comparison to the right hemisphere, whereas women did not show a difference between hemispheres. Again, this supports the theory that men tend to process verbal information in the left hemisphere, whereas women process verbal information bilaterally. The findings by Van Dyke et al. (2009) suggest that the lateralized semantic priming methodology is effective in detecting individual differences in laterality.

Summary

To summarize, the proposal that men and women differ in degrees of laterality is highly contested in the literature, as it is often an inconsistent finding. However, when sex differences are found, they generally follow the trend that men are more lateralized than women. In taking a broader look at the interaction between sex and laterality, the complexity of individual differences becomes increasingly apparent. Verbal and visual-spatial abilities, gender identity, personality, and hormone exposure have been found to be related to individual differences in both laterality and sex. Therefore, it is feasible that these variables play a role in moderating or mediating the relationship between sex and laterality, or that one variable drives all the differences between the others. Although portions of this picture have been previously investigated (e.g., the role of visual-spatial skills in sex differences in laterality), few studies, if any, have investigated the relative contributions of the aforementioned variables. In addition, few studies have attempted to evaluate individuals with sex-atypical and sex-typical abilities to prevent a restricted range of variance. Few studies, if any, have utilized two laterality tasks to form a composite rather than relying on only one measure. Based upon the literature reviewed, the following predictions were made:

1) It was expected that men would be more likely to process information in a lateralized fashion, whereas women would be more likely to process information in a bilateral fashion.
    a. Specifically, men would have a greater advantage of the left hemisphere (right ear) over the right hemisphere (left ear) in dichotic listening, whereas women would not show this difference. Similarly, men would have greater left hemisphere dominance for language (as evidenced in greater right-ear advantage) compared to women.
    b. As found in Van Dyke et al. (2009), women were expected to show bilateral processing of language as evidenced by priming more with contralateral presentations than ipsilateral presentations in a lateralized semantic priming task. Additionally, it was expected that men would not show bilateral processing of language as evidenced by no difference between contralateral presentations and ipsilateral presentation.
    c. As found in Van Dyke et al. (2009), men would also show strong lateralization evidenced in faster reaction times to ipsilateral presentations with the left hemisphere (right visual field) than with the right hemisphere (left visual field), whereas women would not show this difference.

2) Visual-spatial skills would be positively related to degree of lateralization. If the findings from Van Dyke et al. (2009) are replicated, visual-spatial skills would be positively related to degree of lateralization in women, whereas verbal skills would be positive related to degree of lateralization in men.
3) Neuroticism was expected to be inversely related to degree of lateralization. Although few studies have analyzed the other four factors in relation to laterality, the current study proposed to explore potential relationships between all five factors and lateralization. If neuroticism is the only five-factor trait that is related to laterality, this may provide discriminant validity of the factor. Based upon previous research of the role of cerebral hemispheres in language (Beeman, 1993) and emotion (Hall, Witelson, Szechtman & Nahmias, 2004), it was hypothesized that openness and neuroticism would be inversely related to left hemisphere lateralization, whereas conscientiousness, extraversion and agreeableness would be positively related to degree of left hemisphere lateralization.
4) Masculinity was hypothesized to be positively related to degree of laterality, whereas femininity would either be unrelated or inversely related with degree of laterality.
5) The 2D:4D digit ratio was hypothesized be positively related with degree of laterality.
6) Men will show higher masculinity, 2D:4D digit ratio and degree of lateralization than women, and they will show less femininity and neuroticism than women.

Because men and women will be equated for verbal and visual-spatial ability, these characteristics will not show relation to sex.

7) Exploratory analyses would examine the relative contributions of sex, verbal skills, visual-spatial skills, personality, gender identity, and prenatal hormone exposure to the degree of lateralization in individuals. Because few, if any, studies have included all of these variables, it is difficult to determine which variables influence degree of lateralization the most.
8) The semantic priming task was expected to yield faster reaction times to targets preceded by highly related primes than to unrelated primes. Additionally, priming data would replicate the findings from Van Dyke et al. (2009). Specifically:
    a. Reaction times with ipsilateral presentations would be faster than reaction times with contralateral presentations.
    b. Priming would be greater with contralateral presentations in comparison with ipsilateral presentations.
9) Dichotic listening and lateralized semantic priming tasks would yield significantly related laterality scores. Differences between dichotic listening and lateralized semantic priming may suggest that lateralization in auditory processing and lateralization in visual processing, or lateralization in perception and lateralization in semantic processing, are distinct. If this is the case, hypotheses with laterality as the dependent variable would be examined separately between dichotic listening and lateralized semantic priming.

CHAPTER 2 METHOD

Participants

Eighty-nine adults (44 women, 45 men) were recruited from the Wayne State University subject pool as well as from advertisements displayed around the Wayne State University and the College for Creative Studies. All participants were right-handed, native English speakers with normal or corrected-to-normal vision and normal hearing. Exclusion criteria included left-handedness, as well as history of stroke, head injury or seizures, current pregnancy, and being older than age 40.

Measures

The *Wechsler Test of Adult Reading* (WTAR; The Psychological Corporation, 2001) was used to assess reading ability. Participants read aloud a list of 50 words; scores are based on accuracy of pronunciation. The WTAR has an internal consistency of .90-.97 and correlates with VIQ at r = .75 and FSIQ at r = .73 (Strauss, Sherman & Spreen, 2006).

Verbal and spatial ability were assessed with the *Wechsler Abbreviated Scale of Intelligence* (WASI; The Psychological Corporation, 1999). The WASI is a screening battery with four subtests: Vocabulary, Similarities, Block Design, and Matrix Reasoning. This test was formed based on prior research, suggesting these subtests load heavily on general intellectual ability (*g* factor) and also tap the constructs of verbal/crystallized and nonverbal/fluid functioning (Strauss, Sherman & Spreen, 2006). The WASI has an internal consistency of .96 for the VIQ, .96 for the PIQ, and .98 for the FSIQ in adults. The FSIQ of the WASI is correlated .92 with the FSIQ from the Wechsler

Adult Intelligence Scale, Third Edition (WAIS-III; The Psychological Corporation, 2002) in adults. The test takes approximately 30 minutes to administer.

To assess gender identity, participants completed the *Bem Sex Role Inventory* (BSRI; Bem, 1974). This inventory contains masculinity and femininity subscales, which are used to classify individuals as masculine (high masculinity, low femininity), feminine (high femininity, low masculinity), androgynous (high masculinity, high femininity) or undifferentiated (low masculinity, low femininity). The 20-item short form was utilized, as it has been found by confirmatory factor analysis that the BSRI short form (α_M = .82, α_F = .89) is more reliable than the 40-item long form (α_M = .85, α_F = .81), and offers greater utility (Campbell, Gillaspy & Thompson, 1997).

In addition to the BSRI, *digit ratios* were measured to estimate prenatal hormone exposure. The ratio between the second and fourth digits (2D:4D digit ratio) has been hypothesized to indicate fetal exposure to androgen and estrogen levels, with greater ratios being associated with more estrogen and less androgen (Schmukle, Liesenfeld, Back & Egloff, 2007). In addition, differences between these ratios have been found to correspond to several sex-differentiated skills, such as spatial ability (Sanders, Bereczkei, Csatho & Manning, 2005). Manning, Fink, Neave and Caswell (2004) found that the popular method of photocopying participants' hands yielded lower digit ratios than direct measures, possibly due to differences in sizes of fat pads when pressed against photocopy surfaces. Therefore, finger length was determined by measuring with calipers to the nearest millimeter from the basal crease to the fingertip along the medial line bisecting the finger. Burton, Henninger and Hafetz (2005) reported inter-rater reliabilities of .94 to .99 in measuring digit ratio. Additionally, participants' hands were scanned and saved for reference.

Participants also completed the 44-item *Big Five inventory* (BFI; John & Srivastava, 1999) to measure the five factor personality traits of openness, agreeableness, extraversion, conscientiousness, and neuroticism. This measure takes approximately 5 minutes to administer and holds an alpha of .83.

Participants completed the Edinburgh Handedness Inventory (EHI; Oldfield, 1971) to ensure that they were right-hand dominant.

Apparatus

The priming experiment consisted of 320 trials composed of words from a database of word associations (Nelson, Mcevoy, & Schreiber, 1994). Each trial was composed of an English prime word followed by a target word that was either an English word or a pronounceable pseudoword created by altering a single phoneme of an English word (e.g., "MEAM"). Prime-target pairs were either high associates (e.g. ABOVE-BELOW) or unrelated (e.g. ABOVE-CLOUD), each condition having an equal number of stimuli. High associates consisted of word pairs that were free-associated by at least 50% of the participants, whereas unrelated words consisted of word pairs that were free-associated by less than 2% of the participants in Nelson, Mcevoy and Schreiber's study. Target stimuli consisted of 50% words and 50% pseudowords to avoid the development of a biased response pattern. Primes and targets were presented either to the right or left of the center of the screen and all trials were randomized. Stimuli were presented on a personal computer using SuperLab Pro and written in lowercase, 35-point Arial font on black letters with light yellow background.

Means on reaction time and accuracy data were computed for each subject based separately on trials for correct lexical decisions in the word conditions and correct lexical decisions in the pseudoword conditions. Reaction time means were calculated for each individual after removing data points that are two standard deviations above and below the mean within the individuals' correct lexical decisions in the word condition. Accuracy was calculated for each individual by determining the percentage of correct responses to word stimuli for each condition. Individuals with accuracy lower than 70% were excluded from reaction time and priming analyses. The reaction time data yielded 16 variable combinations consisting of association strength (high vs. neutral), prime location (R vs. L), target location (R vs. L) and SOA (50 vs. 400). The priming effect was calculated as the difference in reaction times between unrelated and related trials. Specifically, semantic priming is traditionally defined as RT unrelated condition - RT related condition (Meyer & Schvaneveldt, 1971). Reaction times for pseudoword trials and for errors were examined to determine if systematic differences exist between conditions. The priming task lasted approximately 22 minutes.

The Dichotic Consonant Vowel test (D-CV) from a professional auditory test company (Audiotec, 2007) was administered to measure ear advantage. The task involves binaural presentations of consonant-vowel pairs via Altec Lansing AHP524 stereo headphones. Two sets of 30 trials were administered in counterbalanced order between participants. Participants were instructed that they would hear two words and they were to report the two words they heard. Scores were based on correct responses per ear, with ear advantage calculated as (total correct right ear - total correct left ear) /

(total correct right ear + total correct left ear). This portion of the experiment lasted approximately 10 minutes.

Procedure

Informed consent procedures were completed with all participants per institutional review board guidelines. Participants provided demographic information regarding age, education, and social habits. Participants also completed the EHI, BSRI and BEM questionnaires. A trained examiner administered the WTAR and WASI. See Table 1 for means and standard deviations.

Priming procedures and dichotic listening procedures were administered in counterbalanced order. For the priming task, participants were positioned at 40 cm from the computer screen using a chin rest. The participant read the instructions on the screen as the experimenter provided instructions and answered questions. The participant was instructed to respond as quickly and accurately as possible. Each participant was presented with one block of 16 practice trials with feedback from the experimenter. Test trials immediately followed the practice trials.

A fixation point (+) was presented at the center of the screen and participants were instructed to focus their gaze on that spot at all times. Half of the trials consisted of the prime word appearing on either the right or left side of the screen for 35 ms followed by a 15 ms mask of white noise (total SOA = 50). The other half of the trials consisted of the prime word appearing on either the right or left side of the screen for 385 ms followed by a 15 ms mask of white noise (total SOA = 400). For all trials, the target word was then presented on either the right or left side of the screen for 185 ms. The participant determined whether the target was a word and responded by pressing the appropriate key on the keyboard (using right hand) and response time and accuracy were recorded. Half the trials presented the prime and target to the same visual field and half the trials presented the prime and target to different visual fields. Prior to the priming experiment, participants underwent 4 trials measuring baseline response time in which the fixation point (+) was presented at the center of the screen, followed by a series of X's (XXXXX) appearing at the center of the screen for 35 ms, followed by a 15 ms mask and then a series of #s (#####) appearing at the center of the screen for 185 ms. The participants were instructed to press the response button as quickly as possible once they saw the #s. This was to emulate the 50 ms SOA priming trials without words or lateralization.

For the dichotic listening procedure, participants used stereo headphones with the capabilities of presenting lateralized stimulus and of lateralized volume adjustment. Volume was centralized, with a brief presentation of sound through the individual channels to ensure that the participant can hear both channels adequately. Participants reported the stimuli that they heard to the experimenter, who recorded the responses on a score sheet.

Analysis

After the data were screened for outliers and statistical assumptions for all analyses were checked separately between sexes, descriptive statistics were calculated for all measures (see Table 1). Distributions between men and women were checked for VIQ and PIQ using the Kolmogorov-Smirnov test of equivalence between two independent groups.

A *priming index* was calculated separately for reaction time and accuracy, based upon Brugger et al.'s (1993) formula, which modified the ear advantage formula from dichotic listening experiments in which ear advantage = (total correct right ear - total correct left ear) / (total correct right ear + total correct left ear). Using priming data, an accuracy index was calculated as (total correct in LVF - total correct in RVF) / (total correct in LVF + total correct in RVF).

Because in reaction time data, a smaller reaction time signals greater efficiency, the priming index was calculated as (RT in RVF – RT in LVF) / (RT in RVF + RT in LVF). The laterality index ranges from -1 (maximum left-hemisphere asymmetry) and +1 (maximum right-hemisphere asymmetry). Values of zero reflect equal accuracy and/or reaction time in both visual fields, suggesting no hemispheric asymmetry. Overall reaction time and accuracy indices were calculated, as well as individual indices for each SOA and subsequently converted into z scores. As the accuracy and response time indexes were significantly related, $r = .34$, $p = .003$, they were combined to form a *priming index*. However, as the *priming index* was not significantly related to the *dichotic listening index*, $r = .03$, $p = .771$, these indexes were not combined.

Lexical decision data were first examined across groups and then between groups using descriptive statistics, t tests, and repeated measures analyses of variance (ANOVAs). Then, more specific hypotheses were examined using t tests and regression analyses. Effect sizes were based on the rationale provided by Cohen (1988). We used the convention that small, medium, and large effect sizes of *d* ($d = |\mu_x - \mu_y|/\sigma$) correspond to 0.2, 0.5, and 0.8, respectively, with independent samples t tests. For paired-samples t tests, we used the effect size dz, which is similar to Cohen's *d* except the formula accounts for the intercorrelation between the two variables, $dz = |\mu_z|/\sigma_z = |\mu_x - \mu_y|/\sqrt{(\sigma_x^2 + \sigma_y^2 - 2\rho_{xy} \cdot \sigma_x \cdot \sigma_y)}$ (Faul, Erdfelder, Lang & Buchner, 2007). Small, medium, and large effect sizes of *dz* also correspond to 0.2, 0.5, and 0.8. For ANOVAs, partial eta squared (η_p^2) to estimate strength of association. Whereas eta squared (η^2) depends upon other effects within the design, η_p^2 only contains variance for the effect of interest and error (Tabachnick & Fidell, 2001). The convention that small, medium, and large effect sizes of η_p^2 correspond to 0.01, 0.06 and 0.14 was used (Cohen, 1977).

CHAPTER 3 RESULTS

See Table 2 for bivariate correlations between dependent and independent variables. Bivariate correlations were also conducted for men and women separately (see Table 3 and Table 4).

Lexical Decision: Word Condition Response Time

Prior to analyzing lexical decision data, mean baseline response times and number of errors (i.e. omission of response to #s or commission of response to Xs) were analyzed between sexes with independent t tests. No significant sex differences between mean response time, t (82) = 1.11, p = .269, d = .25, or error rate, t (85) = -.45, p = .656, d = .09, were found.

Complete ANOVA results can be found in Tables 6-15, as only significant findings will be discussed here.

A 2 x 2 x 2 x 2 repeated measures ANOVA was conducted with SOA (50 ms vs. 400 ms), prime location (right hemisphere vs. left hemisphere), target location (right hemisphere vs. left hemisphere), and association (high associates vs. neutral associates). See Table 5 for means and standard deviations and Table 6 for a complete summary of ANOVA results. A significant main effect was found for SOA, F (1, 71) = 119.78, p < .001, ηp^2 = .63, in which the 400 ms SOA resulted in significantly faster response times than the 50 ms SOA. A significant main effect was found for target, F (1, 71) = 4.59, p = .036, ηp^2 = .06, in which left hemisphere targets resulted in significantly faster response times than right hemisphere targets. A significant main effect was found for association, F (1, 71) = 21.81, p < .001, ηp^2 = .24, in which highly associated word pairs resulted in faster response times than neutrally associated word pairs.

In addition to main effects, several significant interactions were found. A significant SOA x prime location interaction was found, F (1, 71) = 8.12, p = .006, ηp^2 = .10, in which prime location did not significantly affect response time in the 50 ms SOA, t (75) = -.82, p = .418, dz = 0.09, whereas left hemisphere primes resulted in faster response times than right hemisphere primes in the 400 ms SOA, t (74) = 4.36, p < .001, dz = 0.51. A significant SOA x association interaction was found, F (1, 71) = 69.48, p < .001, ηp^2 = .50, in which the neutrally associated word pairs resulted in faster response times than highly associated word pairs in the 50 ms SOA, t (75) = 2.57, p = .012, dz = 0.30, whereas the highly associated word pairs resulted in faster response times than neutrally associated word pairs in the 400 ms SOA, t (74) = -12.77, p < .001, dz = 1.51. A significant prime location x target location interaction was found, F (1, 71) = 86.26, p < .001, ηp^2 = .55, in which ipsilateral presentations resulted in faster response times than contralateral presentations, t (71) = 9.29, p < .001, dz = 1.11. A significant target x association interaction was found, F (1, 71) = 4.66, p = .034, ηp^2 = .06, in which left hemisphere targets resulted in faster response times than right hemisphere targets in highly associated word pairs, t (75) = 3.34, p = .001, dz = 0.39, but not in neutrally associated word pairs, t (74) < -.01, p = .999, dz < 0.01. A significant SOA x prime location x association interaction was found, F (1, 71) = 22.21, p < .001, ηp^2 = .24, in which within the 50 ms SOA, right hemisphere primes resulted in faster response times than left hemisphere primes with neutrally related word pairs, t (75) = -2.31, p = .024, dz = 0.27, but no significant difference was found in highly related word pairs, t (78) = .95, p = .347, dz = 0.11. However, within the 400 ms SOA, left hemisphere primes resulted in faster response times than right hemisphere primes with neutrally related word pairs, *t* (77) = 5.00, *p* < .001, *dz* = 0.57, whereas no difference was found with highly related word pairs, *t* (75) = .81, *p* = .421, *dz* = 0.09. A significant SOA x target location x association interaction was found, *F* (1, 71) = 5.65, *p* = .020, ηp^2 = .07, in which within the 50 ms SOA, no significant differences were found between right hemisphere targets and left hemisphere targets in both highly associated and neutrally associated word pairs. However, within the 400 ms SOA, left hemisphere targets resulted in faster response times than right hemisphere targets in highly associated word pairs, *t* (75) = 4.11, *p* < .001, *dz* = 0.47, whereas right hemisphere targets resulted in faster response times than left hemisphere targets in neutrally associated word pairs, *t* (77) = -2.05, *p* = .044, *dz* = 0.23. A significant prime location x target location x association interaction was found, *F* (1, 71) = 6.22, *p* = .015, ηp^2 = .08, in which ipsilateral presentations were only marginally faster with highly associated word pairs than with neutrally related word pairs, *t* (74) = -1.92, *p* = .059, *dz* = 0.22, whereas contralateral presentations were significantly faster with highly associated word pairs than with neutrally related word pairs, *t* (74) = -4.82, *p* < .001, *dz* = 0.56.

To examine these data for sex differences, a similar ANOVA was conducted with the addition of sex as a between-groups variable. Therefore, the 2 x 2 x 2 x 2 x 2 ANOVA was composed of SOA (50 ms vs. 400 ms), prime location (right hemisphere vs. left hemisphere), target location (right hemisphere vs. left hemisphere), association (high associates vs. neutral associates) and sex (men vs. women). See Table 5 for means and standard deviations and Table 7 for a complete summary of ANOVA results. All previous main effects and interactions remained significant. The addition of sex did not produce a significant between groups main effect. However, a significant sex x prime location x target location interaction was found, *F* (1, 70) = 9.47, $p = .003$, $\eta p^2 = .12$, in which ipsilateral response times were faster than contralateral response times in both men, *t* (33) = 8.01, $p < .001$, *dz* = 1.38, and women, *t* (37) = 5.73, $p < .001$, *dz* = 0.90. Although both groups had faster response times to ipsilateral presentations than to contralateral presentations, the effect was smaller in women. To further investigate this effect, ipsilateral response times were subtracted from contralateral response times to create a deviation score. An independent samples t test indicated that the difference between contralateral and ipsilateral response times was significantly greater in men than in women, *t* (70) = 3.08, $p = .003$, *d* = 0.72.

In summary, overall the 400 ms SOA resulted in faster response times than the 50 ms SOA, left hemisphere targets resulted in faster response times than right hemisphere targets, and highly associated word pairs resulted in faster response times than neutrally associated word pairs. Additionally, interactions indicated that within the 50 ms SOA, neutrally-related word pairs resulted in faster response times than highly-related word pairs, whereas within the 400 ms SOA highly-related word pairs resulted in faster response times than neutrally-related response times.

In examining prime location, within the 50 ms SOA, prime location did not have a significant effect on response time. However, within the 400 ms SOA, left hemisphere primes resulted in faster response times than right hemisphere primes. Furthermore, within the 50 ms SOA, prime location did not have a significant effect in highly-associated word pairs, whereas right hemisphere primes resulted in faster response times than left hemisphere primes in neutrally-associated word pairs. However, within the 400 ms SOA, prime location had no effect on response time in highly-associated word pairs, whereas left hemisphere primes resulted in faster response times than right hemisphere primes in neutrally-related word pairs.

In examining target location, in highly-associated word pairs, left hemisphere targets resulted in faster response times than right hemisphere targets, whereas in neutrally-associated word pairs, target location had no significant effect on response time. Furthermore, within the 50 ms SOA, target location did not result in significantly different response times in either highly associated or neutrally-associated word pairs. However, within the 400 ms SOA, left hemisphere targets were faster than right hemisphere targets with highly-associated word pairs, whereas right hemisphere targets were faster than left hemisphere targets with neutrally-associated word pairs.

In examining the interaction between prime location and target location, overall, ipsilateral presentations resulted in faster response times than contralateral response times. In ipsilateral presentations, association had no significant effect on response times, whereas in contralateral presentations, highly associated word pairs resulted in significantly faster response times than neutrally related word pairs.

The addition of sex as a between groups variable did not change the results aside from a significant prime x target x sex interaction in which both sexes responded faster to ipsilateral presentations than contralateral presentations. However, the effect was significantly stronger in men than women.

Lexical Decision: Pseudoword Condition Response Time

A 2 x 2 x 2 repeated-measures ANOVA was conducted on response time from the pseudoword condition with SOA (50 ms vs. 400 ms), prime location (right hemisphere vs. left hemisphere) and target location (right hemisphere vs. left hemisphere) as within-subject factors. See Table 5 for means and standard deviations and Table 8 for a complete summary of ANOVA results. A significant main effect was found for SOA, F (1, 75) = 64.82, p < .001, ηp^2 = .46, in which the 400 ms SOA resulted in significantly faster response times than the 50 ms SOA. A significant main effect was found for target location, F (1, 75) = 5.43, p = .022, ηp^2 = .07, in which left hemisphere targets resulted in significantly faster response times than right hemisphere targets. A significant prime location x target location interaction was found, F (1, 75) = 44.30, p < .001, ηp^2 = .37, in which ipsilateral presentations resulted in faster response times than contralateral response times.

To examine these data for sex differences, a similar ANOVA was conducted with the addition of sex as a between-groups variable. Therefore, the 2 x 2 x 2 x 2 ANOVA was composed of SOA (50 ms vs. 400 ms), prime location (right hemisphere vs. left hemisphere), target location (right hemisphere vs. left hemisphere) and sex (men vs. women). See Table 5 for means and standard deviations and Table 9 for a complete summary of ANOVA results. All previous main effects and interactions remained significant. The addition of sex did not produce a significant between-groups main effect. However, a significant SOA x prime x target x sex interaction emerged, F (1, 74) = 10.86, p = .002, ηp^2 = .13, in which men responded faster to ipsilateral presentations than contralateral presentations in the 50 ms SOA, t (38) = 4.46, p < .001, dz = 0.71, but not the 400 ms SOA, t (37) = 1.64, p = .109, dz = 0.26. In contrast, women responded faster to ipsilateral presentations than contralateral presentations in both the 50 ms SOA, t (38) = 2.87, p = .007, dz = 0.46, and 400 ms SOA, t (37) = 4.40, p < .001, dz = 0.71. To further interpret the interaction, ipsilateral response times were subtracted from contralateral response times for each SOA separately and then analyzed with independent samples t tests between sexes. Within the 50 ms SOA, the difference between ipsilateral and contralateral response times was significantly greater in men than women, *t* (76) = 2.31, *p* = .024, *d* = 0.52. However, within the 400 ms SOA, the difference between ipsilateral and contralateral response times was significantly greater in women than men, *t* (74) = -2.33, *p* = .023, *d* = 0.53.

In summary, within the pseudoword condition, the 400 ms SOA resulted in faster response times than the 50 ms SOA, left hemisphere target presentations resulted in faster response times than right hemisphere target presentations, and ipsilateral presentations resulted in faster response times than contralateral presentations. These patterns were also found within the word condition. Additionally, within the 50 ms SOA, men exhibited a significantly greater advantage to ipsilateral presentations than contralateral presentations in comparison to women, whereas within the 400 ms SOA, women exhibited a significantly greater advantage to ipsilateral presentations than contralateral presentations in comparison to men.

Lexical Decision: Priming

A 2 x 2 x 2 repeated measures ANOVA was conducted with SOA (50 ms vs. 400 ms), prime location (right hemisphere vs. left hemisphere), and target location (right hemisphere vs. left hemisphere). See Table 5 for means and standard deviations and Table 10 for a complete summary of ANOVA results. A significant main effect was found for SOA, *F* (1, 71) = 69.48, *p* < .001, ηp^2 = .50, in which the 400 ms SOA resulted in greater priming than the 50 ms SOA A significant main effect was also found for target location, F (1, 71) = 4.66, p = .034, ηp^2 = .06, in which left hemisphere targets resulted in greater priming than right hemisphere targets.

A significant SOA x prime location interaction was found, F (1, 71) = 22.21, p < .001, ηp^2 = .24, in which in the 50 ms SOA, left hemisphere primes resulted in greater priming than right hemisphere primes, t (75) = -2.47, p = .016, dz = 0.38, whereas in the 400 ms SOA, right hemisphere primes resulted in greater priming than left hemisphere primes, t (74) = 3.58, p = .001, dz = 0.59. A significant SOA x target location interaction was found, F (1, 71) = 5.65, p = .020, ηp^2 = .07, in which in the 50 ms SOA, no significant difference was found between right hemisphere targets and left hemisphere targets, t (75) = 0.03, p = .980, where in the 400 ms SOA, left hemisphere targets resulted in greater priming than right hemisphere targets, t (74) = -4.52, p < .001, dz = 0.74. A significant prime location x target location interaction was found, F (1, 71) = 6.22, p = .015, ηp^2 = .08, in which contralateral presentations resulted in greater priming than ipsilateral presentations, t (71) = -2.49, p = .015, dz = 0.30.

To examine these data for sex differences, a similar ANOVA was conducted with the addition of sex as a between-groups variable. Therefore, the 2 x 2 x 2 x 2 ANOVA was composed of SOA (50 ms vs. 400 ms), prime location (right hemisphere vs. left hemisphere), target location (right hemisphere vs. left hemisphere) and sex (men vs. women). See Table 5 for means and standard deviations and Table 11 for a complete summary of ANOVA results. All previous main effects and interactions remained significant. The addition of sex did not produce a significant between-groups main effect. However, a significant prime x target x sex interaction emerged, F (1, 70) = 5.96, p = .017, ηp^2 = .08, in which men exhibited significantly more priming to contralateral presentations than ipsilateral presentations, t (33) = -3.05, p = .004, dz = 0.52, whereas women did not show a difference between the two presentations, t (37) = -0.24, p = .814, dz = 0.04.

In summary, the 400 ms SOA resulted in greater priming than the 50 ms SOA. Within the 50 ms SOA, left hemisphere primes resulted in greater priming than right hemisphere primes, whereas within the 400 ms SOA, right hemisphere primes resulted in greater priming than left hemisphere primes. Additionally, within the 50 ms SOA, no difference was found between right and left hemisphere targets, whereas within the 400 ms SOA, left hemisphere targets resulted in greater priming than right hemisphere targets. Overall, contralateral presentations resulted in greater priming than ipsilateral presentations; however, when examined by sex, contralateral presentations resulted in greater priming than ipsilateral presentations among men, whereas women showed no difference between the two presentations.

Lexical Decision: Word Condition Accuracy

A 2 x 2 x 2 x 2 repeated measures ANOVA was conducted on accuracy data within the word condition with SOA (50 ms vs. 400 ms), prime location (right hemisphere vs. left hemisphere), target location (right hemisphere vs. left hemisphere), and association (high associates vs. neutral associates). See Table 5 for means and standard deviations and Table 12 for a complete summary of ANOVA results. A significant main effect was found for SOA, F (1, 74) = 204.68, p < .001, ηp^2 = .73, in which the 400 ms SOA resulted in significantly greater accuracy than the 50 ms SOA. A significant main effect was found for target, F (1, 74) = 9.25, p = .003, ηp^2 = .11, in which left hemisphere targets resulted in significantly greater accuracy than right hemisphere targets. A significant main effect was found for association, F (1, 74) = 6.31, p = .014, ηp^2 = .08, in which neutrally associated word pairs resulted in greater accuracy than highly associated word pairs.

In addition to main effects, several significant interactions were found. A significant SOA x prime location interaction was found, F (1, 74) = 8.35, p = .005, ηp^2 = .10, in which prime location did not significantly affect accuracy in the 50 ms SOA, t (77) = 1.21, p = .230, dz = 0.14, whereas left hemisphere prime location resulted in greater accuracy than right prime locations in the 400 ms SOA, t (75) = -4.12, p < .001, dz = 0.47. A significant SOA x target location interaction was found, F (1, 74) = 8.55, p = .005, ηp^2 = .10, in which in the 50 ms SOA, left hemisphere target location resulted in greater accuracy than right hemisphere target location, t (77) = -3.20, p = .002, dz = 0.36, whereas in the 400 ms SOA, no difference was found between the two target locations, t (75) = -0.27, p = .790, dz = 0.03. A significant SOA x association interaction was found, F (1, 74) = 99.89, p < .001, ηp^2 = .57, in which the neutral associates resulted in greater accuracy than high associates in the 50 ms SOA, t (77) = -6.99, p < .001, dz = 0.72, whereas the high associates resulted in greater accuracy than neutral associates in the 400 ms SOA, t (75) = 7.28, p < .001, dz = 0.67. A significant prime location x target location interaction was found, F (1, 74) = 68.41, p < .001, ηp^2 = .48, in which ipsilateral presentations resulted in greater accuracy than contralateral presentations, t (74) = 8.27, p < .001, dz = 0.95. A significant SOA x prime location x association interaction was found, F (1, 74) = 20.51, p < .001, ηp^2 = .22, in which within the 50 ms SOA, right hemisphere primes resulted in greater accuracy than left hemisphere primes with neutrally related word pairs, t (77) = 3.77, p < .001, dz = 0.36, but no significant difference were found in highly related word pairs, *t* (78) = -1.21, *p* = .231, *dz* = 0.19. However, within the 400 ms SOA, left hemisphere primes resulted in greater accuracy than right hemisphere primes with neutrally related word pairs, *t* (76) = -3.76, *p* < .001, *dz* = 0.37, whereas no difference was found with highly related word pairs, *t* (76) = -1.61, *p* = .112, *dz* = 0.09. A significant SOA x target location x association interaction was found, *F* (1, 74) = 4.50, *p* = .037, ηp^2 = .06, in which within the 50 ms SOA, left hemisphere targets resulted in greater accuracy than right hemisphere targets with neutrally associated word pairs, *t* (77) = -3.31, *p* = .001, *dz* = 0.37, whereas no significant difference was found between left and right hemisphere targets in highly associated word pairs, *t* (78) = -1.86, *p* = .067, *dz* = 0.21. Within the 400 ms SOA, left hemisphere targets resulted in greater accuracy than right hemisphere targets in highly associated word pairs, *t* (76) = -2.34, *p* = .022, *dz* = 0.27, whereas no difference in accuracy was found between left and right hemisphere targets with neutrally associated word pairs, *t* (76) = 1.11, *p* = .269, *dz* = 0.13. A significant prime location x target location x association interaction was found, *F* (1, 74) = 14.91, *p* < .001, ηp^2 = .17, in which within ipsilateral presentations, neutrally associated word pairs resulted in greater accuracy than highly related word pairs, *t* (77) = -4.48, *p* < .001, *dz* = 0.50, whereas within contralateral presentations, no significant difference was found in accuracy between highly associated word pairs and neutrally associated word pairs, *t* (75) = 0.04, *p* = .970, *dz* < .01.

To examine these data for sex differences, a similar ANOVA was conducted with the addition of sex as a between-groups variable. Therefore, the 2 x 2 x 2 x 2 x 2 ANOVA was composed of SOA (50 ms vs. 400 ms), prime location (right hemisphere vs. left hemisphere), target location (right hemisphere vs. left hemisphere), association (high vs. neutral) and sex (men vs. women). See Table 5 for means and standard deviations and Table 13 for a complete summary of ANOVA results. All previous main effects and interactions remained significant. The addition of sex did not produce a significant between-groups main effect, nor did it produce any additional interactions.

In summary, in regard to accuracy within the word condition, greater accuracy is produced by the 400 ms SOA over the 50 ms SOA, left target location over right target location, and neutrally related pairs over highly related word pairs. Within the 50 ms SOA, left hemisphere targets resulted in greater accuracy than right hemisphere targets, whereas prime location does not significantly affect accuracy. More specifically, with neutrally related word pairs, right hemisphere prime locations resulted in greater accuracy than left hemisphere prime locations, and left hemisphere target locations resulted in greater accuracy than right hemisphere target locations, whereas with highly related word pairs, location of prime and target did not significantly affect accuracy. Additionally, within the 50 ms SOA, neutrally associated word pairs resulted in greater accuracy than highly related word pairs. Within the 400 ms SOA, left hemisphere primes resulted in greater accuracy than right hemisphere primes, whereas target location does not significantly affect accuracy. More specifically, with neutrally related word pairs, left hemisphere prime locations resulted in greater accuracy than right hemisphere prime locations, whereas target location does not significantly affect accuracy. With highly related word pairs, left hemisphere target location resulted in greater accuracy than right hemisphere target location, whereas prime location did not significantly affect accuracy. Additionally, within the 400 ms SOA, highly related word pairs resulted in greater accuracy than neutrally related word pairs. Also, ipsilateral presentations resulted in greater accuracy than contralateral presentations. More specifically, within ipsilateral presentations, neutrally related word pairs resulted in greater accuracy than highly related word pairs, whereas within contralateral presentations, association did not significantly affect accuracy.

Lexical Decision: Pseudoword Condition Accuracy

A 2 x 2 x 2 repeated measures ANOVA was conducted on accuracy data within the pseudoword condition with SOA (50 ms vs. 400 ms), prime location (right hemisphere vs. left hemisphere), and target location (right hemisphere vs. left hemisphere). See Table 5 for means and standard deviations and Table 14 for a complete summary of ANOVA results. A significant main effect was found for SOA, F (1, 78) = 172.86, $p < .001$, $\eta p^2 = .69$, in which the 400 ms SOA resulted in significantly greater accuracy than the 50 ms SOA. A significant main effect was found for prime location, F (1, 78) = 19.46, $p < .001$, $\eta p^2 = .20$, in which right hemisphere primes resulted in greater accuracy than left hemisphere primes. A significant main effect was found for target, F (1, 78) = 12.23, $p = .001$, $\eta p^2 = .14$, in which left hemisphere targets resulted in significantly greater accuracy than right hemisphere targets.

In addition to main effects, several significant interactions were found. A significant SOA x target location interaction was found, F (1, 78) = 7.70, $p = .007$, $\eta p^2 = .09$, in which in the 50 ms SOA, left hemisphere target location resulted in greater accuracy than right hemisphere target location, t (78) = 3.68, $p < .001$, $dz = 0.42$, whereas in the 400 ms SOA, no difference was found between the two target locations, t (78) = 0.85, $p = .398$, $dz = 0.10$. A significant prime location x target location interaction was found, *F* (1, 78) = 38.17, $p < .001$, $\eta p^2 = .33$, in which ipsilateral presentations resulted in greater accuracy than contralateral presentations, *t* (78) = 6.18, $p < .001$, *dz* = 0.70. A significant SOA x prime location x target location interaction was found, *F* (1, 78) = 23.61, $p < .001$, $\eta p^2 = .23$, in which within the 50 ms SOA, ipsilateral presentations resulted in greater accuracy than contralateral presentations, *t* (78) = 7.23, $p < .001$, *dz* = 0.90, whereas within the 400 ms SOA, presentation did not significantly affect accuracy, *t* (78) = 0.69, *p* = .493, *dz* = 0.08.

To examine these data for sex differences, a similar ANOVA was conducted with the addition of sex as a between groups variable. Therefore, the 2 x 2 x 2 x 2 ANOVA was composed of SOA (50 ms vs. 400 ms), prime location (right hemisphere vs. left hemisphere), target location (right hemisphere vs. left hemisphere), and sex (men vs. women). See Table 5 for means and standard deviations and Table 15 for a complete summary of ANOVA results. All previous main effects and interactions remained significant. The addition of sex did not result in a significant main effect, nor did it result in additional interactions.

In summary, in regard to accuracy in the pseudoword condition, the 400 ms SOA resulted in greater accuracy than the 50 ms SOA, right hemisphere primes resulted in greater accuracy than left hemisphere primes, and left hemisphere targets resulted in greater accuracy than right hemisphere targets. More specifically, within the 50 ms SOA, left hemisphere targets resulted in greater accuracy than right hemisphere targets, whereas within the 400 ms SOA, target location did not significantly affect accuracy. Additionally, ipsilateral presentations resulted in greater accuracy than contralateral presentations. More specifically, within the 50 ms SOA, ipsilateral presentations resulted in greater accuracy than contralateral presentations, whereas within the 400 ms SOA, presentation did not significantly affect accuracy.

Dichotic Listening

Independent and paired-samples t tests were used to analyze dichotic listening data. Right ear (left hemisphere) presentations resulted in faster response times than left ear (right hemisphere) presentations, t (88) = 5.23, p < .001, dz = 0.56. When analyzed separately, this finding was significant in both men, t (44) = 4.30, p < .001, dz = 0.64, and women, t (43) = 3.26, p = .002, dz = 0.49. No significant difference in right ear advantage was found when comparing men and women, t (87) = 0.30, p = .770, d = 0.05.

Laterality Indices with Verbal and Visual-spatial Abilities

As previously mentioned, dependent variables REA and Priming Index were analyzed separately as they were not significantly related. The regression analysis in which REA served as the dependent variable and the centered VIQ, PIQ, and their interaction term were entered as independent variables yielded no significant effects. The regression analysis in which the Priming Index served as the dependent variable and the centered VIQ, PIQ, and interaction term were entered as independent variables also yielded no significant effects. These same analyses were conducted separately for each sex. None of the analyses produced significant effects for either sex.

Additional regressions were conducted on mean overall response times for both the word and pseudoword conditions, mean overall accuracy for both the word and pseudoword conditions, and overall mean priming. VIQ and PIQ were entered in the first step and their interaction term was added in the second step as independent variables for each regression. The independent variables did not account for significant variance in both word and pseudoword condition response time, nor did it account for significant variance in priming and pseudoword accuracy. However, the predictors did account for significant variance in accuracy within the word condition (R^2 = .09). The only significant predictor was PIQ (*β* = .30).

To further examine these findings, similar regressions were conducted separately for each sex. Independent variables did not account for significant variables in mean overall accuracy within both word and pseudoword conditions, nor in overall mean priming. However, significant variance was predicted in both word (R^2 = .32) and pseudoword accuracy (R^2 = .20) in men, although not in women. In men, PIQ was the strongest and only significant predictor of accuracy in both word (*β* = .58) and pseudoword (*β* = .34) conditions. See Table 16 for a summary of these regressions.

Laterality Indices with Personality Measures

Next, the relationship between laterality variables and personality variables were explored (see Table 2). Bivariate correlations of REA and Prime Index with BFI scales openness, conscientiousness, extraversion, agreeableness, neuroticism and BSRI scales masculinity and femininity yielded only one significant correlation between Prime Index and agreeableness, r = .26, p = .025. All other correlations were not significant. Bivariate correlations of mean response time for both word and pseudoword conditions, mean accuracy for both word and pseudoword conditions, and mean priming with BFI and BSRI scales yielded no significant results (see Table 2). When analyzed for each sex separately, no significant correlations were found between REA and Prime Index and personality scales. However, in men, a significant positive relationship was found between pseudoword accuracy and femininity, r = .33, p = .032, as well as a significant negative relationship between pseudoword response time and conscientiousness, r = -.36, p = .026. See Table 3 for a complete correlation table for men. Additionally, in women, masculinity was positively related to total response time, r = .33, p = .049, total priming, r = .43, p = .008, total accuracy, r = .40, p = .012, and total pseudoword response time, r = .33, p = .042. Additionally, in women, extraversion was positively related to total response time, r = .35, p = .031, total priming, r = .32, p = .050, and total pseudoword response time, r = .37, p = .022. In women, neuroticism was negatively related to total response time, r = -.36, p = .027. See Table 4 for a complete correlation table for women.

Laterality Indices and Digit Ratio

Bivariate correlations of REA and Priming Index with digit ratio were found to be non-significant. Bivariate correlations of word and pseudoword response time, word and pseudoword accuracy and priming with digit ratio were also found to be non-significant. Bivariate correlations were conducted between digit ratio and other independent variables, specifically visual-spatial ability, verbal ability, masculinity, femininity, and five-factor personality traits, to explore if it was related to the expected variables. Digit ratio was positively related to VIQ (r = .33, p = .003), PIQ (r = .23, p = .040), and negatively related to masculinity (r = -.27, p = .012). See Table 5.

Laterality Indices and Measures of Multiple Domains

Finally, regressions were conducted to investigate the relative contributions of sex, PIQ, VIQ, neuroticism, masculinity, and digit ratio in accounting for variance in REA and in the Priming Index. See Table 5 for bivariate correlations. These predictors did not account for a significant amount of variance in REA nor in the Priming Index. Additional regressions were conducted with the same independent variables with mean word and pseudoword response time, word and pseudoword accuracy, and priming. The only regression that emerged as significant was with word accuracy, R^2 = .24, F (6, 76) = 4.05, p = .001, with PIQ (β = .41), sex (β = .39), and masculinity (β = .26) serving as significant predictors.

Similar regressions were conducted separately for men and women. PIQ, VIQ, neuroticism, masculinity, and digit ratio did not predict significant variance in REA, Priming Index, mean word response time, mean pseudoword response time, or mean priming for both men and women. However, in men, significant variance was explained in word condition accuracy, R^2 = .35, F (5, 39) = 4.10, p = .004, with PIQ (β = .65) as the only significant predictor. Additionally, in men, significant variance was explained in pseudoword condition accuracy, R^2 = .25, F (5, 39) = 2.65, p = .037, with PIQ (β = .33) as the only significant predictor and digit ratio (β = .29) and neuroticism (β = .26) approaching significance. In women, significant variance was not explained in any of the dependent variables.

CHAPTER 4 DISCUSSION

The current study was the first to utilize two different laterality measures, lateralized semantic priming and dichotic listening, to examine inter- and extra-hemispheric processing. By examining variations within lateralized semantic priming and comparing it to dichotic listening, the current study provided a broader understanding about the importance of time course in interhemispheric communication in language processing.

First, a relatively strong relationship was found between dichotic listening and lateralized semantic priming at the short SOA, although the two measures of laterality were not strongly related overall. One may speculate that dichotic listening measures pre-lexical lateralization, more a process of stimulus discrimination than semantic analysis, whereas lateralized semantic priming measures lateralization in semantic processing. This explanation may account for the relationship between response time to semantically related word pairs separated by a brief delay and the dichotic listening task. Specifically, response time to semantically related word pairs presented with a separation of 50 ms was related to right ear bias with simple binaural phonemic presentations, which entail simultaneous presentations with no delay. Considering that the dichotic listening stimuli is composed of phonemes containing no clear semantic information, this relationship suggests that the short delay in presenting semantically related word pairs results in pre-lexical processing, involving more pre-lexical, or perceptual, processing than semantic processing, similar to the processes required for a dichotic listening task. If so, one could conclude that particular time restrictions in language processing may result in a perceptual process rather than a semantic process, even when semantic information is present.

This explanation is further supported by the interaction between interstimulus delay and association. The current study found that within the 50 ms SOA, neutrally associated word pairs result in faster response times and greater accuracy than the 400 ms SOA, whereas in the 400 ms SOA, highly associated word pairs result in faster response times and greater accuracy than the 50 ms SOA. This suggests that semantic activation is only advantageous after a sufficient amount of time or interhemispheric communication. It is possible that within the short delay, the spread of activation is not sufficient to be advantageous and even distracting in making decisions. Therefore, priming unrelated concepts, which do not sequester cognitive resources as related stimuli, might result in optimal performance. Conversely, within the long delay, the spread of activation is allowed sufficient time to be beneficial in making decisions and therefore highly associated concepts are advantageous. It is also possible that in short interstimulus delays, semantic connections are being initially established thus requiring more resources for highly related concepts than neutrally related concepts.

It may be that the human information processing system is always biased towards one sensory field or the other, and this may be greater under certain circumstances. For example, Richards and French (1992) investigated semantic activation through responsiveness to threat-related in comparison to neutral concepts in individuals who were classified as having high trait anxiety characteristics compared to those who were classified as having low trait anxiety characteristics. During short interstimulus delays, no differences were found between individuals with high and low trait anxiety. However, during long interstimulus delays, only individuals with high trait anxiety characteristics showed more responsiveness to threat-related concepts. The authors argued that individuals with high trait anxiety characteristics “lock on” (p. 503) to threatening interpretations. Considering these findings in addition to those of the current study, it is possible that semantic biases may occur after sufficient time is given for interhemispheric communication, whereas insufficient time may prevent or inhibit these biases. These findings may be useful in assessing treatment responsiveness. For example, Murphy, Yiend, Lester, Cowen & Harmer (2009) investigated the differential responsiveness to different emotionally valenced facial expressions in individuals who were treated with different anti-anxiety medications and placebo. However, they only utilized one long time delay and did not measure responsiveness at a short delay. Gathering information at both short and long delays may provide greater comparisons both within and between treatment groups. Additionally, greater information about time course influencing responsiveness to information may lead to a time point of optimal measurement.

Upon further examination of the patterns of language processing in semantically related word pairs, a number of findings from Van Dyke et al. (2009) were replicated. The strong finding that ipsilateral presentations result in faster response times than contralateral presentations was replicated. As the current experiment utilized different stimuli than Van Dyke et al. (2009), it is unlikely that these findings are spurious. It is possible that ipsilateral presentations result in faster responses because no interhemispheric transfer is required. Interhemispheric transfer may result in a greater time delay, as the priming information must travel a greater distance. As ipsilateral presentations resulted in faster response times than contralateral presentations even when responding to pseudowords, it is possible that this pattern is independent of processing meaning. Overall, this suggests that interhemispheric transfer time does affect the speed of response. This may have subtle implications for information that is presented peripherally instead of centrally in natural settings.

Although ipsilateral conditions result in faster reaction times, contralateral conditions resulted in greater priming, which was observed in previous lateralized semantic priming studies (Van Dyke, et al., 2009; Hutchinson et al., 2003). One potential explanation for this phenomenon is that the time required for interhemispheric transfer allows for greater network spreading activation, resulting in greater priming. This hypothesis is supported by the findings in the current study and previous studies that longer SOAs result in greater priming (Van Dyke, et al., 2009; Burgess & Simpson, 1988). Although no conclusive data are available demonstrating the actual speed of interhemispheric transfer across the corpus callosum in humans, estimates are available. Using evoked potentials, it has been estimated that ipsilateral reaction time falls within the 2-3 ms range whereas contralateral reaction time falls within the 8-25 ms range (Hoptman & Davidson, 1994). Additionally, interhemispheric transfer time in infrahumans using single-cell evoked responses in rabbits has been found to occur in less than 10 ms (Bianki, 1993). Although these transfer times appear minute, within a typical semantic priming paradigm, the information may transfer between hemispheres several times even during a short 50 ms interstimulus delay. In the current study, the slower response time to contralateral presentations in comparison to ipsilateral presentations, albeit small, would allow the information to transfer several times between hemispheres, thus allowing greater activation of the semantic network and consequently greater priming.

In addition, it is possible that contralateral stimuli activate both hemispheres, allowing each to contribute to priming. Several studies demonstrate that the two cerebral hemispheres function as a dynamic and interacting system with right and left hemispheres contributing different nuances to information (Chiarello, Senehi & Nuding, 1987; Chiarello, Burgess, Richards & Pollock, 1990; Anaki, Faust, Kravetz, 1998). Specifically, previous studies suggest that the left-hemisphere specializes in fine coding, or narrow activation of semantic network, whereas the right-hemisphere specializes in course coding, or broad semantic activation. For example, in a sample of participants with schizotypal personality disorder and schizophrenia utilizing a battery of creativity measures, evidence was found that the two hemispheres interact over time in a dynamic manner to provide a constant interplay between narrow and broad (or fine and coarse) perceptions, meanings and concepts (Poreh, Whitman & Ross, 1994). In this manner, for example, the left hemisphere defines words crisply while the right hemisphere maintains the background arousal necessary for changes in a semantic network (e.g. changes in meaning). Under normal conditions, this inter-hemispheric interplay permits a continuous reconsideration of meaning and allows for creative consideration of alternative meanings. In the current study, it is possible that cross-hemisphere priming increases the collaboration of the two hemispheres resulting in both a slower reaction time and increased priming.

In addition to replicating the differences produced by intra-hemispheric and inter-hemispheric stimulation Van Dyke, et al. 2009, the current study also found that, overall, the longer delay in presenting information resulted in faster responses and greater accuracy. It is possible that longer delay between word presentations allows greater spread of activation in the semantic network. Furthermore, highly related word pairs resulted in faster responses, greater priming, and greater accuracy, which are consistent with Van Dyke, et al. 2009 and Hutchinson, et al. 2003. This further supports the prior findings that greater transfer time and association promotes greater efficiency and accuracy in information processing.

A second focus of this project was to explore individual differences as they relate to hemispheric lateralization, giving special attention to sex differences. Regarding sex differences and laterality, it was hypothesized that men would respond to information in a more asymmetrically lateralized fashion, whereas women would respond to information in a bilateral fashion on all laterality measures. However, the expected sex differences were not found. Specifically, men were expected to process phonemic information dominantly in the left hemisphere and to a greater extent than women. However, both men and women demonstrated left hemisphere dominance to a similar extent, thus failing to support the expected sex difference. Additionally, it was predicted that men would show similar priming to both contralateral and ipsilateral presentations whereas women would prime more to contralateral presentations than to ipsilateral presentations as in Van Dyke et al. (2009). It was also predicted that within ipsilateral presentations, men would respond faster to left hemisphere presentations than right hemisphere presentations whereas women would not show this pattern as in Van Dyke et al. (2009). However, neither of these predictions was supported. Specifically, both men and women primed more with contralateral presentations than ipsilateral presentations with this difference being considerably more pronounced in men than women. Also, both men and women responded faster to information presented ipsilaterally to the left hemisphere in contrast to the right hemisphere. The inconsistent findings between the current study and Van Dyke et al. (2009) have a number of possible implications. For example, the inconsistency may be related to sampling differences between the two studies. Specifically, the current study took greater precautions in gathering information from a sample with a wide range of abilities in both men and women, whereas Van Dyke et al. (2009) did not. However, if this were the case, one would have expected to see a larger relationship between ability and degree of lateralization. The discrepancy between the two studies could also be a function of procedural differences. The current study employed a much briefer lexical decision procedure (20 minutes) in comparison to the former study (55 minutes). It is possible that fatigue or practice effects factored into the findings in Van Dyke et al. (2009). However, if the inconsistent findings are solely explained by procedural differences, one would expect that the current study would not replicate other findings from the former study. Instead, it is likely that the inconsistencies are due to a factor for which the two studies did not account. For instance, Hutchinson (2007) found that attentional control and expectancy generation affect semantic priming. As the current study and Van Dyke et al. (2009) did not measure these constructs, it is unknown whether they would have explained the inconsistencies between the two studies.

Additionally, the current study did not support the hypothesis that visual-spatial ability would be positively related to degree of lateralization. Furthermore, the Van Dyke et al. (2009) finding that visual-spatial skills are related to degree of lateralization in women and verbal skills are related to degree of lateralization in men was not replicated. The current study attempted to ensure that the information gathered represented men and women with a wide range of both visual-spatial and verbal abilities, whereas Van Dyke et al. (2009) did not. Therefore, range restriction or sampling bias does not adequately explain the absence of relationship between ability and lateralization. As with the inconsistent findings within laterality measures, it is possible that the current study did produce the expected results due to an unmeasured construct, such as attention or working memory (Hutchinson, 2007).

The exploration of the relative contributions of biological sex, verbal ability, visual-spatial ability in addition to neuroticism, masculinity, and digit ratio on lateralization yielded that none of these factors adequately account for varying degrees of lateralization. Unfortunately, as with the body of literature investigating the relationship between the aforementioned individual differences and lateralization, the current study produced inconsistent evidence. Because the current study utilized the same or similar measures as those used in supportive studies, it is not believed that the inconsistent findings are a product of measurement error. As the current study measured a limited set of individual differences from potentially endless possibilities, it is possible that variations in lateralization are explained by factors not included in this study, such as attention, working memory or executive functioning. Alternatively, the relationship between individual differences and laterality may be spurious and exaggerated, particularly considering that usually only positive findings are available in the literature whereas negative findings are often omitted.

The exploratory analyses of the five-factor personality traits and laterality yielded no significant relationships with laterality variables overall. Although women did demonstrate greater neuroticism than men as expected, neuroticism was not found to be negatively related to degree of lateralization, thus failing to support the current study's hypothesis. Neuroticism was only negatively related to response time in women. This may suggest that neuroticism is related to overall responsiveness or vigilance (Richards & French, 1992). Overall, masculinity was not related to degree of laterality, which may be explained by range restriction, especially considering that insufficient women with relatively high levels of masculinity and men with relatively high levels of femininity were included.

The hypothesis that the 2D:4D digit ratio would be positively related to degree of laterality was not supported; though exploratory analyses yielded that the 2D:4D digit ratio is positively related to verbal and visual-spatial ability and negatively related to masculinity. Given that previous research suggests that low 2D:4D digit ratios are related to high prenatal testosterone levels in comparison to prenatal estrogen levels, whereas high 2D:4D digit ratios are related to high prenatal estrogen levels in comparison to prenatal testosterone levels (Manning, Scutt, Wilson & Lewis-Jones, 1998; Lutchmaya, Baron-Cohen, Raggat, Knickmeyer and Manning, 2004), the negative relationship between masculinity and digit ratio was expected. Additionally, the positive relationship between verbal ability and digit ratio is expected as less the brain received less testosterone (Jackson, 2008; Witelson & Nowakowski, 1991). However, the positive relationship between digit ratio and visual-spatial ability is in the opposite direction expected. It is possible that the measurements obtained in the current study were not adequately precise, thus failing to reproduce the findings in the literature. Alternatively, as an exploratory measure, it is possible that the 2D:4D digit ratio is not a reliable estimate of prenatal hormone exposure.

In short, findings of this study provide a number of implications about studies of laterality and individual differences. Primarily, the findings suggest that the type of stimuli and time course of their presentation likely determine more about language processing than do measures of individual differences. More specifically, it appears that variations in time largely affect the fashion in which information is processed.

The current study carried several strengths, such as utilizing numerous measures from various domains related to laterality in a repeated measures experiment. However, it would benefit from improvements, considering some outcomes were not as expected. For example, previous studies have shown relationships between REA and sex (Cowell & Hugdahl, 2000; Hiscock, Inch, Jacek, Hiscock-Kalil& Kalil, 1994); however, this was not found in the current study. Assessing the dichotic listening stimuli with a similar measure would establish that the findings were reliable and not an artifact of the stimuli. Additionally, the study would have benefited from measuring working memory and processing speed, as these may have moderated or mediated response time and accuracy variables as suggested by Hutchinson (2007). Instead of administering the Wechsler Abbreviated Scale of Intelligence (WASI), administering the Wechsler Adult Intelligence Scale, 4th edition (WAIS-4; The Psychological Corporation, 2008) would have gathered information about verbal and visual-spatial ability as well as working memory and processing speed.

The current study would have also benefited from including additional SOAs, such as 25 ms and 100 ms, Abeare, Raiter, Hutchinson, Moss and Whitman (2003) investigated the interaction between hemispheres examining the response over time using six different SOAs (i.e. 35, 50, 200, 400, and 700 ms). A reciprocally cycling pattern was found during short SOAs (i.e. 35, 50, and 200 ms) and convergence of priming during long SOAs (400 and 750 ms), suggesting that one hemisphere was actively inhibited during periods of arousal in the other. By utilizing several SOAs, Abeare et al. (2003) were able to demonstrate a dynamic interaction over time. With additional SOAs, the current study may have provided further information about the time course of pre-lexical and semantic processing and if the transition between the two is discrete or continuous.

There are no studies in the semantic priming literature examining individual differences in semantic priming across SOAs. This would require a very large number of subjects and a large number of SOAs. The total number of words differing in relatedness is finite word pairs would need to be repeated, further complicating this type of study. A single experiment (Raiter, 2006) studied six subjects for a year presenting them with hundreds of word pairs over six SOAs. The only conclusion from this study was that individual differences in lexical processing speed exist; people show maximal priming at different SOAs. Nevertheless, if individual differences are predictive of lateralization at certain points in semantic processing but not others, future experiments would be more cognizant in including multiple time points. Furthermore, if some individuals are found to process semantic information earlier than others, it may be useful in determining if this relates to personality or psychopathology.

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Table 1

Descriptive statistics between sexes

	Men		Women		Difference		K-S test
	M	*SD*	*M*	*SD*	*t*	*d*	*z*
Demographics							
Age	21.71	4.87	20.91	4.02	0.85	0.18	0.51
EHI	24.93	6.06	24.84	5.44	0.08	0.02	0.52
WASI							
Vocab	52.89	6.58	52.84	8.03	0.03	0.01	0.6
Sim	52.40	6.96	52.37	6.45	0.02	< 0.01	0.66
Blocks	53.47	9.42	50.00	10.64	1.62	0.35	1.06
Matrix	52.84	7.06	52.33	7.09	0.34	0.07	0.29
VIQ	103.98	9.10	104.16	10.03	-0.09	0.02	0.55
PIQ	105.00	12.37	101.84	11.81	1.23	0.26	0.98
FSIQ	105.33	10.06	103.33	10.28	0.93	0.20	0.66
WTAR SS	105.16	11.50	103.36	12.75	0.70	0.15	0.55
Big Five							
O	37.71	5.86	34.86	6.18	2.23*	0.48	1.22
C	36.40	6.74	36.11	5.14	0.22	0.05	0.52
E	34.92	8.46	33.44	8.71	0.81	0.17	0.58
A	37.38	6.59	38.41	6.98	-0.71	0.15	0.88
N	25.61	8.08	30.17	9.31	-2.85*	0.53	1.43*
BEM							
F	52.36	7.28	56.52	7.63	-2.16*	0.56	1.21
M	51.82	8.31	46.95	10.01	2.50*	0.54	1.53*
2:4 Digit Ratio							
Right	0.97	0.04	0.98	0.04	-1.55	0.34	1.20
Left	0.97	0.03	0.99	0.03	-2.74*	0.60	1.32
REA	0.11	0.17	0.10	0.20	0.30	0.05	0.76
Lexical Decision							
Word RT	559.20	95.38	549.88	112.58	0.38	.09	0.79
Pseudoword RT	709.72	130.11	686.22	116.28	0.83	.19	0.69
Word AC	0.88	0.05	0.90	0.04	-1.89	.44	1.11
Pseudoword AC	0.82	0.10	0.80	0.10	0.98	.20	0.95
Priming	26.83	48.95	25.16	46.11	0.15	.04	0.72

Note: $*p < .05$, $**p < .001$

Table 2

Bivariate correlations between independent and dependent variables

	REA	Prime Index	Word RT	Pseudo RT	Word Ac	Pseudo Ac	Prime
Sex	-.03	-.02	-.05	-.10	.26*	.01	-.02
EHI	-.03	.02	-.02	.08	-.10	-.01	-.04
WTAR	.07	-.18	-.04	-.01	.08	.06	-.18
VIQ	.06	-.11	-.18	-.13	-.14	.01	-.27*
PIQ	-.10	-.07	.13	.16	.08	.10	-.20
FSIQ	-.06	-.11	.01	.03	-.06	.05	-.29*
Digit Ratio	.14	-.16	-.05	.01	.05	.06	-.20
BFI O	.13	-.08	.11	.19	.13	-.17	.16
BFI C	-.10	.14	.08	-.21	.03	.06	-.19
BFI E	.14	-.06	.24*	.21	.01	-.03	.18
BFI A	.03	.26*	.09	.03	.11	.08	.17
BFI N	-.04	-.02	-.18	-.01	.05	.03	-.01
BSRI M	.14	-.01	.22	.14	.05	-.03	.21
BSRI F	.03	.05	.08	-.08	.09	.17	-.03

Note: *$p < .05$; REA = Right ear advantage, Index = Prime Index, RT = Response time, Ac = Accuracy, EHI = Edinburgh handedness index, WTAR = Wechsler Test of Adult Reading, VIQ = Verbal IQ, PIQ = Performance IQ, FSIQ = Full Scale IQ, BFI O = BFI Openness, BFI C = BFI Conscientiousness, BFI E = BFI Extraversion, BFI A = BFI Agreeableness, BFI N = BFI Neuroticism, BSRI M = BSRI Masculinity, BSRI F = BSRI Femininity

Table 3

Bivariate correlations between independent and dependent variables in men

	REA	Index	Word RT	Pseudo RT	Word Ac	Pseudo Ac	Prime
EHI	.09	-.08	-.25	-.04	-.25	< .01	-.13
WTAR	.24	-.14	.20	.14	.03	.17	-.02
VIQ	.04	.01	-.13	-.12	-.18	.01	-.14
PIQ	-.08	-.01	.23	.26	.28	.28	-.15
FSIQ	-.05	-.03	.14	.11	.05	.16	-.19
Digit Ratio	.09	-.10	.04	.08	.10	.26	-.28
BFI O	.21	-.02	.17	.16	.09	-.12	.25
BFI C	-.16	.20	-.16	-.36*	.20	.03	-.10
BFI E	.15	-.13	.06	.05	.01	-.02	< .01
BFI A	-.08	.23	-.07	.01	.22	.16	.15
BFI N	-.05	-.02	.12	.07	-.09	.16	< .01
BSRI M	.06	-.15	.04	-.09	-.07	-.10	-.04
BSRI F	-.05	.06	-.06	-.23	-.06	.33*	< .01

Note: **p*< .05; REA = Right ear advantage, Index = Prime Index, RT = Response time, Ac = Accuracy, EHI = Edinburgh handedness index, WTAR = Wechsler Test of Adult Reading, VIQ = Verbal IQ, PIQ = Performance IQ, FSIQ = Full Scale IQ, BFI O = BFI Openness, BFI C = BFI Conscientiousness, BFI E = BFI Extraversion, BFI A = BFI Agreeableness, BFI N = BFI Neuroticism, BSRI M = BSRI Masculinity, BSRI F = BSRI Femininity

Table 4

Bivariate correlations between independent and dependent variables in women

	REA	Index	Word RT	Pseudo RT	Word Ac	Pseudo Ac	Prime
EHI	-.15	.12	.16	.22	.09	-.02	.06
WTAR	-.07	-.21	-.20	-.17	.20	-.06	-.31
VIQ	.07	-.20	-.22	-.15	-.13	-.01	-.39*
PIQ	-.13	-.14	.01	-.01	-.03	-.16	-.27
FSIQ	-.08	-.19	-.12	-.09	-.10	-.10	-.40*
Digit Ratio	.21	-.22	-.12	-.04	-.17	-.32*	-.11
BFI O	.05	-.15	.05	.19	.34*	-.25	.09
BFI C	-.04	.07	.30*	-.01	-.28	.12	-.29
BFI E	.13	-.01	.35*	.37*	.31	-.04	.32*
BFI A	.12	.29	.21	.07	-.07	-.03	.19
BFI N	-.02	-.02	-.36*	-.04	.08	-.11	.01
BSRI M	.19	.10	.32*	.33*	.40*	.06	.43*
BSRI F	.12	.06	.20	.12	.15	-.04	-.06

Note: **p*< .05; REA = Right ear advantage, Index = Prime Index, RT = Response time, Ac = Accuracy, EHI = Edinburgh handedness index, WTAR = Wechsler Test of Adult Reading, VIQ = Verbal IQ, PIQ = Performance IQ, FSIQ = Full Scale IQ, BFI O = BFI Openness, BFI C = BFI Conscientiousness, BFI E = BFI Extraversion, BFI A = BFI Agreeableness, BFI N = BFI Neuroticism, BSRI M = BSRI Masculinity, BSRI F = BSRI Femininity

Table 5

Lexical decision mean response times and priming

	50 ms SOA				400 ms SOA			
	Female		Male		Female		Male	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
RhRh								
Pseudo	721.29	160.34	711.10	151.09	622.15	115.32	681.09	197.97
High	591.98	140.15	627.39	209.72	467.40	121.43	478.42	129.74
Neutral	566.40	119.89	522.02	142.64	521.97	151.60	531.80	123.41
Prime	-25.58	118.75	-100.59	162.96	54.57	109.12	53.71	95.28
RhLh								
Pseudo	758.65	176.62	794.80	201.92	675.72	131.51	664.77	145.72
High	649.77	183.52	671.07	163.63	485.36	121.77	492.75	88.82
Neutral	616.61	246.38	646.01	174.43	602.59	163.22	665.68	178.06
Prime	-33.16	220.44	-25.05	164.91	117.23	105.19	164.44	151.65
LhRh								
Pseudo	778.88	203.42	850.89	253.61	686.30	167.68	675.03	148.61
High	636.38	170.97	703.76	224.81	498.85	115.92	539.88	132.89
Neutral	625.89	149.23	737.97	255.00	534.19	130.20	598.91	141.77
Prime	-2.54	144.23	34.21	245.96	35.33	72.58	55.60	99.94
LhLh								
Pseudo	724.08	157.68	710.43	193.54	596.20	103.59	627.86	123.45
High	571.61	160.20	576.98	143.45	427.02	94.58	428.21	80.39
Neutral	578.95	149.56	538.36	107.68	491.56	138.85	522.52	137.01
Prime	7.34	93.32	-38.61	103.55	64.54	92.24	80.73	95.49

Table 6

Effect of SOA, Prime, Target and Association on Word Condition Response Time

Effect	*df*	*F*	*p*	ηp^2
SOA	1,71	119.78	< .001	.63*
Prime	1,71	2.68	.106	.04
Target	1,71	4.59	.036	.06*
Associate	1,71	21.81	< .001	.24*
SOA X Prime	1,71	8.11	.006	.10*
SOA X Target	1,71	0.79	.376	.01
SOA X Associate	1,71	69.48	< .001	.49*
Prime X Target	1,71	86.26	< .001	.55*
Prime X Associate	1,71	0.45	.503	.01
Target X Associate	1,71	4.66	.034	.06*
SOA X Prime X Target	1,71	0.96	.331	.01
SOA X Prime X Associate	1,71	22.21	< .001	.24*
SOA X Target X Associate	1,71	5.65	.020	.07*
Prime X Target X Associate	1,71	6.22	.015	.08*
SOA X Prime X Target X Associate	1,71	< 0.01	.969	<.01

Note: *$p < .05$

Table 7

Effect of SOA, Prime, Target, Associate and Sex on Word Condition Response Time

Effect	*df*	*F*	*p*	ηp^2
SOA	1, 70	117.78	< .001	.63*
Prime	1, 70	2.51	.118	.03
Target	1, 70	5.00	.029	.07*
Associate	1, 70	21.52	< .001	.24*
Sex	1, 70	0.14	.707	<.01
SOA X Prime	1, 70	8.10	.006	.10*
SOA X Target	1, 70	0.94	.337	.01
SOA X Associate	1, 70	71.17	< .001	.50*
SOA X Sex	1, 70	< 0.01	.968	< .01
Prime X Target	1, 70	99.63	< .001	.59*
Prime X Associate	1, 70	0.51	.478	.01
Prime X Sex	1, 70	0.70	.406	.01
Target X Associate	1, 70	4.59	.036	.06*
Target X Sex	1, 70	2.09	.153	.03
Associate X Sex	1, 70	0.02	.882	< .01
SOA X Prime X Target	1, 70	1.07	.305	.02
SOA X Prime X Associate	1, 70	23.00	< .001	.25*
SOA X Prime X Sex	1, 70	0.13	.719	< .01
SOA X Target X Associate	1, 70	5.64	.020	.07*
SOA X Target X Sex	1, 70	1.77	.188	.02
SOA X Associate X Sex	1, 70	1.70	.197	.02
Prime X Target X Associate	1, 70	7.35	.008	.09*
Prime X Target X Sex	1, 70	9.47	.003	.12*
Prime X Associate X Sex	1, 70	0.60	.441	.01
Target X Associate X Sex	1, 70	< 0.01	.953	< .01
SOA X Prime X Target X Associate	1, 70	< 0.01	.963	< .01
SOA X Prime X Target X Sex	1, 70	0.97	.327	.01
SOA X Prime X Associate X Sex	1, 70	1.61	.209	.02
SOA X Target X Associate X Sex	1, 70	0.09	.763	< .01
Prime X Target X Associate X Sex	1, 70	5.96	.017	.08*
SOA X Prime X Target X Associate X Sex	1, 70	2.42	.125	.03

Note: $*p < .05$

Table 8

Effect of SOA, Prime, Target and Association on Pseudoword Condition Response Time

Effect	*df*	*F*	*p*	ηp^2
SOA	1, 75	64.82	< .001	.46*
Prime	1, 75	0.10	.747	< .01
Target	1, 75	5.43	.022	.07*
SOA X Prime	1, 75	2.63	.109	.03
SOA X Target	1, 75	0.04	.851	< .01
Prime X Target	1, 75	44.30	< .001	.37*
SOA X Prime X Target	1, 75	2.54	.115	.03

Note: *$p < .05$

Table 9

Effect of SOA, Prime, Target, Association and Sex on Pseudoword Condition Response Time

Effect	*df*	*F*	*p*	ηp^2
SOA	1, 74	64.17	< .001	.46*
Prime	1, 74	0.10	.749	< .01
Target	1, 74	5.42	.023	.07*
Sex	1, 74	0.69	.409	.01
SOA X Prime	1, 74	2.63	.109	.03
SOA X Target	1, 74	0.04	.852	< .01
SOA X Sex	1, 74	0.25	.617	< .01
Prime X Target	1, 74	43.95	< .001	.37*
Prime X Sex	1, 74	0.05	.819	< .01
Target X Sex	1, 74	0.89	.348	.01
SOA X Prime X Target	1, 74	2.87	.094	.04
SOA X Prime X Sex	1, 74	0.83	.366	.01
SOA X Target X Sex	1, 74	0.16	.686	< .01
Prime X Target X Sex	1, 74	0.41	.522	.01
SOA X Prime X Target X Sex	1, 74	10.86	.002	.13*

Note: *$p < .05$

Table 10

Effect of SOA, Prime and Target on Priming

Effect	*df*	*F*	*p*	ηp^2
SOA	1, 71	69.48	< .001	.49*
Prime	1, 71	0.45	.503	.01
Target	1, 71	4.66	.034	.06*
SOA X Prime	1, 71	22.21	< .001	.24*
SOA X Target	1, 71	5.65	.020	.07*
Prime X Target	1, 71	6.22	.015	.08*
SOA X Prime X Target	1, 71	< 0.01	.969	<.01

Note: *$p < .05$

Table 11

Effect of SOA, Prime, Target and Sex on Priming

Effect	*df*	*F*	*p*	ηp^2
SOA	1, 70	71.17	< .001	.50*
Prime	1, 70	0.51	.478	.01
Target	1, 70	4.59	.036	.06*
Sex	1, 70	0.02	.882	<.01
SOA X Prime	1, 70	23.00	< .001	.25*
SOA X Target	1, 70	5.64	.020	.07*
SOA X Sex	1, 70	1.70	.197	.02
Prime X Target	1, 70	7.35	.008	.09*
Prime X Sex	1, 70	0.60	.441	.01
Target X Sex	1, 70	< 0.01	.953	<.01
SOA X Prime X Target	1, 70	< 0.01	.963	<.01
SOA X Prime X Sex	1, 70	1.61	.209	.02
SOA X Target X Sex	1, 70	0.09	.763	<.01
Prime X Target X Sex	1, 70	5.96	.017	.08*
SOA X Prime X Target X Sex	1, 70	2.42	.125	.03

Note: $*p < .05$

Table 12

Effect of SOA, Prime, Target and Association on Word Condition Accuracy

Effect	*df*	*F*	*p*	ηp^2
SOA	1, 77	198.69	< .001	.72*
Prime	1, 77	< 0.01	.958	< .01
Target	1, 77	10.42	.002	.12*
Association	1, 77	5.77	.019	.07*
SOA X Prime	1, 77	9.41	.003	.11*
SOA X Target	1, 77	4.91	.030	.06*
SOA X Association	1, 77	102.96	< .001	.57*
Prime X Target	1, 77	67.15	< .001	.47*
Prime X Association	1, 77	3.30	.073	.04
Target X Association	1, 77	0.14	.705	< .01
SOA X Prime X Target	1, 77	3.26	.075	.04
SOA X Prime X Association	1, 77	22.54	< .001	.23*
SOA X Target X Association	1, 77	5.63	.020	.07*
Prime X Target X Association	1, 77	18.09	< .001	.19*
SOA X Prime X Target X Association	1, 77	0.12	.732	< .01

Note: **p* < .05

Table 13

Effect of SOA, Prime, Target, Association and Sex on Word Condition Accuracy

Effect	*df*	*F*	*p*	ηp^2
SOA	1, 76	197.17	< .001	.72*
Prime	1, 76	< 0.01	.957	< .01
Target	1, 76	10.46	.002	.12*
Association	1, 76	5.72	.019	.07*
Sex	1, 76	5.47	.022	.07*
SOA X Prime	1, 76	9.32	.003	.11*
SOA X Target	1, 76	4.90	.030	.06*
SOA X Association	1, 76	102.24	< .001	.57*
SOA X Sex	1, 76	0.41	.524	.01
Prime X Target	1, 76	67.02	< .001	.47*
Prime X Association	1, 76	3.31	.073	.04
Prime X Sex	1, 76	5.46	.022	.07*
Target X Association	1, 76	0.15	.703	< .01
Target X Sex	1, 76	1.31	.256	.02
Association X Sex	1, 76	0.38	.537	.01
SOA X Prime X Target	1, 76	3.24	.076	.04
SOA X Prime X Association	1, 76	22.26	< .001	.23*
SOA X Prime X Sex	1, 76	0.23	.631	< .01
SOA X Target X Association	1, 76	5.61	.020	.07*
SOA X Target X Sex	1, 76	0.93	.338	.01
SOA X Association X Sex	1, 76	0.46	.498	.01
Prime X Target X Association	1, 76	18.18	< .001	.19*
Prime X Target X Sex	1, 76	0.85	.360	.01
Prime X Association X Sex	1, 76	1.29	.259	.02
Target X Association X Sex	1, 76	1.97	.165	.03
SOA X Prime X Target X Association	1, 76	0.12	.733	< .01
SOA X Prime X Target X Sex	1, 76	0.56	.458	.01
SOA X Prime X Association X Sex	1, 76	0.06	.809	< .01
SOA X Target X Association X Sex	1, 76	0.70	.406	.01
Prime X Target X Association X Sex	1, 76	1.35	.249	.02
SOA X Prime X Target X Association X Sex	1, 76	< 0.01	> .999	< .01

Note: $*p < .05$

Table 14

Effect of SOA, Prime, Target and Association on Pseudoword Condition Accuracy

Effect	*df*	*F*	*p*	ηp^2
SOA	1, 81	129.44	< .001	.62*
Prime	1, 81	22.32	< .001	.22*
Target	1, 81	13.75	< .001	.15*
SOA X Prime	1, 81	0.44	.511	.01
SOA X Target	1, 81	7.86	.006	.09*
Prime X Target	1, 81	37.72	< .001	.32*
SOA X Prime X Target	1, 81	16.89	< .001	.17*

Note: *$p < .05$

Table 15

Effect of SOA, Prime, Target, Association and Sex on Pseudoword Condition Accuracy

Effect	*df*	*F*	*p*	ηp^2
SOA	1, 80	133.80	< .001	.63*
Prime	1, 80	21.98	< .001	.22*
Target	1, 80	13.55	< .001	.14*
Sex	1, 80	0.01	.943	.00
SOA X Prime	1, 80	0.42	.518	.01
SOA X Target	1, 80	8.08	.006	.09*
SOA X Sex	1, 80	3.15	.080	.04
Prime X Target	1, 80	37.58	< .001	.32*
Prime X Sex	1, 80	0.18	.675	.00
Target X Sex	1, 80	0.80	.373	.01
SOA X Prime X Target	1, 80	17.46	< .001	.18*
SOA X Prime X Sex	1, 80	0.09	.765	.00
SOA X Target X Sex	1, 80	1.57	.214	.02
Prime X Target X Sex	1, 80	0.36	.548	.00
SOA X Prime X Target X Sex	1, 80	2.30	.134	.03

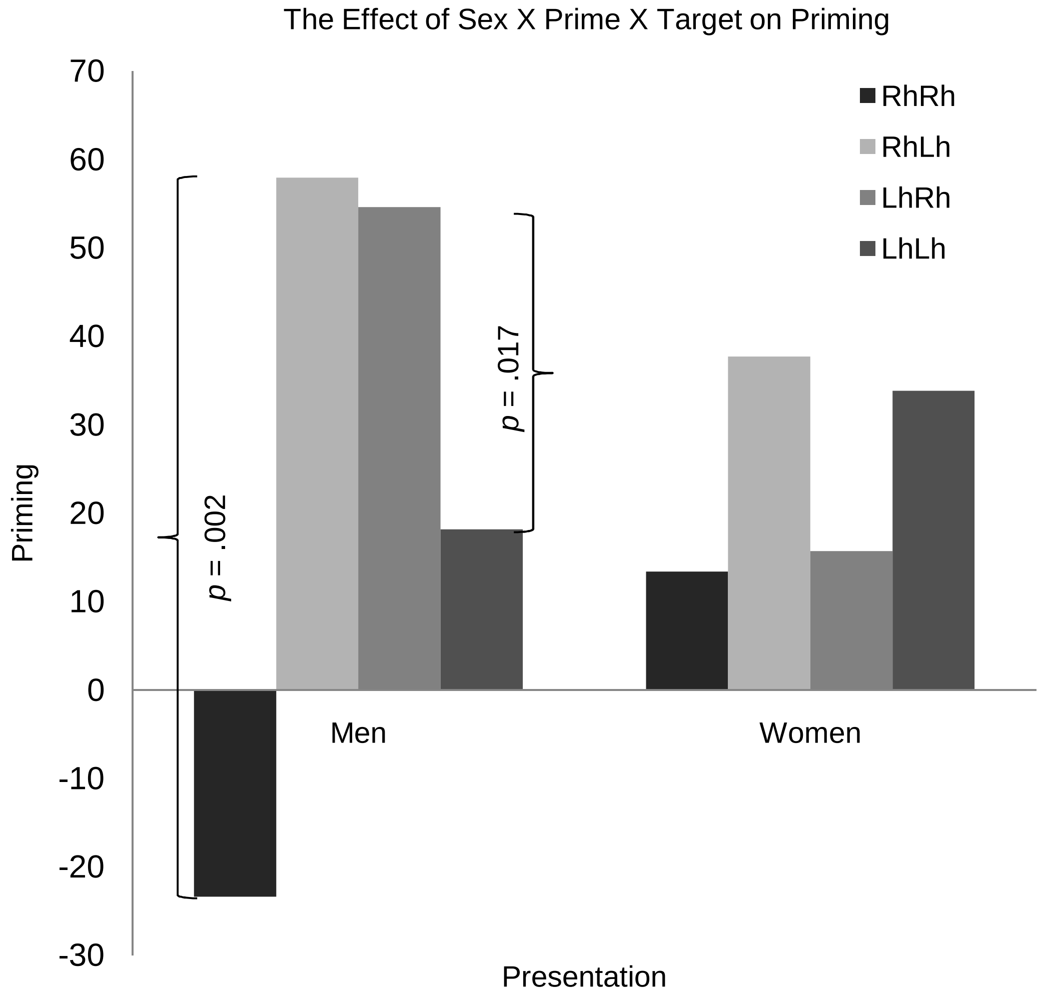
Note: *$p < .05$

Table 16

Effect of VIQ and PIQ on accuracy overall and between sexes

	Word Accuracy			Pseudoword Accuracy		
	β	R^2	$R^2\Delta$	*β*	R^2	$R^2\Delta$
Overall						
Step 1		.08*	.08*		.04	.04
VIQ	-.14			.05		
PIQ	.32*			.18		
Step 2		.09*	.01		.06	.02
VIQ	-.15			.04		
PIQ	.30*			.15		
VIQ X PIQ	-.09			-.16		
Men						
Step 1		.30*	.30*		.15*	.15*
VIQ	-.24			.04		
PIQ	.59**			.37*		
Step 2		.32*	.02		.20*	.05
VIQ	-.23			.06		
PIQ	.58**			.34*		
VIQ X PIQ	-.15			-.23		
Women						
Step 1		.01	.01		.03	.03
VIQ	-.03			.10		
PIQ	-.05			-.19		
Step 2		.02	.02		.07	.04
VIQ	-.06			.05		
PIQ	-.10			-.27		
VIQ X PIQ	-.14			-.23		

Note: *p < .05, **p < .001; VIQ = Verbal Intelligence Quotient, PIQ = Performance Intelligence Quotient


The Effect of Sex X Prime X Target on Priming
70
60
50
40
30
20
10
0
-10
-20
-30
Priming
RhRh
RhLh
LhRh
LhLh
p = .002
p = .017
Men
Women
Presentation

ABSTRACT

INDIVIDUAL DIFFERENCES AND BRAIN LATERALITY IN LANGUAGE PROCESSING

by

SARAH A. VAN DYKE

August 2011

Advisor: R. Douglas Whitman

Major: Psychology (clinical)

Degree: Doctor of Philosophy

Conclusions in the literature regarding the relationship between a lateralized bias in the processing of information and individual differences (e.g., biological sex, gender identity, ability, personality) are inconsistent. Two different measures of laterality were compared: dichotic listening and lateralized semantic priming and their relation to sex, verbal and visual-spatial ability, gender identity, and personality.

Eighty-nine adults (44 women, 45 men) were administered the Wechsler Abbreviated Scale of Intelligence, Bem Sex Role Inventory, and Big Five Inventory in addition to a dichotic listening task and a lateralized semantic priming task that compared ipsilateral and contralateral priming in order to determine the role of interhemispheric transfer. Two stimulus onset asynchronies (SOA; 50 ms and 400 ms) and two levels of association strength (high and neutral) between the prime and the target words were used in the priming task.

Ipsilateral prime-target reaction times were faster than contralateral prime-target presentations, while contralateral presentations resulted in greater semantic priming, suggesting that the time required for interhemispheric transfer allows for greater

semantic activation. Further, greater association strength increased semantic priming only at the longer SOA and only the shorter SOA correlated with the dichotic listening lateralization index. Individual differences were unrelated to the lateralized indices.

The findings suggest that both dichotic listening and the shorter SOA condition measured automatic or perceptual lateralization whereas the longer SOA condition measured post-lexical lateralization of word meaning. Future research focusing on individual differences in the lateralization of information processing should employ and contrast different lateralization measures.

AUTOBIOGRAPHICAL STATEMENT

EDUCATION

Wayne State University, Detroit, Michigan

Ph.D. Candidate, Clinical Psychology, August 2011
Minors: Neuropsychology, Health Psychology

M.A. Clinical Psychology, December 2007

Calvin College, Grand Rapids, Michigan

B.A. Psychology, May 2004

GRANTS FUNDED

Predoctoral Associated Health Rehabilitation Research Fellowship

Project Title:	Utility of the Traumatic Brain Injury Screening Instrument in Predicting Cognitive and Affective Functioning in OEF/OIF Veterans
Facility:	John D. Dingell Veterans Affairs Medical Center, Detroit, MI
Preceptors:	Bradley Axelrod, Ph.D. Christian Schutte, Ph.D.
Amount:	$35,000 October 2009 – September 2010

PUBLICATIONS

Van Dyke, S.A., Axelrod, B.N. & Schutte, C. (2010). Test-retest reliability of the Traumatic Brain Injury Screening Instrument. *Military Medicine*, *175*(12), 947-949.

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