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The Right Hemisphere: An Investigation Into Its Roles in New Word Acquisition and
Possible Individual Differences

A Dissertation submitted in partial satisfaction
of the requirements for the degree of

Doctor of Philosophy

in

Psychology

by

Travellia Febriani Tjokro

August 2010

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Dr. Christine Chiarello, Chairperson

Dr. Steven Clark

Dr. Lawrence Rosenblum

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The Dissertation of Travellia Febriani Tjokro is approved:

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Dedication

I would like to dedicate this dissertation to the memory of my mother, Caroline Gotama and my grandmother, Laila Tjokro. I love you and I miss you, Mama and Ama. Both of you are my inspiration: for your strength, for your kindness, for your love of life. Till we meet again.

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ABSTRACT OF THE DISSERTATION

The Right Hemisphere: An Investigation Into Its Roles in New Word Acquisition and Possible Individual Differences

by

Travellia Febriani Tjokro

Doctor of Philosophy, Graduate Program in Psychology
University of California, Riverside, August 2010
Dr. Christine Chiarello, Chairperson

The current project investigated the right hemisphere role in new word and meaning acquisition, and examined whether this is modulated by an individual's reading skill as measured by Nelson-Denny Reading Test. Beeman proposed that the right hemisphere has a coarse coding style, and is better able to integrate weak semantic relations in contrast to more fine semantic coding within the left hemisphere (Beeman & Chiarello, 1998). A coarse coding style may help in learning the meanings of new words (Ince & Christman, 2002). In addition, a right hemisphere advantage in learning new words may be influenced by reading skill (see Perfetti, Wlotko, & Hart, 2005). The current project also examined quantitative versus qualitative hypotheses for lateralization of word acquisition; the former emphasizes the amount of experience with words, while qualitative hypothesis emphasizes brain maturation state. Two experiments were included in the current

project. The first experiment presented the new words and meanings either 2 or 8 times, thereby varying the number of semantic learning contexts. The second experiment added an English condition. Forced choice recognition tested learning of new words, followed by the critical divided visual field semantic relatedness judgment test. It was predicted that skilled readers would utilize the most appropriate hemispheric strategy, resulting in a left hemisphere advantage for more experienced words, and right hemisphere advantage for less experienced words. Less-skilled readers were predicted to have less hemispheric asymmetry in the more experienced condition. The combined experiment data suggest an advantage for rvf/LH for English words. The top 25% of comprehenders had lvf/RH performance that is much more efficient than the bottom 25% of comprehenders. This was not observed when the groups were divided by median split. In Experiment 2 the English condition had a robust rvf/LH advantage, which was not observed in the 2x and 8x condition. This may be taken to support coarse-fine coding hypotheses. It is concluded that greatly increased experience with words is crucial for rvf/LH advantages to emerge, superior comprehenders have more efficient RH processing, and that left-lateralization occurs through increased experience with individual words (i.e., the quantitative hypothesis is supported).

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Introduction

Human beings' remarkable ability to acquire and use language effectively is one of the major hallmarks of their cognitive ability. This is something that is not found in any other species to the advanced level that is observed in human beings. The interest in the development of language has pervaded psychology precisely because of how language has shaped many human advancements in terms of culture and interpersonal relationships. The study of how language develops gives scientists a lot of information as to how human cognitive structure is assembled and utilized. This, in turn, provides scientists with tools to study other aspects of the human cognitive system. The aspect of the cognitive system that is the focus of the current project is language acquisition, more specifically, new word and meaning acquisition. It is important to study how vocabulary develops in human beings because word learning is an ability that is maintained even later in life (Constantinidou & Baker, 2002). Elderly people are able to learn words well even when other cognitive abilities deteriorate. This is important because it shows that word learning is a durable skill, and understanding its neural mechanisms may shed light as to why it is such a durable skill.

Word learning is made possible through repeated experience with a new word under different contexts and circumstances. As the word learner gains more experience, more information about the word's semantics may be encoded in semantic memory, thus facilitating the new knowledge's establishment in the lexicon and enabling the word learner to use the word knowledge in various contexts later on (Dagenbach, Carr, &

Horst, 1990). The focus of the current project was to examine the differential roles that the brain hemispheres play in acquisition of new words and meanings, and how individual reading comprehension skill may influence hemispheric processing of newly-learned words. But before that, the following subsections will review research that has been done in new word learning both in children and in adults.

New Word Acquisition in Children

The study of how a human being acquires language has naturally begun with the studies of young children acquiring their first language. This by itself is a remarkable feat. The sheer amount of complexities that pervade the process of learning a new language is daunting for adults, let alone for young children. However, young children are able to acquire their first language and use it well to help them learn other aspects of their environment. Children typically learn their first words by approximately 12 months of age, becoming more and more proficient at word learning by the time they are 16-18 months of age (Bloom & Markson, 1998). Children were once considered passive recipients of their environment in terms of learning language; however, more recent research has found that they are very active in the process of learning language (Bloom & Markson, 1998). Much research has been done looking into specific strategies that children use in learning new words. A subset of these studies will be discussed below.

Children have been found to be able to acquire novel words and their meanings very fast after minimal exposure to the new words; a strategy termed ‘fast mapping.’ Carey and Bartlett (1978) first discovered this effect. In the study, 3-year old toddlers

were exposed to a new color word (“chromium”). They were presented with two different trays with different colors. One was red (or other colors that were tested to be familiar to the toddlers), the other was chromium. The results showed that children were able to retain the meaning of chromium and differentiate it from green after just one exposure to the chromium-colored tray. This learning was preserved several days later, meaning that the children had formed a new concept of ‘chromium color’ (Carey & Bartlett, 1978). The researchers also found that the learning of the new meaning through fast mapping did not include the full range of the contents of the new meaning, but only a fraction of it. The findings above were extended to even younger children (16-18 months of age) and a longer period of delay between learning and testing by Gershkoff-Stowe and Hahn (2007). In addition, these researchers also found priming effects in these young children. Children who fast-mapped new words and then were repeatedly presented with those new words and meanings were able to learn other, less frequently presented words faster than children who never got the chance to have repeated presentation of the words they learned. That is, it seems that knowing more words ‘prime’ the system to learn more words (Gershkoff-Stowe & Hahn, 2007); this conclusion echoed the conclusion made earlier in the study by Goodman, McDonough, and Brown (1998). The fast mapping studies show that young children are equipped with a specific ability and bias toward learning new words and their meanings quickly, and then use what they know to learn additional words. The study by Gershkoff-Stowe and Hahn (2007) also underlined the importance of repeated experience in learning new words and their meanings. This is a

principle that was examined more deeply by researchers looking into the importance of statistical learning in children's language learning.

Experience-dependent (statistical) learning in 8-month-old infants was examined by Saffran, Aslin, and Newport (1996). The authors specifically looked at the infants' ability to recognize words based on their sound boundaries (speech parsing ability). The infants were exposed to 2-minute long sequences of various speech sounds that were created by the researchers. Later, their recognition of these speech sounds was tested along with speech sounds they never heard before. The results indicated that the infants were able to differentiate speech sounds they had heard before from those they never heard before. Hence, repeated experience with certain novel stimuli helped infants learn the speech stimuli. Experience-dependent learning also happens as young children navigate the enormous amount of ambiguous stimuli present in the environment by finding statistical regularity in the co-occurrence of the novel words with specific referents (Smith & Yu, 2008). These will be important as well later on as these children become older and learn more words.

As can be gleaned from studies on fast mapping and statistical learning, it seems that children are able to acquire novel words and meanings quickly (after just single exposure, as shown by studies of fast mapping), and repeated experience with these novel words and meanings solidifies their place in the mental lexicon of the children. This, in turn, will help children acquire more words.

Studies above have helped shed light on some tools that children use in their quest to acquire new words. Some researchers have looked specifically into how young children acquire the semantics of the new words. Clark (1973) asked the question of how a word meaning acquired by a child develops into an adult-level meaning. In her landmark paper elaborating on Semantic Feature Acquisition hypothesis, Clark asserted that the first time a child acquires a new meaning/concept, this meaning is not as complete as the one that the child will eventually develop as an adult. The child only has a partial entry of this word in his/her lexicon. Due to the children's more incomplete entries for the meaning of a word, the categories that the children made based on this incomplete information are also larger and less discriminative than the ones made by adults (i.e., overextension) (Clark, 1973). In fact, Clark used the phenomenon of overextension and her studies of it to support her conception that children's semantics are not as complete as adults. In a way, children learn by trial and error as they try to refine semantics and eventually categories (see also Carey & Bartlett, 1978).

The studies above have delved head-on to the various issues surrounding children's new word acquisition, which is nothing but remarkable. Children are active agents in learning their first words. Some of the tools that young children use in order to acquire language are also used in somewhat modified formats by adults later in life when adults acquire new words and concepts. Next, I will try to draw connections among the skills shown by children in new word acquisition and how adults later utilize these skills, which will later form the basic argument for the current projects.

One thing to note is that studies done on adults will obviously be different from studies done on young children in terms of the types of stimuli and instructions given to them. I will try to draw connections based on the underlying theme of specific skills that are seen in children and adults (e.g., “ability to acquire new words quickly”). I make no assumption that the skills are based on the same processing. In fact, I believe that the skills in adults may exist in a somewhat modified format due to adults being more adept at using various sources of information and the sheer amount of stored information available to adults that is not yet available to young children.

New Word Acquisition in Adults

The notion that children acquire the semantics of a new word gradually (Clark, 1973) finds its counterpart in adults through studies done on various levels of knowledge of word meanings. Durso and Shore (1991) introduced the notion of known words, frontier words, and unknown words to their experiments. A known word is defined as a word that a subject can define correctly. A frontier word is defined as a word the subject recognizes as a valid English word but is unable to define. An unknown word is a word that the subject denies as a true English word. Through a series of 7 experiments, the researchers conducted prechecks to determine a subject’s level of word knowledge (unknown, frontier, or known) for the stimuli that would later be used in the experiment. The series of experiments used two tasks and their variations. In a sentence decision task, the subjects were presented with an English sentence that utilized correct use of the known, frontier, or unknown words, and a second sentence that contained incorrect use of these levels of

words. The incorrect sentence violated either a general constraint of a word's meaning or a specific constraint of a word's meaning. Therefore, the subject had to decide which of the two sentences used the target word correctly. The second task was the word judgment task. The subjects had to choose which word of a pair contained the closest meaning to the target word.

The researchers major findings were that the subjects were able to process unknown words better than chance, that frontier and unknown words were processed differently; that is, frontier words contacted specific episodic information more often than unknown words. Frontier words had better performance than unknown words when the retrieval cue was sentence, but not when the retrieval cue was a word. This was taken as a support to the notion that sentence as a retrieval cue was more likely to activate specific episodic experiences (Durso & Shore, 1991). Possibly there were differing levels of semantic knowledge in terms of how word is processed. It could be that there were these different levels of semantic knowledge in the process of children's semantic acquisition process as well. Durso and Shore (1991)'s findings as well as Clark (1973)'s hypothesis and her studies to confirm it underline the possibility that in children and adults, meanings exist in gradients instead of an all-or-none situation. It is very likely that repeated experience with the new word helps refine and complete a new meaning.

Adults were found to be able to acquire new words in a fast manner through a study done by Clay, Bowers, Davis, and Hanley (2007). The study used a Picture Word Interference paradigm. The subjects were exposed to some novel objects with novel

names. Then, they were tested by asking them to name the novel objects as fast as they could. In the critical condition, the novel object was presented with a written word distractor that was semantically-related or unrelated to the object. The amount of interference (i.e., lower accuracy and slower latency) that a subject experiences when a semantically-related distractor was presented relative to an unrelated word distractor was taken as an indication that the new object concept has been acquired by the subject. Among the most important results of the study was that there was indeed more interference naming novel objects when a semantically-related distractor was presented compared to unrelated distractor. The subjects were able to learn the new object and its referent only with a single exposure (Clay et al., 2007). This study's findings on adults new word learning were reminiscent of the findings by Carey and Bartlett (1978) and Gershkoff-Stowe and Hahn (2007) on fast mapping in children. It seems that both adults and children have an ability to quickly acquire new words and their concepts, in some cases after only a single exposure.

However, in order for the new concepts to be solidified and stabilized in the mental lexicon, some additional experience may be needed. Gaskell and Dumay (2003) conducted several experiments looking into the role of memory consolidation in solidifying newly-learned materials. The paradigm they used was slightly similar to the paradigm used by Clay, Bowers, Davis, and Hanley (2007); that is, they looked at the interference created by the newly-learned words on the words that are previously established. Gaskell and Dumay (2003) specifically looked at phonological interference of newly-learned

words on other, previously-established words that are phonologically similar. They asserted that a new word is considered to be established in the mental lexicon when it becomes an inhibitor to another word, phonologically similar to it. The researchers had several conditions: no delay and 5-day delay. As predicted by the researchers, memory consolidation, which occurred during sleep, led the 5-day delay condition to show inhibitory effects of a new word on previously-established, phonologically similar word. This result seems reminiscent of the results found in young children using a more child-friendly paradigm and 24-hour delay (see Goodman, McDonough, & Brown, 1998). The underlying theme of the importance of memory consolidation in both children and adults' new word acquisition is undeniable.

In adults, some experiments were conducted to look into the semantic aspect of new word acquisition. More specifically, the researchers wanted to investigate the process of adding new information to semantic memory and the amount of repetition needed to induce automatic priming for new semantic information. The researchers regarded the presence of automatic priming as a sure sign that the new information had been established in semantic memory (Dagenbach, Carr, & Horst, 1990). These researchers conducted a series of experiments using primed lexical decision of various episodic and semantic stimuli learning conditions (i.e., unrelated word-word pairing and newly-learned words and their synonyms pairing) which showed the relationship between episodic and semantic memory in adults (Dagenbach, Carr, & Horst, 1990). The main findings of these series of experiments were that there was a failure to find automatic priming for previ-

ously unrelated word-word pairing, and that increased training period led to episodic priming of newly-learned association. The researchers concluded that attempting to forge a link between previously existing, but unrelated words was much harder than to forge a completely new link between a newly-learned word and its synonym. The current study took this conclusion into consideration by requiring the subjects to learn new words and meanings, and then make semantic relatedness judgment decision between the new words and previously existing English words.

In conclusion, in adults and children new word acquisition appear to be underlined by similar themes that are more advanced in adults. The similar themes are: the speed at which new words can be acquired, the importance of having additional experience with the words to refine and complete the meanings, and memory consolidation process to solidify the words and meanings in the cognitive network.

Brain Development and Language Acquisition Process

The studies mentioned above have found similar underlying themes of language development in adults and children; however, they do not take into account the brain organization that may provide a substrate for similar as well as differential processes in adults and children. The rate of myelination of brain language structures correlated positively with emergence of vocabulary and the vocabulary spurt (Pujol, Soriano-Mas, Ortiz, Sebastian-Galles, Losilla, & Deus, 2006). This study provides strong evidence of the close relationship between brain structural maturation and emergence of certain language functions. Another team of researchers conducted a longitudinal study looking at children

who had perinatal brain injuries and the impacts these injuries had on various cognitive functions. Interestingly, in children 12-35 months old, a significant delay in vocabulary comprehension was found when the right, but not the left, hemisphere had been damaged (Stiles, Bates, Thal, Trauner, & Reilly, 2002). A meta-analysis conducted by Hull and Vaid (2007) affirmed that early bilinguals (i.e., bilinguals who acquired their second language before 6 years old) showed an increased right hemisphere involvement in studies using methods such as dichotic listening. These findings suggest that the right hemisphere is important in early word learning, as will be explored further in the current study.

A study was also done with older children and adolescents looking at how vocabulary size may be related to the size of some brain structures. Lee et al. (2007) tested verbal skills of 34 adolescents (12-16 years old) and took structural MRI scans of their brain. The adolescents with larger vocabularies were found to have thicker gray matter density in the posterior supramarginal gyrus of the left inferior parietal lobe. Similar results were found in an earlier study, which was done with monolingual and bilingual adults. Gray matter density in the parietal cortex is thicker in bilinguals compared with monolinguals, and it is negatively correlated with the age of acquisition of second language; that is, the younger the age of acquisition of the second language, the thicker the gray matter density (Mechelli, Crinion, Noppeney, O'Doherty, Ashburner, Frackowiak, & Price, 2004). These studies show that brain changes within the left hemisphere are associated with changes in language experience.

However, these studies have not specifically addressed the issue of left hemisphere specialization for verbal processing. Therefore, a question to be solved is: how does language experience lead to left hemispheric specialization of language processing for most adults? There are two possible mechanisms that have been proposed (Mills, Plunkett, Prat, & Schafer, 2005). A qualitative mechanism proposes that left lateralization of language processes occurs because brain maturation processes shift the way an infant processes known words. It is proposed that there is a critical period in which the brain matures. Before this critical period, verbal processing is proposed to happen more bilaterally, while verbal processing that happens after this critical period is handled by the left hemisphere, including the processing of new vocabulary items. This view implies that the left-lateralization process involves substantial neural changes in the way language is processed when comparing children and adults. A quantitative mechanism would propose that increased experience and familiarity with individual words shifts the brain processing from more bilateral to be more left-lateralized (Mills, Plunkett, Prat, & Schafer, 2005). These researchers conducted an ERP study on 20 month olds to test these two views. Specific ERP components that were examined were the components in N200-500 window, which should show the largest amplitude (negative) on novel words paired with novel objects. The toddlers were taught new novel objects paired with novel words in a puppet show and were later tested along with familiar words paired with familiar objects. Their level of vocabulary comprehension and production was also tested through the MacArthur Communicative Development Inventory (CDI). The results supported the

quantitative hypothesis. Children with high production scores on the CDI indeed showed more bilateral distribution of ERP in novel words, with more focal distribution of ERP components (to the left hemisphere) to familiar words. Children with low CDI scores showed bilateral distribution of ERP over all stimuli types. Thus, the experience with individual words greatly influenced left-lateralization of familiar word processing in children who had better comprehension and production scores in CDI. This study provided a possible explanation as to how lateralization process may happen postnatally specifically in terms of verbal processing. An fMRI study found that during an early phase of brain development (i.e., third trimester – neonates), several brain structures were not lateralized or even favored the right hemisphere even though structures that would later be important for language functions (e.g., Heschl gyrus and planum temporale) were found to already be left-lateralized (see Dehaene-Lambertz, Hertz-Pannier, & Dubois, 2006). This may mean that some core structures for verbal processing have had the tendency to be left-lateralized very early in development, and postnatally, and additional experience with words helps in focusing more additional structures needed for language processing to be left lateralized (see also Feldman, 2005).

However, as mentioned above, the right hemisphere is not useless in language processing, especially during early word learning (see Stiles et al., 2002; Feldman, 2005). Thus, early on, the right hemisphere was playing a role in new word learning; however, as exposure to the words increases, the left hemisphere starts to predominate. At this point, a connection could be drawn to the qualitative vs. quantitative arguments presented

earlier. Adults have much more mature brains compared to children. If the qualitative argument is supported in adults, then we should see that newly-learned words (less exposure) should be left-lateralized because the adult brain is already mature. However, if the quantitative argument is supported in adults, newly-learned words should be right-lateralized because they have not yet accumulated enough exposure to warrant left-lateralization. This was tested in the current project.

Various studies using the divided visual field paradigm in adults usually obtained left hemisphere advantages for word stimuli (e.g., Leiber, 1976; Weems & Zaidel, 2004; Weems & Zaidel, 2005). It is possible that these studies did not use paradigms that allowed right hemisphere advantages to be shown (these studies have used paradigms such as lateralized lexical decision and repetition priming, which may not require access to less common meanings of a word). Studies that had found right hemisphere advantages have used paradigms such as summation priming, which provide evidence that less common meanings have been accessed (see Beeman, Friedman, Grafman, Perez, Diamond, & Lindsay, 1994).

The current project attempted to investigate the roles that the right hemisphere might play in the acquisition of new words in adults, more specifically in semantic acquisition of these new words taking into account different levels of experience with new words and meanings and memory consolidation process as occurs during sleep. The coarse-fine coding style hypotheses of the hemispheric processing provide a framework for the current research.

Coarse vs. Fine Hemispheric Processing Style

Beeman and colleagues proposed that the RH has a coarse coding style of stimulus processing, in that the RH is very good at integrating distant semantic relations. It is proposed that the RH is able to activate larger semantic fields related to the stimulus presented to it. The right hemisphere is also responsible for maintaining a broad array of possible meanings of a word, therefore it may show an advantage when the less common meaning of the word is accessed (Beeman & Chiarello, 1998). This view of RH processing may relate to the findings that early on in word acquisition, young children used larger and less discriminative categories than adults (Clark, 1973). This kind of early word processing seems to resemble RH processing style; this may imply that the RH plays an important role in early word acquisition. On the other hand, according to Beeman, the LH finely codes the stimuli. LH processing is adept at picking up closely-related semantic connections, which may only be available for well-learned words; thus, LH may have an edge in processing of familiar words. This way of looking at how the hemispheres process information is supported by the anatomical configuration of each hemisphere. Right hemisphere anatomy has been found to be more interconnected than the left hemisphere, and it included dendrites that branched further from soma in the RH, more white matter, more diffuse electrophysiological responses, and higher correlation of activity across regions (Beeman, 2005; Hutsler & Galuske, 2003). This was argued to support the coarse style of processing (Beeman, 2005). On the other hand, left hemisphere anatomy is less interconnected compared to the right hemisphere, with the pyramidal cell

dendrites on average branched closer to the soma (i.e., cell body) than the branching of the same cell dendrites in the right hemisphere (Beeman, 2005; Hutsler & Galuske, 2003). This anatomical configuration may yield a disadvantage for obtaining inputs from distant sources; thus, it processes stimuli in a finely-coded manner (Beeman, 2005).

Support for the coarse vs. fine coding style of the hemispheres comes from various semantic priming studies (e.g., Beeman, Friedman, Grafman, Perez, Diamond, & Lindsay, 1994; Ince & Christman, 2002). Ince and Christman (2002) incorporated a notion that is similar to the coarse vs. fine coding hemispheric processing style differences. The experiment itself utilized three different kinds of words: known words, (the words that the participants have no difficulty in defining and using in a novel sentence), frontier words (words which the participants are able to use in a novel sentence, but cannot recall their meaning), and unknown words. The researchers theorized that left hemisphere activated only the most highly-related words and may even inhibit weakly-related words, whereas the right hemisphere activated broader sets of semantic codes (including the weak ones). The researchers predicted that due to the unique nature of each hemisphere's style of processing, they would process categorical and associative relations differently. More specifically, the left hemisphere was predicted to show facilitation for categorical knowledge, and the right hemisphere for associative knowledge. In the experiment, all of the primes were words, while for targets, half were words and half were nonwords. The primes consisted of known, frontier, and unknown words which were tailored individually to the participants through the use of LOWKAT (Level of World Knowledge As-

assessment). There were 3 different kinds of prime-target relationships. The target and prime can be categorically-related, associatively-related, or unrelated. The primes were presented in the center of visual field, while the targets were presented to either the left hemisphere or the right hemisphere.

Ince and Christman (2002) found that targets that were categorically- and associatively-related to known words obtained right hemisphere facilitation. Frontier words, on the other hand, only facilitated associatively-related targets in the right hemisphere, which was taken to mean that the frontier words have not reached the familiarity level that permitted categorization. The fact that associatively-related frontier words showed right hemisphere facilitation, while the left hemisphere showed only inhibitory effects on associatively-related frontier words, may indicate that the hemispheres differ in their manner of word meaning acquisition, with new meaning acquisition favoring the right hemisphere (Ince & Christman, 2002). However, the fact that they only found priming for categorical relation for known words and not for frontier words seem to contradict their claim that the right hemisphere was proficient at new meaning acquisition. If that were the case, then priming for categorical relations should also be found for frontier words (as a sign that the right hemisphere was able to learn the meaning of the frontier words faster than the left hemisphere to the level that it could prime a categorical relation).

In general, the study claimed to find a right hemisphere role in new meaning acquisition; however, the findings supporting this were weak. One problem with the study

was that the stimuli given to the subject (i.e., known, frontier, and unknown words) were individualized; therefore, for each subject, the number of words in each category was different. This may introduce some complexity in the statistical tests. In addition, the findings that the LH showed only inhibition raise questions about the study. The LH has been found to show semantic facilitation advantages on various verbal tasks (see Weems & Zaidel, 2004; Weems & Zaidel, 2005), the fact that this study found only LH inhibition is problematic.

The current study tried to avoid these problems by creating new words and meanings to be used as target words. This controlled the amount of prior exposure and the level of knowledge across subjects.

Individual Differences in Reading Comprehension Skill

Another relevant variable is the association between an individual's level of language comprehension and hemispheric lateralization of new words. Perfetti, Wlotko, and Hart (2005) conducted an ERP study looking at how adults learned the meanings of rare English words, and found differential ERP effects for adults who were skilled comprehenders (top 20% scores of those tested on Nelson-Denny test of comprehension) and less-skilled comprehenders (bottom 20% scores of those tested on the Nelson-Denny). More specifically, the researchers looked at the P600 and N400 components. P600 is regarded as a marker for episodic memory processes (previously encountered words will induce P600), while N400 is a marker for semantic processes (larger N400 for word that is incongruent with the context). Skilled comprehenders showed stronger P600 effects

when newly learned words were presented to them compared to less-skilled comprehenders. Skilled comprehenders also showed stronger N400 effects when the newly learned words were presented in an incongruent context (Perfetti et al., 2005). These ERP results may suggest that skilled comprehenders learned more words because they have better ability to retain both episodic and semantic aspects of the new word. It is clear from this study that the brain of skilled comprehenders showed differential ERP patterns from the brain of less-skilled comprehenders in a task that requires learning meanings of rare words, a task similar to the one that was employed in this dissertation.

A study conducted with toddlers also found differential ERP components distribution in high vocabulary comprehenders compared to the low comprehenders; that is, more bilateral for novel words and more left-lateralized for familiar words only for high comprehenders, while low comprehenders showed bilateral distribution for all stimuli (Mills et al., 2005). The abovementioned studies on adults and toddlers thus seemed to indicate that differences in brain ERP distribution for skilled and less skilled comprehenders emerged early in life, and these differences were also observed when adults were tested.

If indeed the right hemisphere plays a role in new meaning acquisition, as was found, albeit weakly, in studies by Ince and Christman (2002), then it could be predicted that people who are better comprehenders will show less hemispheric asymmetries in learning new words due to the increased performance of the right hemisphere. In other words, better right hemisphere functioning may lead to a better acquisition of new words,

and an accumulation of such processes may lead to better vocabulary and comprehension skills.

Experiment 1

The current study aimed to study the hemispheres' differential roles in semantic acquisition of new words, taking into consideration the amount of experience that the subjects had with the new words and their reading comprehension skill. The current study investigated whether the number of experiences with a novel word influences which hemisphere plays a larger role in semantic acquisition. Bolger, Balass, Landen, and Perfetti (2008) had found in their studies on instance-based learning that variation in the learning contexts for rare words led to better learning of these words. The current project investigated how varying of the amount of context for learning new words may modulate the way that these new words were processed by each hemisphere.

This study was conducted across two consecutive days. Tasks were given as follows: Nelson-Denny Reading Test, encoding phase, acquisition test phase, and semantic relatedness judgment test. In the encoding phase, the participants were required to learn a set of newly-created words and their meanings ('Lingo'). The encoding phase was not lateralized to make sure it was closer to the actual experiences of new word learning.

The use of an encoding task that involved learning newly-created words had some advantages. First, it used stimuli that subjects had never been exposed to. Second, previous studies had utilized regular English words and rare English words as their stimuli, which meant these words had previously established representations in the mental lexicon

(and in case of rare English words, the concepts that they represented may be familiar to subjects even though subjects could not relate the concept to a specific English term). Using completely new words and meanings in this study had the advantage of being able to control for prior experience with the words. This ensured that all stimuli started at the same level of familiarity, both for the terms themselves and the concepts they represented.

Regarding the task used for the testing phase, previous experiments done by the author using lateralized lexical decision failed to show much evidence for right hemisphere advantages in tasks that were predicted to show such advantages. It could be that the lexical decision task was not sensitive enough in gauging semantic-based processing of words that were newly-learned. Therefore, in order to gauge how newly-acquired word meaning was modulated by hemispheric processing style, a lateralized semantic relatedness judgment task was used.

There were two major aims of the current project. First, to study the hemispheres' differential roles in semantic acquisition of new words, taking into consideration the differential amount of experience that the subjects had with the new words. Second, to examine how the level of comprehension ability as tested by the Nelson-Denny reading test may be correlated with hemispheric processing of newly acquired words.

The following sections will explicitly lay out the hypotheses.

Hypotheses on Coarse-Fine Coding Style of the Hemispheres

The theoretical proposal that this hypothesis tests, is the coarse vs. fine coding style of the hemispheres. It is proposed that the right hemisphere coarse-coding style is advantageous in conditions where words are newly learned. These words will not have strong semantic connections yet due to the recency of their acquisition. The coarse coding style may facilitate early word meaning acquisition because it does not require close semantic connections to have been made to process the stimuli. In contrast, the left hemisphere fine coding style requires close semantic connections to have been made for processing to be executed efficiently, and this level of semantic connections should be acquired later. Based on these theoretical points, the following predictions can be made with regard to novel words that are experienced less (i.e., 2x) and that are experienced more (i.e., 8x).

It is predicted that in the less experience (2x) condition, the typical rvf/LH advantage will be reduced, or even eliminated. Due to the minimal amount of experience, it can be assumed that few semantic connections are formed by this point. Therefore, the left hemisphere fine-coding style may not be advantaged, while the right hemisphere coarse-coding style may afford it some edge in processing less-experienced words. In terms of the hemispheric asymmetry, **it is predicted that there will be less hemispheric asymmetry in less experience, compared to the more experience, condition.**

Better overall performance is expected in the more experience condition than in less experience, for both rvf/LH and lvf/RH. However, the rate of improvement is pre-

dicted to differ by hemisphere. The fine coding style of rvf/LH coupled with the increased experience with the individual novel words will afford rvf/LH greater improvement in performance. It is expected that the lvf/RH will show improvement, but it is not as much as shown by the rvf/LH, because at this point, the novel word has grown much more familiar, more semantic connections may have been made, and thus the rvf/LH fine coding style may have a peak processing advantage. **Thus, there will be larger hemispheric asymmetry in the more experience compared to less experience, due largely to greater LH improvement.**

Qualitative vs. Quantitative Hypothesis

Alternative hypotheses were also formed based on the qualitative and quantitative hypotheses. *The qualitative hypothesis* asserted that left-lateralization of new vocabulary is associated with brain maturation processes that occur during childhood. **Adults have mature brains, therefore, if qualitative hypothesis is supported, then we should see that newly-learned words have LH advantages (accuracy and RT) regardless of the amount of experience with words.**

The quantitative hypothesis asserted that left-lateralization of new vocabulary is associated with increasing experience with individual words. In other words, it asserted that words that have had less exposure to a person will be right-lateralized. The words become more and more left-lateralized as they are experienced more. **Therefore, if the quantitative hypothesis is supported, then we should see that Lingo terms with less experience will have a right hemisphere advantage, while Lingo words with more**

experience will have a left hemisphere advantage. The quantitative hypothesis is similar to those of the coarse-fine coding style hypothesis. This indicates that there may be some degree of flexibility in terms of the hemispheric processing of words. It seems that the coarse-fine coding style hypotheses describes the mechanism of processing in each hemisphere, and these differential hemispheric mechanisms can provide the basis for shifts in processing due to the quantity of experience. In other words, the underlying theme for both quantitative hypothesis and coarse-fine coding style hypotheses is the progression of lateralization from one hemisphere to the other depending on the amount of experience with the stimuli.

Hypotheses on Individual Differences

The hypothesis based on individual differences predicted that **an increased performance of the RH will lead skilled comprehenders to have less hemispheric asymmetry compared to less-skilled comprehenders in less experience condition.**

It is predicted that skilled comprehenders will perform better than less-skilled comprehenders, indicating that better right hemisphere functioning may lead to a better acquisition of new words, and an accumulation of better acquisition of new words leads to better vocabulary and comprehension skills.

On the other hand, in the more experience condition, when the words become more familiar, it is predicted that there will be an increased left lateralization for both skilled and less-skilled comprehenders. This is due to the fine coding style of the left hemisphere will give it an edge in processing words with more familiarity. However, the

left lateralization will be more pronounced in the skilled comprehenders; thus, **in more experience condition, there will be more hemispheric asymmetry in skilled compared to less skilled comprehenders.**

Therefore, it is predicted that skilled comprehenders will show differential hemispheric advantages depending upon the amount of experience with the words. In skilled comprehenders, each hemisphere will be able to perform at its peak depending on the amount of experience with words. Thus, RH advantage will be found in less-experienced words, and LH advantage in more-experienced words. On the other hand, less-skilled comprehenders may not show such differential hemispheric advantages to the extent showed by skilled comprehenders, due to possible less efficient distribution of hemispheric processing in less-skilled comprehenders.

Two statistical analyses analyzed individual differences. A median-split analysis divided subjects into two groups: comprehenders that score above the median (skilled comprehenders) vs. comprehenders that score below the median (less-skilled comprehenders). ANOVA analyses were then conducted comparing the two different groups.

Hypotheses are also formulated for each visual field. **It is predicted that in lvf/RH, a significant interaction between amount of experience and comprehension skills will be found.** The skilled comprehenders may be at the peak of RH processing, while less-skilled may not be. This may lead skilled comprehenders to perform much better than less-skilled in less experience condition; thus, large performance difference between the two skill groups in less experience condition. On the other hand, the perform-

ance difference between the two skill groups may be smaller in the more experience condition because additional experience with new words may help the RH of less-skilled to do better.

It is predicted that such interaction between amount of experience and comprehension skills will also be observed in the rvf/LH. The LH of skilled comprehenders is better than the LH of less-skilled comprehenders. Both will be influenced in the same way by the amount of experience. In less experience condition, minimal experience with words is predicted to lead both the LH of skilled and less-skilled to be unable to perform at its peak. In more experience condition, increased experience with words will benefit the fine coding style of the LH of both skill groups. However, due to possible better LH performance for skilled comprehenders, skilled comprehenders may afford a much greater improvement in more experience condition compared to less-skilled, and this may lead to larger performance difference between the two groups in more experience condition.

Correlational analyses will also be conducted between hemispheric asymmetries for less experience stimuli and reading comprehension scores, and between more experience stimuli and reading comprehension scores. **It is predicted that stronger negative correlations between performance on reading tests and the hemispheric asymmetry will be found for less-experienced words than for more-experienced words.** This prediction is made considering the possibility that skilled comprehenders may have more efficient right hemisphere processing of newly-learned words, and this may lead to the

right hemisphere of skilled comprehenders to benefit in processing less experience words. This benefit may help reduce hemispheric asymmetry for skilled comprehenders in processing less experience words. On a different note, skilled comprehenders by definition will perform better on the comprehension test than less-skilled comprehenders. Therefore, the prediction is that as the reading comprehension scores increase, hemispheric asymmetry will decrease for the less experience words.

Method

Participants

Experiment 1 included 48 participants, with equal number of males and females. Participants were native English speaking, right-handed UCR students recruited through introductory psychology classes. The participants received course credit for participation. All had normal or corrected-to-normal vision. Handedness was assessed by a five-item preference questionnaire (Bryden, 1982) which yields a handedness index that ranges from +1.00 (extremely right-handed) to -1.00 (extremely left-handed). Average handedness was +0.78.

Design

This experiment utilized a 2x2x2 within subjects design. The independent variables were: the amount of experience (2x vs. 8x), visual field of stimulus presentation (L vs. R), and the type of response in the semantic judgment test (related vs. unrelated). The dependent variables were accuracy and correct reaction times.

Materials

The stimuli were taken from previous studies that the author has conducted with some modifications. One hundred and twelve words were selected from the MRC Psycholinguistic Database (Coltheart, 1981). These words were highly imageable (range from 400-700) nouns, minimum 1 in Kucera frequency (Kucera & Francis, 1967), and consisted of 3-6 letters. Lingo words were created by replacing one letter in each of these words to form a pronounceable string that was not an English word. The position of the letter replaced varied from word to word, with each letter position changed equally often.

The 112 Lingo words were presented to 36 subjects (18 females) in a norming study to ensure that these were not actual (rare) English words known by undergraduates. The Lingo words were presented on a computer. The subject was given question on the computer screen in the following format: “Is VESDEL an English word?” The subject had to choose an answer by using a mouse to click a button on the screen for “Yes” or “No.” The Lingo words were randomly intermixed with actual, rare, English words (e.g., “AVULSE”) and some relatively more familiar English words (e.g., “ABDOMEN”) to prompt the subjects to think about their response carefully. The rare English words were taken from the website: <http://phrontistery.info/f.html>.

Seventy-two Lingo items were chosen as experimental stimuli, having been judged to be English words by less than 12% of norming participants. These 72 Lingo words originated from English words which had an average image rating = 564.13, average Kucera frequency = 16.60, and average number of letters = 4.6.

Each of these 72 Lingo words was paired with four related definitions. Some definitions were created by the experimenter based on the criteria of simplicity and uniqueness. Others were created by looking up definitions of words that currently are rarely used from *An Etymological Dictionary of Modern English* (Weekley, 1921). These definitions were short and easily understandable. An example of a definition was “*VESDEL is a poisonous plant that tickles its victims.*” For each definition two questions were created, a Yes question and a No question. For example, “*Does a VESDEL have roots that help it grow?*” and “*Is a VESDEL made of recycled paper products?*” Each Lingo word had one primary definition and three additional definitions to provide greater semantic richness and context; thus, it provided better ecological approximation of the actual word-learning environment. Additional definitions were created by varying the primary definition of Lingo. Across definitions, Lingo words were presented in a varied position: at the beginning of the definition and toward the end of the definition (e.g.: *VESDEL is a poisonous plant that tickles its victims. Alternatively: A poisonous tickling plant like VESDEL needs to be avoided*). The length of the definitions ranged from 6-15 words. The length of the questions ranged from 4-13 words. Examples of definitions and questions are provided in *Appendix A*.

Another norming study was conducted to identify an English word that people found to be most related to each Lingo word and definition, for use in the semantic relatedness judgment test. Forty-four native speakers of English (23 females) took part in this second norming study. None of these subjects had participated in the previous norming

study. Each subject was presented with a Lingo word and its primary definition on a computer screen, and the subject was instructed to type the first word that came to their mind as quickly as he/she could. After the subject finished typing his/her response, the subject clicked a button on the computer screen, and the next Lingo word and definition would appear.

The most frequent response for each Lingo word was selected (on average 11 subjects gave the most frequent response, with range = 4 - 33). If the English word having the most frequent response turned out to have been present in any of the definitions for that particular Lingo word, then the Lingo definition was revised. This was to make sure that no definition included the English word that was used later in the semantic relatedness test.

Seventy-two related English words were selected through the norming, a majority being nouns. Each Lingo stimulus was then randomly re-paired with an English word from the pool of 72 English words; thus creating unrelated Lingo-English pairs. Across all experimental lists, each Lingo was paired with both related and unrelated English words. *Appendix B* contains all 72 Lingo items with their primary definitions and related English words.

In the encoding phase, there were four experimental lists in order to counterbalance the amount of experience (2x vs. 8x) and the order of the Yes/No question (Day 1: Yes; Day 2: No vs. Day 1: No; Day 2: Yes) without repeating the same question for a given subject. In the acquisition test, there were two experimental lists counterbalanced

based on the amount of experience (2x vs. 8x). In the semantic relatedness judgment test, there were a total of eight experimental lists. Lingo stimuli were counterbalanced based on the amount of experience (2x vs. 8x), visual field of presentation (L vs. R), and relatedness with the English word (related vs. unrelated). Across all lists, each Lingo stimulus appeared in each different condition.

Apparatus & Procedure

The experiment was conducted across 2 successive days. No subject had participated in any of the previous norming studies. Each subject was tested individually in a dimly-lit experiment room. All stimuli were presented in black on a white background, using a bold 22-point Helvetica font. Word stimuli were shown in uppercase, while sentence stimuli had only the first letter of the first word capitalized. The Psyscope software package for Mac OS X (<http://psy.cns.sissa.it>) (Cohen, MacWhinney, Flatt, & Provost, 1993) was used to control stimulus presentation, regulate the timing of events, and record subjects' responses. Participants were seated 60 cm in front of an Apple Studio 9217 display. A headrest was used to stabilize head position. Power Mac G4 computers were used for stimulus presentation. The subjects registered their response by pressing a color-coded button on a buttonbox (ioLab Systems). The buttonbox was placed on the right side of the table in a comfortable location for responding. The subjects used their right index finger to press one button, and right middle finger to press the other button. Half the subjects had reverse mapping for the response.

Day 1

Upon arrival in the lab, the subject was instructed to fill out some administrative paperwork (i.e., informed consent, language history, and handedness questionnaire). Next, the subject was given the Nelson-Denny reading test (Brown, Fishco, & Hanna, 1993). The reading test took approximately 35 minutes to complete. The test includes measures of vocabulary and reading comprehension.

Next, after a short break, the encoding phase of the experiment began. In this phase, the subject was told that he/she would learn new words and definitions from a new language called *Lingo*. He/she was required to learn the new words and associated definitions.

There were a total of 72 Lingo and definitions to be learned in four experimental blocks. Two practice blocks preceded the experimental blocks. The first practice block had two trials, and the second had eight trials. These were conducted to ensure the subject's understanding of the procedure. Previous studies by the author had shown that 72 new words could be sufficiently learned in our experimental paradigm. To manipulate the amount of experience for each stimulus, 36 Lingo were repeated eight times in encoding across the two days (4 presentations per day). The other 36 Lingo were only repeated twice across the two days (one presentation per day). To vary the amount of semantic context between the 2x (less experience) and the 8x (more experience) conditions, the 2x Lingo had the primary definition shown twice (once per day). The 8x condition had the primary and the three additional definitions presented on the first day, and these were re-

peated the following day (see *Appendix A* for examples). The presentation of the four definitions was randomized each day, and the primary definition was not always presented first. The participants saw a total of 180 Lingo/day, 45 trials per experimental block.

On each encoding trial, the Lingo word was presented for 2000 ms at the center of the screen. Immediately following, the definition of the Lingo word was presented (e.g., *VESDEL is a poisonous plant that tickles its victims*) for 5000 ms. The subject was instructed to read and comprehend the sentence. The subject was asked to associate the Lingo word to its definition using whatever strategy he/she needed to learn a new word and its definition.

After the sentence disappeared, a Yes/No question about the new word was shown to encourage learning. For example: *Does a VESDEL have roots that help it grow?* The participant was instructed to press the response button as quickly and accurately as possible to indicate their Yes/No answer. The timeout was 5500 ms. Inter Trial Interval (ITI) was 800 ms. Day 1 session took approximately 2 hours.

Day 2

When the subject arrived for his/her Day 2 experimentation, he/she was asked to do the same encoding phase as Day 1. The order of stimulus presentation was randomized. A Lingo word and definition that was paired with a Yes question on Day 1 would be paired with a No question on Day 2, and vice versa. After the encoding phase, the subject took a short break. Then, the subject completed an acquisition test to assess their learning.

The acquisition test included only the primary definition of each Lingo item. There was one practice block with 10 trials and 2 experimental blocks, each with 36 trials. The primary definition of Lingo in the form of a question was presented in the center of the screen, along with two previously-learned Lingo words as possible answers. The two Lingo words were positioned one above the other in the center of the screen, right below the question. One Lingo stimulus was the correct referent and the other was a foil. The question and the choices were present on the screen until the subjects made their response. The subject was instructed to respond as quickly and accurately as possible by pressing a button to indicate which of the two Lingo stimuli correctly referred to that definition. The timeout was 8000 ms. Intertrial interval (ITI) was 800 ms.

After a response was made, feedback was presented (Correct, Error, or Timeout) on the computer screen for 1000 ms. Then, the correct definition was presented regardless of the subject's response for 5000 ms. This was to ensure the subject received proper feedback and learned the Lingo and meanings.

Next, the semantic relatedness judgment test was administered following a short break. There were 2 practice blocks (first practice block had 8 trials, and the second had 12 trials), and 2 experimental blocks (each with 36 trials).

The semantic relatedness judgment test proceeded as follows:

First, a plus sign in black 22-point Helvetica-font was displayed in the center of the screen for 200 ms. An English word followed 100 ms after the plus sign in uppercase in the center of the screen, slightly above the plus sign. The English word stayed on the

screen while a fixation procedure which included a series of 3 plus signs in 22-point Helvetica were then presented rapidly one after another (first plus sign was black for 150 ms, second was red for 100 ms, and third was black for 100 ms). The overall fixation procedure gave a perception of a flickering plus sign in the center of the screen. The plus sign remained on the screen when later the Lingo target was displayed. The English word stayed on the screen for a total of 1500 ms, and was on the screen when the lateralized Lingo target was displayed. The Lingo target was presented in uppercase, 400 ms after the start of the plus sign either in the lvf/RH or the rvf/LH for 125 ms. The SOA was 1375 ms. The eccentricity of the Lingo word was 1.86° from the inner edge of the string to the fixation marker, and subtended 0.50° of vertical visual angle and 1.14° - 2.57° of horizontal visual angle. The subject was instructed to focus his/her gaze on the plus sign in the center only, read the English word carefully, and decide if the following Lingo word was related in meaning to the English word.

The subject was instructed to press one button for “yes, the two are related” and the other button for “no, the two are not related.” The subject was informed that the two words (English – Lingo) are associatively related if the meaning of the two words can go together (i.e., can be associated together). Examples were provided to the participants to ensure proper understanding. The examples were Lingo and English pairs, taken from the examples given during the Encoding session. The subject was instructed to respond as quickly and accurately as possible. The timeout was 4000 ms after the onset of the target. Intertrial interval (ITI) was 1800 ms.

In the semantic relatedness test, there were a total of 72 Lingo, half from the 8x condition (i.e., richer semantic context), and the other half from the 2x condition (i.e., less semantic context). There were 18 trials per experience condition per VF. The experimenter monitored the subject's performance via an additional monitor located outside the experiment room. This was to ensure the subject understood the instructions and performed appropriately.

After finishing the semantic relatedness test, the subject was given a debriefing and thanked for their participation. The Day 2 session lasted for approximately 1.5 hours.

Results

The results of accuracy and reaction time analyses for Experiment 1 are reported in the following order: encoding, 2-AFC acquisition test, semantic relatedness judgment test (basic results without reading skill implemented in the analyses), semantic relatedness judgment (incorporating reading skill in the analyses), and correlational analyses.

Encoding

Two-way ANOVAs were performed on amount of experience with Lingo (2x and 8x) and the type of answer (Yes and No).

For accuracy, the main effect of amount of experience was not significant, $F < 1$. The main effect of answer type was significant, $F(1,47) = 13.39$, $p < 0.01$. No questions had higher accuracy than Yes questions (95.53% vs. 93.38%). The interaction between amount of experience and answer type was not significant, $p > 0.10$.

For reaction times, the main effect of amount of experience was significant, $F(1,47) = 30.77, p < 0.01$. The reaction times for the 8x condition were faster than 2x condition (2056 ms vs. 2182 ms). The main effect of answer type was significant, $F(1,47) = 33.26, p < 0.01$. The reaction times for No answer were faster than Yes answer (2061 ms vs. 2177 ms). The interaction between amount of experience and answer type was not significant, $F < 1$.

Acquisition Test

The accuracy range of the acquisition test was from 68% - 100%, with an average of 86% correct. One-way ANOVAs were performed examining the amount of experience. For accuracy, the main effect of amount of experience was significant, $F(1,47) = 136.55, p < 0.01$. The words that were experienced more had significantly higher accuracy than words that were experienced less (94.49% vs. 76.59%). For reaction times, the main effect of amount of experience was significant, $F(1,47) = 178.23, p < 0.01$. Words that were experienced more were responded to faster than words that were experienced less (2205 ms vs. 2765 ms).

Semantic Relatedness Judgment

Preliminary ANOVA analyses were conducted examining relatedness condition (Related and Unrelated) and it was found these trials did not significantly differ; therefore, this condition was collapsed in further analyses. Two-way ANOVAs were conducted on the amount of experience (2x and 8x) and visual field (lvf/RH and rvf/LH).

For accuracy, the main effect of amount of experience was significant, $F(1, 47) = 53.67$, $p < 0.01$. More-experienced words had higher response accuracy than less-experienced words (73.92% vs. 60.38%). The main effect of visual field was not significant, $p > 0.10$. The interaction between the amount of experience and visual field was not significant, $F < 1$.

For reaction times, the main effect of amount of experience was significant, $F(1, 47) = 19.96$, $p < 0.01$. More-experienced words were responded to faster than less-experienced words (1201 ms vs. 1320 ms). The main effect of visual field was not significant, $F < 1$. The interaction between the amount of experience and visual field was not significant, $p > 0.10$.

Semantic Relatedness Judgment & Nelson-Denny Reading Test (Reading Comprehension Subtest)

A median-split based on the reading comprehension subtest scores was performed to divide the participants into two different skill groups. The less-skilled group comprised of twenty-four participants (10 females), with a mean score of 31 and a range from 1-48. The skilled group consisted of twenty-four participants (14 females), with a mean score of 73, and a range from 50-98. A histogram of the distribution of reading comprehension scores is presented in Figure 1.

Three-way ANOVAs were conducted on visual field (lvf/RH and rvf/LH), skill group (skilled and less-skilled), and amount of experience with new words (2x and 8x).

The means and standard deviation for accuracy are presented in Table 1, and for reaction times in Table 2.

For accuracy, the main effect of skill was not significant, $p > 0.1$. The main effect of amount of experience was significant, $F(1,46) = 62.68$, $p < 0.01$, as the 8x condition had higher accuracy than 2x condition (72.92% vs. 60.38%). The main effect of visual field was not significant, $p > 0.1$. The only significant interaction was experience x skill, $F(1, 46) = 8.89$, $p < 0.05$. Further analyses found that the skill difference was not significant in the 2x condition, $F < 1$, but was significant in the 8x condition, $F(1,46) = 6.75$, $p < 0.05$, with skilled comprehenders having higher accuracy than less-skilled comprehenders (78.17% vs. 69.66%). Skilled comprehenders significantly improved their performance from 2x to 8x condition, $F(1,46) = 43.21$, $p < 0.01$, an improvement from 59.53% to 78.17% (19 points improvement). Less-skilled comprehenders also significantly improved their performance from 2x to 8x condition, $F(1,46) = 8.14$, $p < 0.05$, an improvement from 61.23% to 69.68% (9 points improvement). The interaction is displayed in Figure 2, and indicates a greater benefit from increased experience for skilled, relative to less skilled, participants.

For reaction times, the main effect of skill was not significant, $F < 1$. The main effect of amount of experience was significant, $F(1,46) = 19.54$, $p < 0.01$, 8x condition was faster than 2x condition (1201 ms vs. 1320 ms). The main effect of visual field was not significant, $F < 1$. There were no significant interactions.

Two-way ANOVAs (skill by amount of experience) were then conducted for each visual field to test a priori predictions about hemisphere differences for new word acquisition.

LVF/RH

For lvf/RH accuracy, the main effect of skill was significant, $F(1,46) = 5.80, p < 0.05$. Skilled comprehenders had significantly better accuracy than less-skilled comprehenders in the LVF (69.28% vs. 63.32%). The main effect of amount of experience was significant, $F(1,46) = 28.05, p < 0.01$. Words that were experienced 8x had significantly better accuracy than words were experienced 2x (72.39% vs. 60.22%). The interaction between amount of experience and skill was significant, $F(1,46) = 4.42, p < 0.05$. Further analyses confirmed that there was no significant skill difference in 2x condition, $F < 1$. There was a significant skill difference in 8x condition, $F(1,46) = 9.01, p < 0.01$. Skilled groups had significantly better accuracy than less-skilled (77.78% vs. 66.99%). This interaction is presented in Figure 3a.

For lvf/RH reaction times, the main effect of skill was not significant, $F < 1$. The main effect of amount of experience was significant, $F(1,46) = 11.11, p < 0.01$. The more experienced (8x) words were responded to faster than the less experienced words (2x) (1216 ms vs. 1311 ms). The interaction between amount of experience and skill was not significant, $F < 1$.

Therefore in the lvf/RH, the skill groups differed in accuracy when the new words had experienced more, and not when the new words received minimal experience.

RVF/LH

For rvf/LH accuracy, the main effect of skill was not significant, $F < 1$. The main effect of amount of experience was significant, $F(1, 46) = 34.13, p < 0.01$. Words that were experienced more (8x) had significantly higher accuracy than words that were experienced less (2x) (75.46% vs. 60.55%). The interaction between amount of experience and skill was significant, $F(1,46) = 4.43, p < 0.05$. As shown in Figure 3b, less-skilled comprehenders had higher accuracy than skilled comprehenders in 2x condition, and skilled comprehenders had higher accuracy than less-skilled in 8x condition; however, none of these pairwise contrasts was significant.

For rvf/LH reaction times, the main effect of skill was not significant, $F < 1$. The main effect of the amount of experience was significant, $F(1,46) = 16.06, p < 0.01$. Words that were experienced more were responded to faster than words that were experienced less (1185 ms vs. 1329 ms). The interaction between the amount of experience and skill was not significant, $F < 1$.

Therefore in rvf/LH, skilled comprehenders tended to have worse accuracy than less-skilled comprehenders when there was minimal experience with new words, and the opposite pattern was observed when the experience with new words increased, even though none of these pairwise contrasts was significant.

Correlational Analyses

Correlational analyses were then performed to examine the relationship between hemispheric asymmetry and comprehension scores on the reading test, for each experi-

ence condition. For accuracy asymmetry, Lambda Z was the asymmetry index that was used (Chiarello, Welcome, Halderman, Julagay, Towler, Otto, & Leonard, 2009). For reaction times asymmetry, the standard asymmetry index was used (Chiarello et al., 2009). For asymmetry, a larger number indicates greater left hemisphere advantage.

No significant correlations were observed.

Discussion

This experiment was designed to test hypotheses generated from two theoretical frameworks: coarse-fine coding and the qualitative-quantitative proposition. I will first discuss predictions based on the full sample, and then consider findings relevant to the individual differences predictions.

The coarse-fine coding proposition of hemispheric processing style proposed that the left and right hemispheres have unique processing mechanisms. According to this proposal, coarse coding enables the right hemisphere to maintain a broad array of meanings of a word, activating a larger semantic field related to a stimulus presented to it (Beeman & Chiarello, 1998). This style of processing may be advantageous in the processing of newly-acquired words and meanings, that, by definition, do not yet have strong semantic connections. The right hemisphere coarse coding style may enable newly-learned words and meanings to form weak connections with other words in the network, and these connections may grow stronger over time through repeated experience.

The left hemisphere, on the other hand, is proposed to have a different style of processing. Fine coding style is benefited in the processing of the most relevant meaning

of a word, and it is proposed to be adept at picking up close semantic relationships. This style of processing may not have an edge in processing of newly-acquired words, which by definition will not yet have strong semantic relations with other words in the network. This processing will show benefits for more familiar words, due to the availability of rich semantic connections established by substantial experience with words.

Based on the coarse fine coding proposition, it was predicted that there would be less hemispheric asymmetry in the less experience (2x), compared to more experience (8x) condition, because in the less experience condition, there will be only weak semantic connections formed by this point, and this may not benefit left hemisphere fine coding, while it may benefit right hemisphere coarse coding style. On the other hand, it was predicted that there would be larger left hemispheric asymmetry in the more experience, compared to less experience, condition because in the more experience condition, increased experience with novel words would permit fine coding to improve performance. The lvf/RH will show improvement, but not as much as shown by the rvf/LH, because at this point, the novel word has grown more familiar, more semantic connections may have been made, and thus the rvf/LH fine coding style may have a peak processing advantage.

The coarse fine coding hypotheses were not confirmed. There was no significant interaction between visual field and amount of experience for either accuracy or reaction times, for the sample as a whole. This means that the amount of experience with words did not make a significant difference in influencing hemispheric processing when analyses were done on the entire sample. The right hemisphere did not benefit in the less expe-

rience (2x) condition, and the left hemisphere did not benefit in the more experience (8x) condition.

Hypotheses were also made based on the qualitative and quantitative propositions of lateralization of language. The qualitative hypothesis argues that left lateralization of language is related to brain maturation processes that occur during childhood. Adults have mature brains; therefore, all word processing should be done more efficiently by the left hemisphere. This hypothesis predicted that no matter how much experience adult subjects have with the new words, left hemisphere advantages will occur. On the other hand, the quantitative hypothesis argues that left lateralization of words depends on the amount of experience that the subjects have with each new word. It was predicted that words that have less experience should have a right hemisphere advantage, while words that are experienced more will have left hemisphere advantages. When analyses were done on the full sample, there was no evidence to support any of these hypotheses because hemisphere differences were not observed in any condition.

Individual Differences Analyses

Skilled and less-skilled comprehenders indeed showed differential performance in each visual field. Studies have shown that skilled and less-skilled comprehenders have differential ERP patterns (i.e., stronger N400 and P600 for skilled comprehenders) when learning rare words (Perfetti et al., 2005), and that the presence of variable context helped learning of new meanings and this was related to reading comprehension skill; i.e., better learning by better comprehenders (Bolger et al., 2008). Those studies clearly showed that

baseline comprehension skill influenced performance on word learning tasks, with skilled comprehenders performing better than less-skilled.

In the current experiment, when individual differences (i.e., the skilled vs. less-skilled groups based on median split of the reading comprehension test) were examined, it was predicted that skilled comprehenders would obtain increased performance of the right hemisphere in the processing of less-experienced words (i.e., coarse coding may be more efficient in the skilled comprehenders). This may produce *less* hemispheric asymmetry for more skilled, compared to less-skilled, comprehenders in the less experience condition. In more experience condition, left hemisphere fine coding was expected to benefit the processing of more-experienced words (at least for more skilled comprehenders, thus leading to a more efficient processing of the more experienced words). Hence, skilled comprehenders should have *more* hemispheric asymmetry compared to less-skilled comprehenders in the more-experienced condition. This prediction was not confirmed in the overall analysis because there was no significant three-way interaction of skill, visual field, and amount of experience.

However, when planned comparisons examined each visual field independently, a significant interaction between amount of experience and skill in the lvf/RH was observed, as well as a main effect of skill. Although it was found that there was no skill difference when the words were experienced less, skilled comprehenders did significantly better than the less-skilled for lvf/RH trials only when the words were experienced more. This suggests that the right hemisphere of the skilled comprehenders was able to show

increased benefit from more extensive experience with words. Even the purportedly more efficient coarse coding of the skilled comprehenders seemed to require more than minimal familiarity with the new words.

In terms of the rvf/LH, it was predicted that there would also be a significant interaction between amount of experience and skill. The LH of skilled comprehenders was predicted to be better than the LH of less-skilled comprehenders. However, both will be influenced in the same way by the amount of repetition. In less experience condition, minimal experience with words is predicted to lead both the LH of skilled and less-skilled to be unable to perform at its peak. In the more experience condition, increased experience with words will benefit the fine coding style of the LH of both skill groups. Due to possible better LH performance, skilled comprehenders may perform much better than less-skilled in more experience condition; thus, larger performance difference between the two groups in more experience condition.

For accuracy, it was found that there was a significant interaction between amount of experience and skill: less-skilled comprehenders tended to do better than skilled comprehenders when there was less experience with words, and the opposite pattern was observed when the experience with words increased. However, none of the pairwise contrasts was significant. Interpretation of this finding will be postponed pending the results of Experiment 2.

From the summaries presented above, it appears that coarse-fine coding may not be the best-fit explanation for the results. Interesting individual differences results

emerged when analyses were conducted per visual field. The right hemisphere of skilled comprehenders was able to outperform the right hemisphere of the less-skilled readers only after more experience with the new words. A richer context and more experience with new words appeared to enhance right hemisphere processing for skilled comprehenders. This way of processing information by the right hemisphere (i.e., advantage in richer context and more experienced condition relative to poorer context and less experienced condition) is the opposite of what the coarse coding would predict. Coarse coding would predict an advantage of the right hemisphere in processing newly-acquired words, particularly when the new words have been experienced only a few times, by assisting these words in forming more connections in the semantic network. Apparently, the right hemisphere of the skilled comprehenders was better able to make use of the somewhat richer experience relative to the less-skilled. Or perhaps the current operational definition of “less experienced” and “more experienced” was not adequate. A right hemisphere advantage may not appear at the earliest stage of word acquisition, but it may appear when experience is somewhat greater.

Further experimentation is needed to determine whether or not the coarse fine coding proposition would fare better when the amount of experience with words is different from what was presented in the current experiment (2x vs. 8x). It could be that when the experience with words is greatly increased (e.g., highly-familiar English words), left hemisphere fine coding could process the stimuli more optimally. This was addressed in Experiment 2.

Even though the results did not provide clear support for the coarse fine coding proposition, the results may indicate that the right hemisphere is indeed important in word meaning acquisition, as shown by the current finding that the right hemisphere showed a significant difference between the two skill groups when words and meanings were experienced more. This was not seen in the left hemisphere.

The findings of the current experiment thus showed some differences in the way the left and right hemisphere process new words, albeit not a huge difference. This may be taken to support the notion that the left hemisphere is *not* the only hemisphere involved in language acquisition, even for mature brains. This provides weak support for the quantitative proposition, which allowed for some flexibility in the way the hemispheres process new words (i.e., new words are processed more bilaterally, and as experience with these words increases, processing of these words will be lateralized to the left). It could be that the 8 exposures in this experiment did not reach the level of familiarity that would allow the left hemisphere to dominate processing. Also, it is important to note that the second day presentation of Lingo and the definitions cannot benefit from memory consolidation during sleep.

The results suggested a right hemisphere that is proficient in learning new words and meanings (at least in skilled comprehenders) and it is able to use context information to boost its performance, while left hemisphere performance failed to significantly differentiate skilled from less-skilled comprehenders. This does not seem to be in line with the view obtained from imaging studies. An fMRI study examined the learning of novel vo-

cabulary through associative pairing (Breitenstein, Jansen, Deppe, Foerster, Sommer, Wolbers, & Knecht, 2005). The learning took place in 5 training blocks, each pseudoword appeared 10 times with a particular picture (associative pairing) across the five training blocks. The results showed that increased vocabulary proficiency was correlated with increased activity in the left inferior parietal cortex, and successful acquisition of new lexicon depended on correlational amplitude changes between the left hippocampus and neocortical regions (Breitenstein et al., 2005). Wong, Perrachione, and Parrish (2007) presented participants with pairs of pictures and pitch patterns (e.g., a picture of dog paired with “pesh” spoken with a rising tone), and asked the participants to learn the pitch pattern and the vocabulary, which was novel to these participants. The training was conducted over three to four sessions per week. Each session required the subjects to learn 6 artificial words, with 3 pitch patterns for each word. Therefore, there were a total of 18 words to be learned each session, each with its own pitch pattern and a corresponding picture. The same pairings were presented in later sessions. A participant was determined to have reached the training threshold when he/she performed at 95% accuracy rate or there was not 5% or more improvement for four consecutive sessions.

After they reached the threshold, participants were scanned as they discriminated the pitch patterns they had learned. This study showed that successful learners’ novel pitch patterns were associated with increased activation in the left posterior superior temporal gyrus, while less successful learners had increased activation in the right superior temporal region and right inferior frontal gyrus (Wong et al., 2007). Research also has

shown the role of the left inferior temporal cortex in semantic processing in reading, and when comparing familiar and novel words, there was more activation in the left inferior temporal cortex for novel words (see Price, 2000).

Therefore, the imaging studies have demonstrated a critical role of left hemisphere structures in the process of word learning, with more recruitment of the right hemisphere by people who were less successful learners. The imaging studies above found critical roles of left hemisphere structures in the process of word learning after the participants obtained approximately the same amount of experience as those in the current study (i.e., 10 times as in Breitenstein et al., 2005), and after the participants obtained considerably more experience with the new stimuli (over the course of 3-4 sessions per week, as in Wong et al., 2007) than the participants in the current experiment. The findings of left hemisphere benefits in more experience stimuli in neuroimaging paradigms contrasts with the current behavioral study, which showed more of the right hemisphere benefit in using richer context to learn new words, at least for skilled comprehenders.

This possible dissociation between imaging and behavioral results is intriguing. It is very likely that the different paradigms and stimuli used in imaging and behavioral studies may contribute to the seemingly opposite findings. It is also possible that the threshold used in imaging studies to decide if a structure is considered to be “activated” may not be low enough to capture possibly weaker right hemisphere activations. Furthermore, the methodology used by the researchers (e.g., ROI – Region Of Interest) may

not put an emphasis on activation in the right hemisphere. The current behavioral study examined the accumulation of activity across the brain. Therefore, the results of the orchestrated effort by various parts of the right hemisphere may emerge in a behavioral study as an advantage for the left visual field.

Experiment 2

One curious result of the current project was the lack of a rvf/LH advantage for the semantic relatedness judgment, regardless of the amount of experience or reading skill. There are two possibilities as to why this may be the case: first, the rvf/LH may require much higher familiarity with words in order to show processing benefits. Second, the task currently used (semantic relatedness judgment) may not be sensitive enough to capture asymmetric processing. Experiment 2 addressed these possibilities.

Stroobant, Buijs, and Vingerhoets (2009) conducted a functional transcranial Doppler ultrasonography study looking at the lateralization index for different tasks (cued word generation, sentence construction, reading, and semantic decision). For the semantic decision task, the participants had to decide which one of three words was not synonymous with the other two. Semantic decision was found to have the lowest left hemisphere lateralization index. It is possible that a meaning-based task like semantic decision may rely more on right hemisphere processing than other language tasks (Stroobant, Buijs, & Vingerhoets, 2009; see also St George, Kutas, Martinez, & Sereno, 1999). Other researchers conducted DVF semantic priming experiments looking at how each hemisphere processed centrally presented primes (two single-word primes) and lateralized targets.

There were three conditions of prime-target relationship: both primes were related to the dominant meaning of the target, both primes were related to the subordinate meaning of the target (convergent primes), or one prime related to the dominant and the other to the subordinate meaning of the target (mixed condition / divergent primes). Subjects performed either a lateralized lexical decision or a lateralized semantic relatedness judgment task (Faust & Lavidor, 2003). The researchers found that compared to lexical decision, in the semantic relatedness judgment, the largest effect of mixed primes was found for lvf/RH presentation. The semantic relatedness judgment task requires a sustained activation of meaning to make the semantic decision. This may be argued to involve more of the right hemisphere capacity for meaning processing, especially when there are multiple meanings to be accessed (i.e., coarse coding) (Faust & Lavidor, 2003). The essence of the semantic decision is thus the sustained activation of meanings, and this may be regulated more bilaterally; therefore, RVF advantages may be reduced in this task.

Experiment 2 involved a new group of subjects performing the same tasks as in Experiment 1, with the addition of a second semantic relatedness test at the end of Day 2. This task used only highly familiar English word pairs matched on forward associative strength to the English-Lingo pairs. Experiment 2 also provided a replication and increased power for individual difference comparisons when the Lingo findings are combined with Experiment 1.

If the rvf/LH indeed requires much more familiarity with the words before it can show benefits, then we will see a benefit of rvf/LH presentation for the semantic related-

ness judgment with English word pairs for both skilled and less-skilled comprehenders. In addition, it is predicted that there will be greater LH advantage for the skilled comprehenders compared to less-skilled comprehenders. This assumes the more efficient LH of skilled comprehenders will benefit to a greater degree than the LH of less-skilled comprehenders in processing highly familiar English words.

However, if indeed the semantic relatedness judgment task is not sensitive enough to capture asymmetric processing, then we will not see overall rvf/LH advantage for English pairs.

Method

Participants

Experiment 2 included 48 participants, with equal number of males and females. Participants were native English speaking, right-handed UCR students recruited through introductory psychology classes or through advertisements. Average handedness score was +0.80.

Design

The design of the experiment for the encoding and forced choice acquisition test was identical to Experiment 1. The design of this experiment is 2 (visual field: LVF vs. RVF) x 3 (amount of experience: 2x vs. 8x vs. English) x 2 (the type of response in the semantic judgment test: Related vs. Unrelated). The dependent variables were accuracy and correct reaction times.

Materials

Experiment 2 utilized the same materials as Experiment 1 for the Encoding, Acquisition Test, and semantic relatedness judgment with English-Lingo pairs. For the English word pair stimuli, seventy-two English word pairs were selected from University of South Florida Association Norms (Nelson, McEvoy, & Schreiber, 1998). These pairs were matched closely to the English-Lingo pairs in terms of the forward associative strength ($=0.256$). The lateralized English targets were 3-6 letters long (means = 4.8 letters). See *Appendix C* for English word pairs stimuli list. The English pairs were randomly re-paired to form unrelated pairs. There were eight experimental lists (half were reverse mapped).

Apparatus & Procedure

The procedure for Experiment 2 was the same as Experiment 1, the only difference was the addition of English word pairs semantic relatedness judgment task at the end of Day 2. The participants were told that they had to continue to make semantic relatedness judgments, except that in this phase, they would make meaning relatedness decision on two English words instead of English and Lingo. There were 36 trials per VF in the English word pairs semantic relatedness judgment test.

Results

Encoding

Two-way ANOVAs were performed on amount of experience (2x and 8x) and the type of answer (Yes and No).

For accuracy, the main effect of answer type was not significant, $p > 0.10$. The main effect of amount of experience was not significant, $F < 1$. The interaction between answer type and amount of experience was not significant, $F < 1$. The only difference from Experiment 1 results was that in Experiment 1, the main effect of answer type was significant.

For reaction times, the main effect of answer type was significant, $F(1,47) = 10.86$, $p < 0.01$. No answer was responded to faster than Yes answer (2035 ms vs. 2117 ms). The main effect of amount of experience was significant, $F(1,47) = 67.64$, $p < 0.01$. The reaction times for 8x condition were faster than 2x condition (2013 ms vs. 2139 ms). The interaction between amount of experience and answer type was not significant, $p > 0.10$. All the results for reaction times replicated Experiment 1.

Acquisition Test

The accuracy range of the acquisition test was from 71% - 99%, with an average of 87% correct. One-way ANOVAs were performed examining the amount of experience. For accuracy, the main effect of amount of experience was significant, $F(1,47) = 201.51$, $p < 0.01$. The words that were experienced more had significantly higher accuracy than words that were experienced less (96.24% vs. 78.24%). For reaction times, the main effect of amount of experience was significant, $F(1,47) = 194.15$, $p < 0.01$. The words that were experienced more were responded to faster than words that were experienced less (2223 ms vs. 2747 ms). All the results were similar to Experiment 1.

Semantic Relatedness Judgment

Two-way ANOVAs were conducted on the amount of experience (2x, 8x, and English) and visual field (lvf/RH and rvf/LH).

For accuracy, the main effect of amount of experience was significant, $F(2,94) = 80.32$, $p < 0.01$. English had the highest accuracy (83.24%), followed by 8x condition (74.76%), and the lowest accuracy was 2x condition (63.72%). Further analyses confirmed that each of the conditions differed significantly from one another. The main effect of visual field was significant, $F(1,47) = 6.80$, $p < 0.05$. RVF/LH had higher accuracy than LVF/RH (75.63% vs. 72.20%). The interaction between amount of experience and visual field was not significant, $F < 1$. The only difference from Experiment 1 was that in Experiment 1, the main effect of visual field was not significant.

For reaction times, the main effect of amount of experience was significant, $F(2,94) = 60.24$, $p < 0.01$. English was responded to the fastest (897 ms), followed by 8x condition (1060 ms), and the slowest was 2x condition (1148 ms). Further analyses confirmed that each of these conditions differed significantly from one another. The main effect of visual field was significant, $F(1,47) = 10.23$, $p < 0.01$. RVF/LH was faster than LVF/RH (1019 ms vs. 1051 ms). The interaction between the amount of experience and visual field was not significant, $F < 1$. The only difference from Experiment 1 was that in Experiment 1, the main effect of visual field was not significant.

Semantic Relatedness Judgment & Nelson-Denny Reading Test (Reading Comprehension Subtest)

A median-split based on the reading comprehension scores was performed to divide the participants into two different skill groups. The less-skilled group comprised of 24 participants (10 females), with a mean score of 30, and a range from 13-47. The skilled group consisted of 24 participants (14 females), with a mean score of 70, and a range from 50-96. A histogram of the distribution of reading comprehension scores for Experiment 2 is presented in Figure 4.

Three-way ANOVAs were conducted on the amount of experience (2x, 8x, and English), visual field (rvf/LH and lvf/RH), and skill group (skilled and less-skilled). The means and standard deviation for accuracy are presented in Table 3, and for reaction times in Table 4.

For accuracy, the main effect of skill was significant, $F(1,46) = 20.23, p < 0.01$. The skilled group had higher accuracy than less-skilled group (78.38% vs. 69.44%), unlike Experiment 1, where the main effect of skill was not significant. The main effect of visual field was significant, $F(1,46) = 6.96, p < 0.05$. RVF/LH had higher accuracy than LVF/RH (75.62% vs. 72.20%), unlike Experiment 1 where no main effects of visual field were found. The main effect of amount of experience was significant, $F(2,92) = 79.24, p < 0.01$. English had the highest accuracy (83.24%), followed by 8x condition (74.78%) and the lowest accuracy was the 2x condition (63.72%). Further analyses confirmed that these conditions significantly differed from one another. There were no significant inter-

actions, failing to replicate the significant 2-way interaction between amount of experience and skill obtained in Experiment 1.

For reaction times, the main effect of skill was not significant, $F < 1$. The main effect of visual field was significant, $F(1,46) = 10.01, p < 0.01$. RVF/LH stimuli were responded to faster than LVF/RH stimuli (1019 ms vs. 1051 ms). The main effect of visual field was not significant in Experiment 1. The main effect of amount of experience was significant, $F(2,92) = 60.69, p < 0.01$. English was responded to the fastest (897 ms), followed by 8x condition (1061 ms), and the slowest was 2x condition (1148 ms). Further analyses confirmed these conditions differed significantly from one another. There were no significant interactions, just as in Experiment 1.

Analyses were then conducted for each visual field, as in Experiment 1.

LVF/RH

Two-way ANOVAs were conducted between the amount of experience (2x, 8x, and English) and skill group (skilled and less-skilled).

For lvf/RH accuracy, the main effect of skill was significant, $F(1,46) = 20.83, p < 0.01$. The skilled group had better accuracy than the less-skilled (77.61% vs. 66.79%). The main effect of amount of experience was significant, $F(2,92) = 54.42, p < 0.01$. English had the highest accuracy (81.38%) followed by 8x condition (73.71%), and the lowest accuracy was 2x condition (61.51%). Further analyses confirmed these conditions differed significantly from one another. The interaction between amount of experience and

skill was not significant, $F < 1$, which does not replicate the 2-way interaction between amount of experience and skill in lvf/RH in Experiment 1.

For lvf/RH reaction times, the main effect of skill was not significant, $F < 1$. The main effect of amount of experience was significant, $F(2,92) = 44.46$, $p < 0.01$. English had the fastest response (918 ms), followed by 8x condition (1077 ms), and the slowest was the 2x condition (1159 ms). Further analyses confirmed these conditions differed significantly from one another. The interaction between amount of experience and skill was not significant, $F < 1$. These results for reaction times were similar to Experiment 1.

RVF/LH

Two-way ANOVAs were conducted between the amount of experience (2x, 8x, and English) and skill group (skilled and less-skilled).

For rvf/LH accuracy, the main effect of skill was significant, $F(1,46) = 8.82$, $p < 0.05$. The skilled group had better accuracy than the less-skilled (79.15% vs. 72.10%). The main effect of skill was not significant in rvf/LH in Experiment 1. The main effect of the amount of experience was significant, $F(2,92) = 34.85$, $p < 0.01$. English had the highest accuracy (85.11%), followed by 8x condition (75.84%), and the lowest accuracy was 2x condition (65.93%). Further analyses confirmed these conditions differed significantly from one another. The interaction between amount of experience and skill was not significant, $F < 1$. This was different from Experiment 1, because in Experiment 1, there was a significant 2-way interaction between amount of experience and skill in rvf/LH.

For rvf/LH reaction times, the main effect of skill was not significant, $F < 1$. The main effect of amount of experience was significant, $F(2,92) = 44.82$, $p < 0.01$. English was responded to the fastest (877 ms), followed by 8x condition (1044 ms), and the slowest was 2x condition (1136 ms). Further analyses confirmed these conditions differed significantly from one another. The interaction between amount of experience and skill was not significant, $p > 0.10$. These results for reaction times were similar to Experiment 1.

The purpose of Experiment 2 was to examine whether English stimuli would have an rvf/LH advantage. Therefore, two-way ANOVAs were conducted in each experience condition, between visual field and skill.

2X

For accuracy, the main effect of skill was significant, $F(1,46) = 11.53$, $p < 0.01$. Skilled group had higher accuracy than less-skilled (67.94% vs. 59.50%). The main effect of visual field approached significance, $p = 0.06$. RVF/LH had higher accuracy than LVF/RH (65.93% vs. 61.51%). The interaction between visual field and skill was not significant, $p > 0.10$.

For reaction times, none of the main effects or interactions were significant.

8X

For accuracy, the main effect of skill was significant, $F(1,46) = 13.37$, $p < 0.01$. Skilled group had higher accuracy than less-skilled (80% vs. 69.55%). The main effect of visual field was not significant, $F < 1$. The interaction between visual field and skill was not significant, $F < 1$.

For reaction times, none of the main effects or interactions were significant.

English

For accuracy, the main effect of skill was significant, $F(1,46) = 8.75, p < 0.05$. Skilled group had better accuracy than less-skilled (87.20% vs. 79.28%). The main effect of visual field was significant, $F(1,46) = 9.10, p < 0.01$. RVF/LH had better accuracy than LVF/RH (85.11% vs. 81.38%). The interaction between visual field and skill was significant, $F(1,46) = 7.57, p < 0.01$. Further analyses confirmed that skill difference was significant in LVF/RH, $F(1,46) = 15.18, p < 0.01$. The skilled group had higher accuracy than the less-skilled group (87.04% vs. 75.72%). The skill difference was not significant in RVF/LH, $p > 0.10$. When analyses were done examining each skill condition in terms of accuracy, it was found that skilled comprehenders did not show significant visual field difference, $F < 1$. On the other hand, less-skilled comprehenders showed significantly higher rvf/LH accuracy, $F(1,23) = 15.49, p < 0.01, (82.85\% \text{ vs. } 75.72\%)$. The interaction is presented in Figure 5.

For reaction times, the main effect of skill was not significant, $p > 0.10$. The main effect of visual field was significant, $F(1,46) = 10.66, p < 0.01$. RVF/LH was faster than LVF/RH (877 ms vs. 918 ms). The interaction between visual field and skill was not significant, $F < 1$.

Correlational Analyses

Correlational analyses were then performed to examine the relationship between hemispheric asymmetry and performance on the reading comprehension test, for each experience condition, using the same asymmetry indices as Experiment 1.

For accuracy, no significant correlation was observed between comprehension scores and either Lingo experience condition (i.e., 2x and 8x). However, there was a significant negative correlation between reading comprehension scores and English condition hemispheric asymmetry ($r = -0.45$, $p < 0.01$): better comprehension was associated with reduced asymmetry.

For reaction time, there were no significant correlations. Inspection of scatterplots revealed no nonlinear relationships.

Combined Analyses: Experiment 1 & 2

Preliminary analyses were conducted examining possible experiment effects. For accuracy, there was a significant main effect of skill, $F(1,92) = 15.71$, $p < 0.01$. Skilled comprehenders had higher accuracy than less-skilled comprehenders (71.41% vs. 64.99%). There was a significant main effect of amount of experience, $F(1,92) = 119.24$, $p < 0.01$. The 8x condition had higher accuracy than 2x condition (74.35% vs. 62.05%). There was also a significant main effect of VF, $F(1,92) = 4.78$, $p < 0.05$. RVF/LH had higher accuracy than LVF/RH (69.44% vs. 66.96%). For reaction times, there was a significant main effect of experiment, $F(1,92) = 4.99$, $p < 0.05$. Participants in Experiment 2 responded faster than participants in Experiment 1 (1104 ms vs. 1260 ms). There was also

a main effect of amount of experience, $F(1,92) = 41.12, p < 0.01$. The 8x condition was faster than 2x condition (1131 ms vs. 1234 ms). For accuracy and reaction times, there were no significant effects or interactions with experiment; therefore, further combined analyses were done collapsing across experiments, with a combined total of 96 subjects (48 females). These analyses were conducted to provide increased power, since some conflicting results were found across experiments. English-English semantic relatedness judgments were not included in these analyses. Only results from the English-Lingo semantic relatedness judgment task are reported here to examine the experimental hypotheses.

Semantic Relatedness Judgment

Two-way ANOVAs were performed on the amount of experience (2x and 8x) and visual field (rvf/LH and lvf/RH).

For accuracy, the main effect of amount of experience was significant, $F(1,95) = 109.05, p < 0.01$. The 8x condition had higher accuracy than the 2x condition (74.35% vs. 62.05%). The main effect of visual field was significant, $F(1,95) = 4.76, p < 0.05$. RVF/LH had higher accuracy than LVF/RH (69.44% vs. 66.96%). The interaction between amount of experience and visual field was not significant, $F < 1$.

For reaction times, the main effect of amount of experience was significant, $F(1,95) = 41.41, p < 0.01$. The 8x condition was faster than the 2x condition (1131 ms vs. 1234 ms). The main effect of visual field was not significant, $p > 0.10$. The two-way interaction was not significant, $p > 0.10$.

Semantic Relatedness Judgment & Nelson-Denny Reading Test (Reading Comprehension Subtest)

A median split based on reading comprehension subtest scores was performed for the combined sample. The less-skilled group consisted of 48 participants (20 females), with a mean score of 30 and a range from 1-48. The skilled group comprised of 48 participants (28 females), with a mean score of 71 and a range from 50-98. A histogram of the distribution of reading comprehension scores is presented in Figure 6.

Three-way ANOVAs were conducted on amount of experience (2x and 8x), visual field (lvf/RH and rvf/LH), and skill group (skilled and less-skilled). The means and standard deviation for accuracy are presented in Table 5, and for reaction times in Table 6.

For accuracy, the main effect of amount of experience was significant, $F(1,94) = 116.13, p < 0.01$: the 8x condition had higher accuracy than the 2x condition (74.35% vs. 62.05%). The main effect of skill was significant, $F(1,94) = 15.20, p < 0.01$. The skilled group had higher accuracy than the less-skilled (71.41% vs. 64.99%). The main effect of visual field was also significant, $F(1,94) = 4.84, p < 0.05$. RVF/LH had higher accuracy than LVF/RH (69.44% vs. 66.96%). The only significant interaction was a two-way interaction between amount of experience and skill, $F(1,94) = 7.17, p = 0.01$. Further analyses indicated that there was no significant skill difference in the 2x condition, $p > 0.10$, while skilled comprehenders significantly outperformed less-skilled comprehenders in the 8x condition, $F(1,94) = 19.38, p < 0.01, 79.09\%$ vs. 69.61% . Analyses also confirmed that both groups significantly improved their performance from 2x to 8x condition. Skilled

group had 15 points improvement, while less-skilled group had 9 points improvement. The interaction is displayed in Figure 7.

For reaction times, the only significant finding was a significant main effect of amount of experience, $F(1,94) = 41.18, p < 0.01$: the 8x stimuli were responded to faster than the 2x stimuli (1131 ms vs. 1234 ms).

Two-way ANOVAs were then conducted between amount of experience (2x and 8x) and skill (skilled and less-skilled) in each visual field.

LVF/RH

For lvf/RH accuracy, there was a significant main effect of skill, $F(1,94) = 20.74, p < 0.01$. The skilled group had higher accuracy than the less skilled (71.09% vs. 62.83%). There was a significant main effect of amount of experience, $F(1,94) = 60.02, p < 0.01$, with higher accuracy for 8x than for 2x stimuli (73.05% vs. 60.87%). The two-way interaction between amount of experience and skill was not significant, $p > 0.10$.

For lvf/RH reaction times, the only significant finding was a main effect of amount of experience, $F(1,94) = 25.23, p < 0.01$: 8x was faster than 2x (1147 ms vs. 1235 ms). No other significant main effects or interaction were observed.

RVF/LH

For rvf/LH accuracy, there was a significant main effect of skill, $F(1,94) = 4.48, p < 0.05$. The skilled group had higher accuracy than the less-skilled (71.74% vs. 67.15%). The main effect of amount of experience was significant, $F(1,94) = 49.16, p < 0.01$: 8x had higher accuracy than 2x (75.65% vs. 63.24%). There was a significant 2-way interac-

tion between amount of experience and skill, $F(1,94) = 4.60$, $p < 0.05$. Further analyses indicated that the skilled and less-skilled groups did not differ in 2x condition, $F < 1$. However, the skilled group had significantly higher accuracy than the less-skilled in 8x condition, $F(1,94) = 9.11$, $p < 0.01$, 79.84% vs. 71.46%. The interaction is displayed in Figure 8.

For rfv/LH reaction times, the only significant finding was a significant main effect of amount of experience, $F(1,94) = 28.02$, $p < 0.01$: 8x stimuli were responded to faster than 2x stimuli (1114 ms vs. 1233 ms). No other significant main effects or interaction were observed.

Top-Bottom 25% Analyses

Similar analyses as above were conducted using extreme groups approach; i.e., analyses were conducted contrasting top and bottom 25% scores on the reading comprehension test, similar to the approach of Perfetti, et al (2005) who found differential ERP effects for adults based on reading comprehension skill.¹

The poorest comprehenders group consisted of 24 participants whose comprehension scores were in the bottom 25% (range = 1-28, mean = 22). The superior comprehenders group consisted of 24 participants whose comprehension scores were in the top 25% (range = 69-98, mean = 82). For clarity, the groups formed by the top and bottom

¹ Perfetti et al. (2005) contrasted the 20% top and 20% bottom scores in their study. Here 25% cutoffs were used to allow all participants with the same scores to be grouped together.

25% method will be referred to as superior and poorest comprehenders, while the groups formed by median split will be referred to as skilled and less-skilled comprehenders.

As above, these analyses collapsed over experiment and included the Lingo conditions only (2x and 8x). For accuracy, the findings were similar to those using the median split method. The only new result was a significant two-way interaction between skill and visual field for accuracy, $F(1,46) = 6.23, p < 0.05$. This interaction is displayed in Figure 9. Further analyses confirmed that there was no visual field difference in superior comprehenders group, $F < 1$. However, there was a significant difference between visual field in the poorest comprehenders group, $F(1,23) = 9.50, p < 0.05$, with higher accuracy for RVF/LH than for LVF/RH (66.88% vs. 60.82%).² When this interaction was broken down by visual field, it was found that there was a significant skill difference in LVF/RH, $F(1,46) = 29.51, p < 0.01$, with superior comprehenders had higher accuracy than poorest comprehenders (73.36% vs. 60.82%). There was no significant skill difference in RVF/LH, $p = 0.1$.³ It is a concern that this lack of significant skill difference in

² Similar extreme group analyses (top-bottom 25%) were conducted on the English condition in Experiment 2. The results of these analyses should be interpreted with caution because there were only 12 participants per group. For accuracy, the results revealed no significant VF difference for the superior comprehenders, $F < 1$ (rvf/LH trials had slightly lower accuracy than lvf/RH trials: 86.3% vs. 87.7%). On the other hand, accuracy for the rvf/LH was significantly better than for the lvf/RH in the poorest comprehenders, $F(1,11) = 12.93, p < 0.05, 85.14\% \text{ vs. } 75.29\%$. In the reaction times analyses, neither skill nor VF differences were obtained.

³ Extreme group analyses were done separately for Experiment 1 and Experiment 2. The results were similar for Experiment 2 and the combined experiment analyses, while the findings of Experiment 1 were similar to the findings of the Experiment 1 using the median split method.

rvf/LH may be caused by a ceiling effect (for superior comprehenders). However, when the accuracy rates for individual subjects were examined, none was high enough to suggest a ceiling effect; therefore, this concern may be dismissed.

It is possible that this interaction was not found to be significant in the median split analyses, because the median split analyses may have obscured some difference between the two skill groups (e.g., people who scored close to one another on either side of the median would end up in different skill groups). Therefore, analyzing only the top and bottom 25% scores may increase the contrast between the two skill groups.

For reaction times, the same patterns of findings as the median-split method were observed.

Discussion

Experiment 2 – Inclusion of English condition

Experiment 2 was designed to investigate the lack of a RVF/LH advantage in Experiment 1. Two hypotheses were tested as possible explanations for this result. First, if the rvf/LH indeed requires much more familiarity with words before it can show advantages, then we should see a rvf/LH advantage for the semantic relatedness judgment with English pairs. A main effect of visual field for both accuracy and reaction times was obtained for English, but not Lingo, words in Experiment 2, suggesting that well-learned words are processed better in the rvf/LH. The analysis on the English condition also indicated that this result was obtained only for less-skilled comprehenders. However, for reaction times, an overall rvf/LH advantage was observed for both skill groups. In general

the first hypothesis secured some support as a significant rvf/LH advantage was obtained for English, but not Lingo, words.

The second hypothesis was that the semantic relatedness judgment task might not be sensitive enough to capture asymmetric processing. This hypothesis was not confirmed as rvf/LH advantages were obtained for English words as described above.

When analyses were done to examine each amount of experience condition separately (2x, 8x, and English), none of the visual field and skill interactions were found to be significant in the 2x and 8x conditions, and no significant rvf/LH advantage was observed. This, in contrast with the English performance, supports the idea of a greater right hemisphere role for processing newly-learned, as opposed to highly familiar, words. As can be recalled, this also may be taken to support the quantitative hypothesis (i.e., greatly increased experience with individual words is crucial for left lateralization of word processing); however, apparently more than 8 exposures are necessary to obtain rvf/LH advantage. This was opposed to the qualitative proposition, which argued that beyond a certain critical period during childhood, all language processing would be done by the left hemisphere (i.e., if this argument had been supported, then we should have seen LH advantages in the 2x and the 8x conditions, as well as the English condition).

The accuracy and reaction times results are generally consistent with the coarse-fine coding hemispheric processing proposition. Highly familiar stimuli (i.e., English words) showed better processing for the rvf/LH. Left hemisphere fine coding may be benefited in processing familiar English words, because there is ample opportunity for

strong semantic connections to have been made. On the other hand, the lack of a rvf/LH advantage in the 2x and 8x conditions may mean that the right hemisphere plays a role when new words are being learned, and 8 exposures did not increase the level of familiarity enough for the rvf/LH to be advantaged. This supports the coarse coding hypothesis; that is, right hemisphere coarse coding may help facilitate early word acquisition due to its processing style that enables it to maintain a broad array of possible meanings of a word as well as weak meaning connections. This is beneficial for newly learned words, which do not yet have strong semantic connections with other words in the semantic network.

Combined Experiment 1 & 2 - Exclusion of English condition

Some findings of Experiment 1 were not replicated by Experiment 2, yet when experiment was included as an independent variable, no interaction with experiment was observed. This suggests that failures to replicate may be attributed to uncontrolled variability resulting in a loss of statistical power. Therefore, subsequent discussion will focus on findings that emerged when collapsing across experiments, although the English condition cannot be included. One finding of the combined analyses was that a significant main effect of visual field for accuracy, but not reaction time, was found; that is, an advantage of rvf/LH for responding to Lingo items was found for accuracy.

Skill-based analyses were done in two ways: median split and top-bottom 25%. The median split accuracy results obtained main effects of visual field (rvf/LH advantage) and skill (the skilled had better accuracy than the less-skilled group), as well as an

interaction between amount of experience and skill. There was no skill difference in the 2x condition, while the skilled group significantly outperformed the less-skilled in the 8x condition; this particular result replicated Experiment 1. It solidifies the notion that additional experience with new words is absolutely crucial for skilled comprehenders to outperform the less-skilled. This also indicates that indeed the skilled comprehenders are better learners of new words than less-skilled comprehenders. There were no visual field interactions when groups were divided by median split. This method of group division may obscure the difference between groups because some participants with scores close to one another may be assigned to different groups. Therefore, a different method of dividing the two groups was implemented to increase the contrast between superior and very poor comprehenders.

More interesting results were obtained when skill groups were divided by the top-bottom 25% method. Using this method, visual field and skill were found to interact. There was no visual field accuracy difference for superior comprehenders, which indicated a more efficient RH may perform at the level that is close to the LH. The visual field accuracy difference was significant for the poorest comprehenders, which indicated greater LH than RH accuracy. For reaction times, the superior group had faster reaction times than poorest group; however, the pattern of asymmetry was the same. Interestingly, this extreme group approach also yielded an intriguing finding for the English condition, when Experiment 2 participants were divided based on top 25% and bottom 25% scores (12 participants per skill group) (see Footnote 2). Superior comprehenders were found to

have no significant VF difference, while poorest comprehenders had significantly higher rvf/LH accuracy. No significant result was found for reaction times.

These findings may indicate that at least for superior comprehenders, the right hemisphere is very adept at processing not only newly-learned words, but also very familiar English words. It is possible that RH coarse coding may enable such advanced comprehension skill by enhancing the integration of the new words to an existing semantic network, and inferring the meaning of a word from a text.

The findings above may indicate that as a general explanation, coarse and fine coding works well to a certain extent. However, when individual differences are taken into consideration, the coarse fine coding explanation may not be equally descriptive of all groups.

General Discussion

The current experiments were designed to investigate possible differential hemispheric roles in new word and meaning acquisition, taking into account the amount of experience with the new words and reading comprehension skill. Coarse and fine coding hemispheric processing style hypotheses and quantitative and qualitative hypotheses provided the theoretical base for the current project. Beeman and colleagues proposed that the right hemisphere has a coarse processing style, which means that it is adept at processing weakly-related stimuli, and it is able to maintain a broad array of possible meanings of a word (see Beeman & Chiarello, 1998). This was proposed to be beneficial to the process of learning new words, as a new word does not yet have strong semantic connec-

tions formed in the cognitive network; thus, this style of processing is thought to be helpful for the new word to begin to establish semantic connections. The left hemisphere is proposed to have a fine processing style, processing stimuli at a detailed level, and maintaining closely-related semantic relations (see Beeman & Chiarello, 1998). This way of processing stimuli is beneficial to familiar words, because these words have strongly established connections in the semantic network.

When analyses were done by the amount of experience (2x, 8x, and English) in the second experiment, it was found that indeed in the relatively less-experienced conditions (2x and 8x), there was no rvf/LH advantage, which implies a more bilateral processing (i.e., larger role for lvf/RH in these less-experienced conditions). RH coarse coding may contribute to this result because this style of processing may be more suitable for newly-learned words. Summation priming experiments (see Beeman et al., 1994) have found that the RH is adept at processing weak semantic connections. With the current experiment, it can be added that the RH is also adept at an earlier process, when a novel word and meaning are first learned. On the other hand, the English word condition had a robust rvf/LH advantage compared to the 2x and 8x conditions. The English words used in the current experiment are highly familiar. This particular result may be taken to support the fine coding processing style of the left hemisphere. The presence of strong semantic connections for highly familiar English words may resonate well with the fine coding style of the LH; thus, it shows as an advantage of the RVF when familiar English words were presented.

The quantitative-qualitative hypothesis examines how language function becomes left-lateralized in adults. The quantitative hypothesis proposed that left-lateralization occurs as a consequence of increased experience with individual words. The qualitative hypothesis argued that there is a childhood critical period, before which all language functions are processed bilaterally, and after which, all language functions are processed preferentially by the left hemisphere (Mills et al., 2005). The current findings support the quantitative hypothesis, because for adults, English words had rvl/LH advantages, while newly learned words did not.

The findings that supported coarse and fine coding as well as the quantitative hypothesis seem to suggest that there is a certain flexibility in how the hemispheres process verbal information. Both hemispheres process verbal information (as opposed to the popular belief that the left hemisphere is the only verbal brain); however, *which* hemisphere is more adept seems to depend on the level of familiarity of the words. More bilateral processing may happen when the level of semantic knowledge and familiarity is low, while the left hemisphere may be dominant when the level of semantic knowledge and familiarity is high.

Individual Differences

Another picture of hemispheric functioning emerges when individual baseline differences in reading comprehension skill were taken into account. When analyses were done by combining Experiment 1 and 2 (excluding the English condition) and dividing skill using an extreme groups method (top-bottom 25%), interesting skill differences ap-

peared. Superior comprehenders did not show significant hemispheric differences, while poorest comprehenders showed significantly better LH processing. Interestingly, when only English stimuli were considered, using the same extreme groups approach, the same pattern of findings was found. Therefore, extreme groups analyses showed that the LH and RH of superior comprehenders were able to process both new and familiar stimuli with equal competency in terms of accuracy. This was not observed in the poorest comprehenders, in which the RH did show significantly worse performance than the LH.

The results from superior comprehenders provided a possible behavioral manifestation of previous ERP findings that people who are good comprehenders had different electrophysiological responses to new stimuli (Perfetti et al., 2005). Perfetti and colleagues (2005) found that good comprehenders had stronger P600 (episodic markers) and N400 (semantic markers) when processing new stimuli. The current findings suggest that superior comprehenders had more bilateral processing. Therefore, it is possible that the stronger P600 and N400 markers for good comprehenders may stem from more bilateral processing. Bilateral processing may involve more neuronal connections and processing, which may yield stronger electrophysiological potentials.

The right hemisphere has been found to play a role in new meaning acquisition (Ince & Christman, 2002), while the findings from the current experiments suggest that superior comprehenders had more efficient RH processing for both newly-learned words and English words. Therefore, it is possible to deduce that their superior comprehension may stem partly from their RH ability to process newly learned words and meanings effi-

ciently in the first place, and the RH still influences the processing of familiar words. However, the poorest comprehenders may not have had this benefit of efficient RH processing, both for new words and familiar words.

ERP research in novel word learning had found that toddlers who were better comprehenders had a more left-lateralized ERP pattern when words were experienced more, while poorer comprehenders had a more bilateral ERP pattern throughout (Mills et al., 2005). This ERP result is contrary to the current behavioral study in adults, where superior comprehenders had greater bilateral processing, at least for accuracy, while the poorest comprehenders had a more dominant LH processing. It is likely that the seemingly opposite finding is the result of different experimental paradigms (i.e., ERP vs. behavioral) and methods of testing adults and children. However, it is also possible that the right hemisphere role in new word learning changes as one develops (i.e., greater use of the RH may be a marker for poorer comprehension in young children, but for better comprehension in adults). Children and adults have been found to share similar themes in the process of word acquisition: fast mapping, gradual semantic acquisition, and importance of additional experience and memory consolidation. The current findings highlight one potential difference in word and meaning processing that may arise between children and adults when brain functioning is taken into consideration. One possibility as to why this discrepancy may exist is that the semantic network and the state of brain maturation may be different in children and in adults.

The structure that is crucial for bilateral processing, the corpus callosum, is among the slowest to complete myelination, and the functional maturation of the corpus callosum continues until adolescence (Jancke & Steinmetz, 2003). This indicates that young children have an immature corpus callosum. Young children who are poor comprehenders may be using more right hemisphere processing; however, an immature corpus callosum prevents efficient hemispheric communication with the LH. Thus, bilateral processing may not be the most effective way to go about learning new words. Therefore, young children who are poor comprehenders may have two things going against them. First, a smaller semantic network may be less helpful for learning more words. Young children's semantic network may start off sparsely, which may lead to phenomenon such as overextension (see Clark, 1973). This sparse network may permit fast mapping; however, in order to get more fine-tuned nuances of a meaning, a more complete semantic network may be required. Second, the use of more bilateral processing while the corpus callosum may not be functionally mature may impair the process of learning even more.

Adults, on the other hand, have functionally mature corpus callosa, which permits efficient interaction between the RH and LH. Second, adults possess already-established semantic networks as they learn new words. These two factors may well be the necessary precursors for coarse coding of the right hemisphere to display benefits. Adult superior comprehenders may be benefited more from right hemisphere coarse coding as they learn new words compared to the poorest comprehenders. The benefits of right hemisphere coarse coding in superior comprehenders is supported by mature corpus callosum, which

allows efficient interhemispheric communication. Additionally, the rich semantic network already possessed by adults may be extremely advantageous for new words to initiate the formation of semantic connections.

Therefore, the fit of the coarse fine coding hypothesis to the relevant findings may be influenced by an individual differences factor (i.e., baseline reading comprehension skill), as well as the state of brain maturation (especially the corpus callosum).

The current findings (i.e., no visual field difference in superior comprehenders, rvl/LH advantage in poorest comprehenders) seem to be at odds with findings from fMRI studies (see Breitenstein et al., 2005; Wong et al., 2007) which found critical roles of the LH in word learning: less-skilled word learners showed greater RH recruitment. The current behavioral-based experiment suggested that a much more efficient RH is critical in giving superior comprehenders an edge in processing new stimuli, while the brain imaging studies suggested otherwise, that the RH was recruited more by less-skilled learners. As was described earlier in discussion of Experiment 1, these discrepant findings may be the consequences of different testing paradigms (behavioral vs. brain imaging). One way to potentially disentangle the discrepancy is to conduct the same experiments as the current project in brain imaging to see whether the right hemisphere would be recruited by superior comprehenders. Another way is to use the whole brain approach in the imaging analyses, as opposed to an ROI (Region of Interest) (in which a researcher's previous biases and preconception in terms of what areas are likely to be activated may decrease the possibility of finding RH activations).

The current findings, that superior comprehenders showed less asymmetry, while the poorest comprehenders showed more left-lateralized processing seemed to reiterate the findings by Hirnstein, Leask, Rose, and Hausmann (2010). These researchers found that less asymmetry was related to best cognitive performance (in word matching and face decision task), while poorer cognitive performance was related to extreme lateralization. However, other researchers found contrasting results using yet different tasks: larger asymmetry was associated with better reading performance, only in people who were consistent handers and only in word recognition tasks (Chiarello, Welcome, Halderman, & Leonard, 2009). These results suggest that there is no one correct answer as to the relationship between degree of asymmetry and cognitive performance. This relationship may be influenced by many factors, such as: the type of cognitive task used, cognitive skill, and the handedness of the participants. Further study involving a variety of lateralized tasks and cognitive measures is clearly necessary.

Finally, the way new word learning is characterized in the current project can be compared with the way people learn new words in a foreign language. In both cases more than one variant of the same meaning may be encountered, and inference processes may occur at some level. However, learning words in a foreign language differs from learning Lingo because in Lingo, the background language is still English (native language of the participants), while learning new words in new language may entail more grammatical and lexical processing, which was not necessary for Lingo learning. Additionally, semantic connections between English and Lingo words may be made more easily given the

participants were all native speakers of English, while semantic connections between a new word in foreign language and other words in that language may be harder to make, especially when the learner is a novice. Furthermore, the difference between new word learning as measured here and new word learning that occurs in daily life is that the current project is much more structured, with new words and meanings presented dictionary-style, while in real life, more inference processes may be required in order to learn new word meanings.

Limitations

The current study only had 2 days of experimentation; hence, the second day presentation of Lingo items could not benefit from sleep-dependent memory consolidation. It is difficult to assess how the results would be different if the second day Lingo experience also had the benefit of memory consolidation. However, it is likely that we would find an even stronger rvf/LH advantage when the words are more consolidated. Greater memory consolidation may help increase the familiarity of the words, which can be beneficial for the rvf/LH. One way to assess the influence of memory consolidation on the second day presentation of Lingo items would be to conduct the semantic relatedness judgment on a third day.

The amount and number of Lingo exposures (2x and 8x) used here may not provide an optimal opportunity to observe the progression of processing of new stimuli from bilateral to more left-lateralized. Therefore, additional exposure conditions may be warranted, for example: 2x, 8x, 16x, 24x, and English.

Another limitation of the current project is that the number of exposures was confounded with the amount of semantic context (i.e., 2x exposure always had less variation in semantic context than 8x). This was done intentionally to better mimic real-world word learning. The downside of this is that it does not allow us to disentangle the number of exposures from the variety of semantic contexts.

The divided visual field method is an indirect measure of hemispheric functioning. Many brain processes are not observable by this method, which only reveals the behavioral manifestation of hemispheric processing, i.e., accuracy and speed of responding. There is no way to determine, using this method, the exact brain structures that are involved in a certain task. However, this method has revealed important hemispheric asymmetries in a variety of tasks, and appeared, in this study, to differentiate superior comprehenders' processing from that of the poorest comprehenders.

The way in which new words and meanings were created in the current project may also merit additional scrutiny. Lingo word-meaning pairing was assigned arbitrarily in the current study. However, a recent study showed that there may be a non-arbitrary link between a new word's sound and its meaning (Nygaard, Cook, & Namy, 2009). The findings suggested that the correct Japanese word- English meaning pairing was responded to the fastest and most accurately, compared to a random pairing of forms and meanings (Nygaard et al., 2009). Lingo is a newly-created set of words and meanings: the majority of the concepts were never embedded as a part of an actual language, while the words were formed from English words with one letter randomly replaced. Therefore, an

arbitrary relationship between a Lingo word and its meaning may be assumed. The acquisition phase results of the current project showed participants did well in acquiring Lingo words and associated meanings, despite the arbitrariness of the relationship between the word and its meaning.

Future Directions

Future experiments should examine additional days and additional amounts of learning experience. This has two potential benefits: first, it adds memory consolidation benefits to more than just a single day of Lingo presentation; second, varying the amount of experience may help us see the progression of the change from bilateral responding to a more left-lateralized responding (i.e., instead of 2x and 8x and English, a study can be done by adding 16x and 24x exposure condition).

Experiments may also be designed to try to disentangle the effects of the number of exposures from semantic context effects. This could be done by presenting participants with some Lingo items that are repeated only with the same definition, and some other Lingo items which are repeated the same number of times but with different definitions. Thus, the number of exposures is controlled, and semantic context is varied. If number of exposures is more crucial for rvf/LH advantages, then we should see similar results across conditions. However, if semantic context is more important, then we should observe rvf/LH advantages only when semantic context is varied.

One possible way to test if Lingo words and meanings have an underlying non-arbitrary relationship would be to test completely new participants (who were never ex-

posed to the encoding phase of Lingo) in the 2-AFC acquisition test. If indeed Lingo words and meanings have an arbitrary relationship, then we should observe performance at the chance level by these new participants. However, if the Lingo and meaning stimuli have a non-arbitrary relationship, then we should observe above-chance.

Conclusions

There are four major conclusions that can be drawn from the current project. First, the hemispheres are dynamic and flexible. They are shaped by our daily experience. More specifically, new word learning is a crucial skill that helps define us as human beings. This project supports the notion that the left hemisphere is not the only verbal brain. This project also supports the conclusions of previous experiments (see Beeman et al., 1994; Faust & Lavidor, 2003): the right hemisphere plays a crucial role in verbal function. In terms of coarse-fine coding, it seems to be supported in general when individual differences in comprehension are not taken into account. This indicated that coarse-fine coding is able to explain the results of the current experiments; however, it may need to be fine-tuned when baseline comprehension skill is taken into consideration.

Second, reading comprehension skill is associated with the ability of the two hemispheres to process stimuli more efficiently. The current experiments suggest this was especially true for the right hemisphere. Therefore, not only is the right hemisphere crucial in new word learning, it also seems to be the key difference between superior comprehenders and poorest comprehenders; that is, superior comprehenders have RH proc-

essing ability that is so efficient that it is close to the level of the LH, while this was not the case for the poorest comprehenders.

Third, when designing an experiment to try to gauge the RH role in verbal function, it is important to use the type of stimuli and experimental tasks that can actually be processed best by the RH. It can be speculated that many verbal tasks (e.g., lateralized lexical decision, repetition priming) showed a robust LH advantage (e.g., Leiber, 1976; Weems & Zaidel, 2004; Weems & Zaidel, 2005) because these tasks did not allow the RH to use its strength in processing weak semantic connections (lateralized lexical decision only asks for a recognition whether a stimulus is a word or nonword, while repetition priming simply repeats the same stimuli – these tasks may not depend upon semantic connections the way summation priming does). It seems that the RH was able to demonstrate its strength in processing verbal stimuli when the type of task examines the processing of weak semantic relations (e.g., tasks such as summation priming and the current semantic relatedness judgment task).

Finally, as stated in the introduction, word learning is a robust skill that lasts a lifetime. Learning more about how the hemispheres of the brain handle such a robust and complicated task like word learning (it is complicated from the point of view of a researcher, but a 2-year-old can do it with astonishing ease) provides a window to learn how brain and cognition intertwine.

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Appendix A

Sample of Complete Stimulus Set for Two Lingo Items

IBY

PRIMDEF: "An IBY is a tool for making wooden swings"

YES-Q: "Could a carpenter use an IBY?"

NO-Q: "Could a jellyfish use an IBY?"

DEF 2: "An IBY is needed to make wooden swings"

YES-Q: "Could we find an IBY in a hardware store?"

NO-Q: "Is an IBY a food commodity?"

DEF 3: "When a carpenter wants to make a wooden swing, he uses an IBY"

YES-Q: "Is an IBY used to construct wooden swings?"

NO-Q: "Is an IBY used to clean clothes?"

DEF 4: "Proper tools like an IBY are needed to make wooden swings"

YES-Q: "Is an IBY used to construct a wooden object?"

NO-Q: "Is an IBY a type of dessert?"

RELATED ENGLISH: HAMMER

VESDEL

PRIMDEF: "A VESDEL is a poisonous plant that tickles its victims"
YES-Q: "Does a VESDEL have roots that help it grow?"
NO-Q: "Is a VESDEL made of recycled paper products?"

DEF 2: "A VESDEL is a poisonous plant that likes to play with its victims"
YES-Q: "Is a VESDEL considered a living thing?"
NO-Q: "Is a VESDEL an inanimate object?"

DEF 3: "It is tough to find a plant poison antidote, therefore do not touch a VESDEL "
YES-Q: "Do people have to use gloves to take care of a VESDEL?"
NO-Q: "Is a VESDEL sold as a food product?"

DEF 4: "A poisonous tickling plant like VESDEL needs to be avoided"
YES-Q: "Is VESDEL dangerous?"
NO-Q: "Is it possible for a VESDEL to run around?"

RELATED ENGLISH: IVY

Appendix B

Lingo Stimuli with Primary Definition and Related English Word

LINGO	PRIMARY DEFINITIONS	RELATED ENGLISH
IXE	"An IXE is strawberry jam put in a blue jar"	JELLY
HOF	"HOF is a young lady who has seven brothers"	SISTER
PORF	"A PORF is the aunt of a famous pianist"	RELATIVE
VUIL	"A VUIL is a lock for food storage"	PANTRY
ISH	"ISH is lunch for people in a submarine"	FOOD
SHUMB	"A SHUMB is an almond-shaped rock"	STONE
MADHAN	"MADHAN is a sugary homemade margarine"	BUTTER
VESDEL	"A VESDEL is a poisonous plant that tickles its victims"	IVY
BRALCH	"BRALCH is copper money used in a new country"	COIN
FAF	"A FAF is a horse loaded with various jewels"	ANIMAL
GUG	"A GUG is a white eagle with huge claws"	BIRD
NUILL	"A NUILL is a red-colored lettuce grown on a mountain"	VEGETABLE
SPROCE	"A SPROCE is a short-tailed field mouse"	RODENT
ZIE	"A ZIE is a wart-covered monkey leg"	DISEASE
WEF	"A WEF is a flower of a wild plum tree"	BLOSSOM
LUP	"A LUP is a decoration made from frozen jasmine"	FLOWER
LEOK	"A LEOK is a secret code used by spies"	LANGUAGE
LUSBER	"LUSBER is an uncomfortable red sweaty skin condition"	RASH
NUR	"A NUR is an edible statue that tastes like candy"	SWEETS
BOLP	"A BOLP is a bundle of dyed wool"	YARN
GOSTER	"A GOSTER is a kind of spoiled dog with attitude problems"	BRAT
PORU	"A PORU is a pool made for turtle breeding"	POND
BEOR	"A BEOR is a war captive hidden in a jungle"	PRISONER
IBY	"An IBY is a tool for making wooden swings"	HAMMER
PIAKO	"PIAKO is special pepper used in Eskimo food"	SPICE
CEBENT	"A CEBENT is a child who was born in prison"	BABY
SIGY	"A SIGY is a bank manager who always works overtime"	WORKAHOLIC

LINGO	PRIMARY DEFINITIONS	RELATED ENGLISH
GEDAL	"A GEDAL is a kind of cheap cigar"	CIGARETTE
GAX	"GAX is a watery soft rice for sick people"	MEDICINE
PIV	"A PIV is a lemon that has already been peeled"	FRUIT
TAID	"A TAID is an organized group of lightning catchers"	CLUB
SISK	"A SISK is a woman who steals parking meters"	THIEF
SHEN	"A SHEN is an organization for tennis teachers"	GROUP
YUN	"YUN is a tea mixture with peach fragrance"	DRINK
RADUO	"A RADUO is an unmarried princess in a castle"	GIRL
NANDIT	"NANDIT is a cloth to make flags"	FABRIC
HUZ	"A HUZ is a sunny and windy town in a tropical area"	BEACH
RABLI	"A RABLI is a toothless shark"	FISH
PRIEFT	"A PRIEFT is a student of a master artist"	APPRENTICE
TIU	"A TIU is a tamed bear that loves milk"	CUB
PEB	"PEB is a juice made from crushed pears"	BEVERAGE
DANCEF	"DANCEF is an oat cereal with seeds and cherries"	BREAKFAST
CHIF	"CHIF is a disease common in tropical jungles"	MALARIA
PAJADE	"A PAJADE is a silk sock made for new mothers"	STOCKING
MADASE	"A MADASE is a truck-driving arsonist"	CRIMINAL
LIPER	"LIPER is synthetic thread made from plastic"	STRING
ROG	"ROG is special hay to be eaten by newborn calves"	GRASS
BRIOK	"A BRIOK is a metal drawer used by a gardener"	TOOLBOX
AFE	"An AFE is a noisy doctor who babbles"	TALKATIVE
CLOM	"A CLOM is an ounce of gold owned by a grandmother"	MONEY
YUBBER	"A YUBBER is a process to elect a dogcatcher"	VOTE
LEHON	"A LEHON is an elite school for future monks"	MONASTERY
THOIR	"A THOIR is an herb-crusted roasted chicken"	DINNER
RUMDER	"RUMDER is a special drink consumed by ambassadors"	WINE
JOR	"A JOR is a drunken retired attorney"	ALCOHOLIC
ANREL	"ANREL is an aged royal wine"	CHAMPAGNE
JEDAR	"JEDAR is an ancient beer made from maize"	ALCOHOL
MUPE	"A MUPE is a woman-only battle troop"	FEMALE
JANG	"A JANG is a doe that lives in a zoo"	DEER

LINGO	PRIMARY DEFINITIONS	RELATED ENGLISH
HAMEM	"A HAMEM is a wooden seat for a choir leader"	CHAIR
RIDGA	"A RIDGA is a three-legged table"	STOOL
IGG	"An IGG is a large green package of hazardous chemicals"	DANGEROUS
MUZUS	"A MUZUS is a clown who is trained in making animal balloons"	ENTERTAINER
HERZIN	"A HERZIN is an imaginary sister of a young reader"	FRIEND
LERS	"A LERS is a training camp to learn mountaineering skills"	SCHOOL
ARKOR	"An ARKOR is a dealer of silk"	MERCHANT
PEM	"A PEM is a complete suit of armor"	PROTECTION
SAKAGE	"A SAKAGE is a kind of jacket made from seaweed fiber"	SWEATER
SUNIC	"A SUNIC is a purple headband worn by an elderly jazz singer"	ACCESSORY
NICPEL	"A NICPEL is a personalized white wool tie"	CLOTHING
PIFTON	"A PIFTON is an expert in tiger behavior"	TRAINER
DAR	"A DAR is a traditional boat maker"	CRAFTSMAN

Appendix C

English Word Pairs for Semantic Relatedness Judgment

ENGLISH - CENTRALIZED	RELATED ENGLISH - LATERALIZED
SELLER	BUYER
MUSCLE	FLEX
FOOTBALL	TACKLE
MASSAGE	RUB
COLD	ICE
ROUND	OVAL
KING	THRONE
SHINE	POLISH
PEN	PENCIL
HEIGHT	WIDTH
SLEEP	NAP
FAKE	FRAUD
EXIT	ENTRY
FUNERAL	BURIAL
RABBIT	CARROT
STUPID	SMART
ASPIRIN	TABLET
NIECE	NEPHEW
DIAMOND	RUBY
HONK	HORN
HOLLER	HOOT
SUGAR	CANE
MULTIPLY	DIVIDE
THANKSGIVING	TURKEY
STICKY	GLUE
SPOT	DOT
GEOMETRY	ANGLE
BUFFALO	BISON
AWARD	TROPHY

ENGLISH - CENTRALIZED	RELATED ENGLISH - LATERALIZED
TALE	FABLE
PLANT	SOIL
BIKE	PEDAL
WATER	JUG
PARK	LOT
BOOK	NOTE
SOUR	TART
PULL	TOW
CARDS	SPADE
STOMACH	BELLY
TOOTHPASTE	TUBE
GRAPE	RAISIN
ROCKS	GRAVEL
RELIGION	FAITH
EYEBROWS	PLUCK
APPLE	PEAR
STRAW	HUT
BOTTLE	CORK
JEANS	PANTS
INVISIBLE	UNSEEN
PEACE	DOVE
HILL	SLOPE
HAMBURGER	GRILL
BASEMENT	ATTIC
BOAT	PADDLE
INSTRUMENT	CELLO
DISGRACE	SHAME
CHOCOLATE	COOKIE
CHEESE	PIZZA
SHIRT	COLLAR
WASH	RINSE
ODOR	SMELL

ENGLISH - CENTRALIZED	RELATED ENGLISH - LATERALIZED
GORILLA	APE
CHECKERS	CHESS
HEART	LUNG
FLOOR	CARPET
VACATION	RESORT
FRIGHTENED	SCARED
DOLPHIN	FIN
EXCHANGE	SWAP
BLUEBERRY	MUFFIN
TONIC	GIN
PUZZLE	MAZE

Tables

Table 1

Exp 1: Mean (Standard Deviation) Accuracy (Percent Correct) of Skill Group in Each Visual Field and Amount of Experience.

Amount of Experience	LVF		RVF	
	2X	8X	2X	8X
Skilled	60.78% (11.88)	77.78% (10.74)	58.28% (14.30)	78.57% (12.57)
Less-Skilled	59.66% (9.78)	66.99% (13.95)	62.81% (13.21)	72.36% (15.32)
Overall	60.22% (10.78)	72.39% (13.47)	60.55% (13.81)	75.46% (14.21)

Table 2

Exp 1: Mean (Standard Deviation) Reaction Times of Skill Group in Each Visual Field and Amount of Experience.

Amount of Experience	LVF		RVF	
	2X	8X	2X	8X
Skilled	1283 ms (443)	1167 ms (302)	1273 ms (434)	1157 ms (293)
Less-Skilled	1338 ms (424)	1266 ms (448)	1386 ms (517)	1213 ms (384)
Overall	1311 ms (430)	1216 ms (381)	1329 ms (475)	1184 ms (339)

Table 3

Exp 2: Mean (Standard Deviation) Accuracy (Percent Correct) of Skill Group in Each Visual Field and Amount of Experience.

Amount of Experience	LVF			RVF		
	2X	8X	English	2X	8X	English
Skilled	66.90% (10.29)	78.89% (12.13)	87.04% (8.78)	68.98% (14.27)	81.11% (10.01)	87.36% (9.06)
Less-Skilled	56.13% (10.51)	68.53% (13.87)	75.72% (11.20)	62.88% (11.68)	70.56% (16.07)	82.85% (11.52)
Overall	61.51% (11.64)	73.71% (13.92)	81.38% (11.48)	65.93% (13.27)	75.83% (14.28)	85.11% (10.50)

Table 4

Exp 2: Mean (Standard Deviation) Reaction Times of Skill Group in Each Visual Field and Amount of Experience.

Amount of Experience	LVF			RVF		
	2X	8X	English	2X	8X	English
Skilled	1145 ms (318)	1051 ms (301)	869 ms (213)	1133 ms (344)	1001 ms (226)	835 ms (196)
Less-Skilled	1173 ms (336)	1104 ms (264)	966 ms (195)	1139 ms (336)	1086 ms (276)	919 ms (179)
Overall	1159 ms (324)	1077 ms (281)	918 ms (208)	1136 ms (337)	1044 ms (253)	877 ms (191)

Table 5

Exp 1 & 2: Mean (Standard Deviation) Accuracy (Percent Correct) of Skill Group in Each Visual Field and Amount of Experience.

Amount of Experience	LVF		RVF	
	2X	8X	2X	8X
Skilled	63.84% (11.42)	78.34% (11.35)	63.63% (15.13)	79.84% (11.32)
Less-Skilled	57.89% (10.20)	67.76% (13.78)	62.85% (12.34)	71.46% (15.55)
Overall	60.87% (11.18)	73.05% (13.64)	63.24% (13.74)	75.65% (14.17)

Table 6

Exp 1 & 2: Mean (Standard Deviation) Reaction Times of Skill Group in Each Visual Field and Amount of Experience.

Amount of Experience	LVF		RVF	
	2X	8X	2X	8X
Skilled	1214 ms (388)	1109 ms (304)	1203 ms (394)	1079 ms (271)
Less-Skilled	1256 ms (388)	1185 ms (373)	1262 ms (449)	1149 ms (337)
Overall	1235 ms (386)	1147 ms (341)	1233 ms (421)	1114 ms (306)

Figures

Figure 1. Sample distribution of Nelson-Denny reading comprehension scores (median indicated by green vertical line) for Exp. 1 participants.

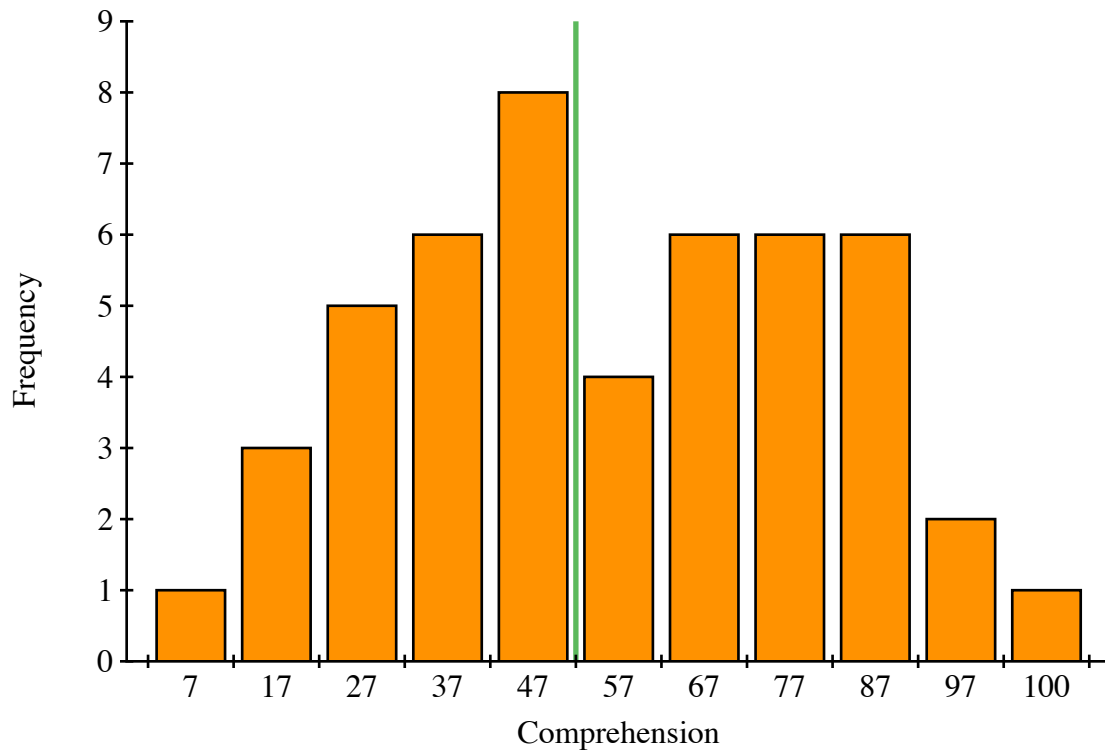


Figure 2. Exp. 1: Accuracy: Interaction between amount of experience and skill.

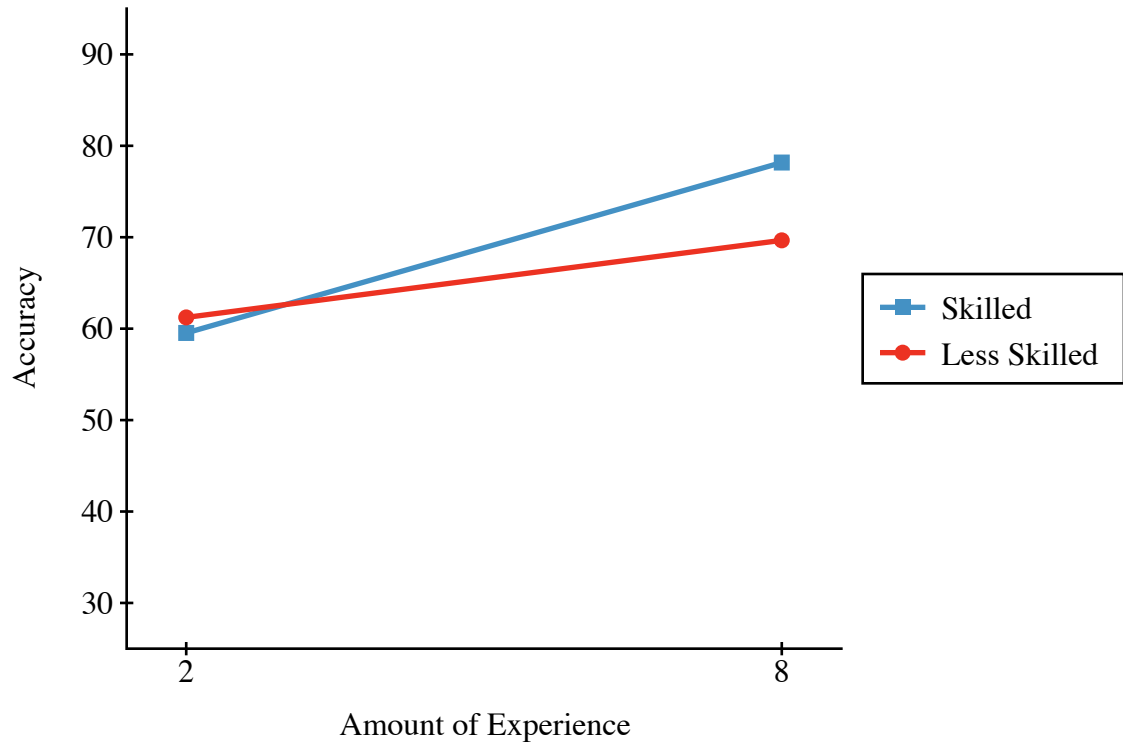
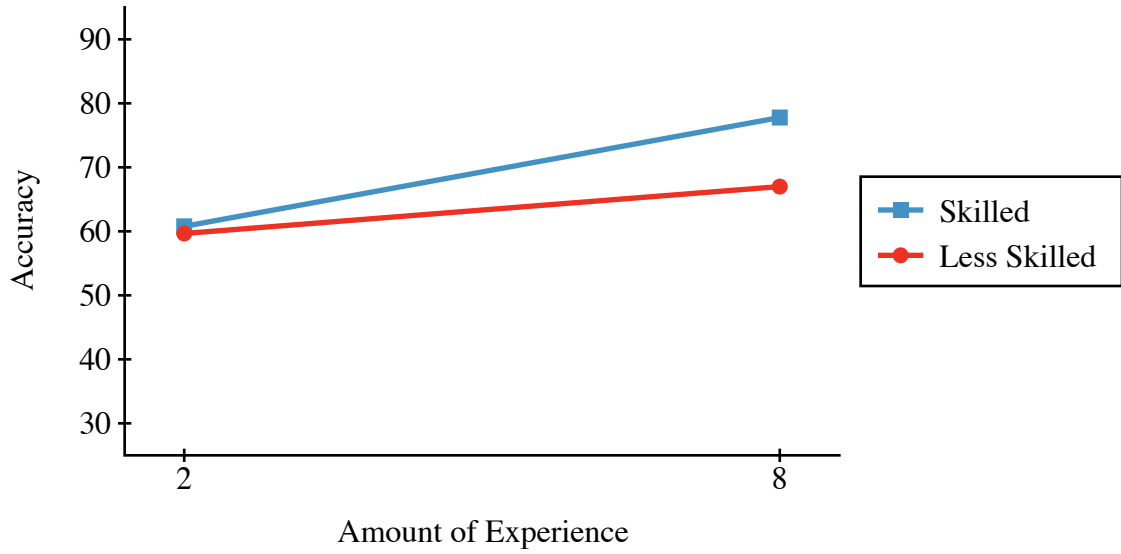


Figure 3. Exp. 1: Accuracy: Interaction between amount of experience and skill in each

VF.

a. lvf/RH.



b. rvf/LH.

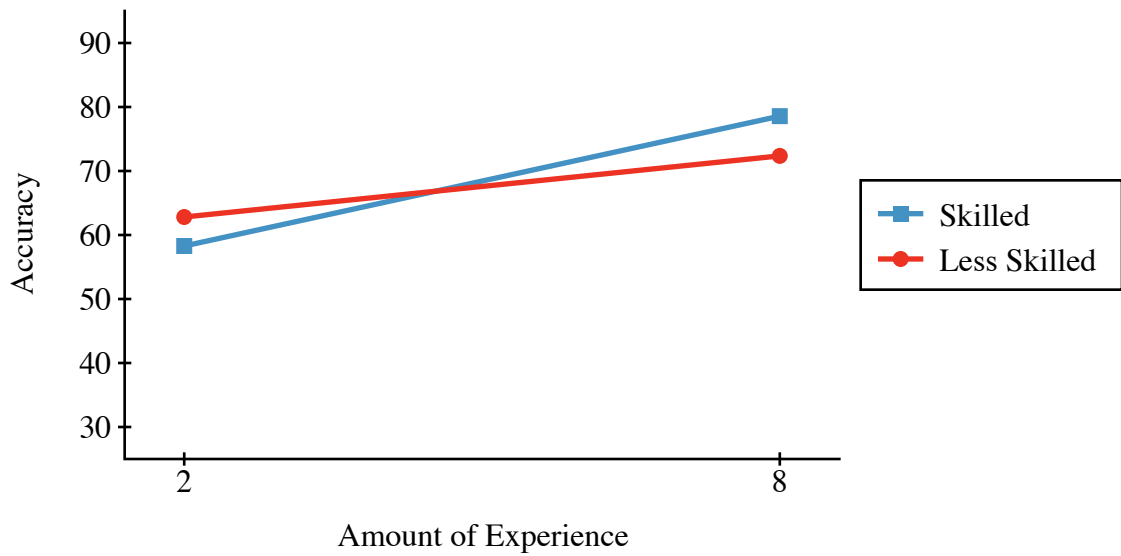


Figure 4. Sample distribution of Nelson-Denny reading comprehension scores (median indicated by green vertical line) for Exp. 2 participants.

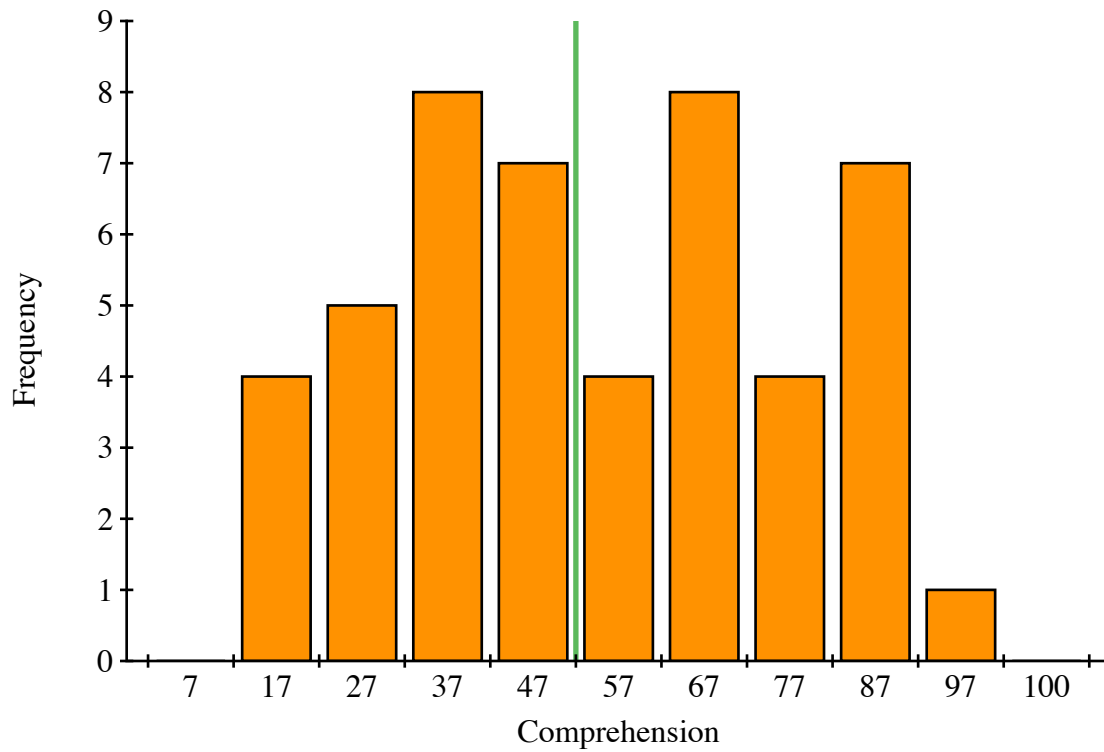


Figure 5. Exp. 2: Accuracy: Interaction between skill and VF (in English condition).

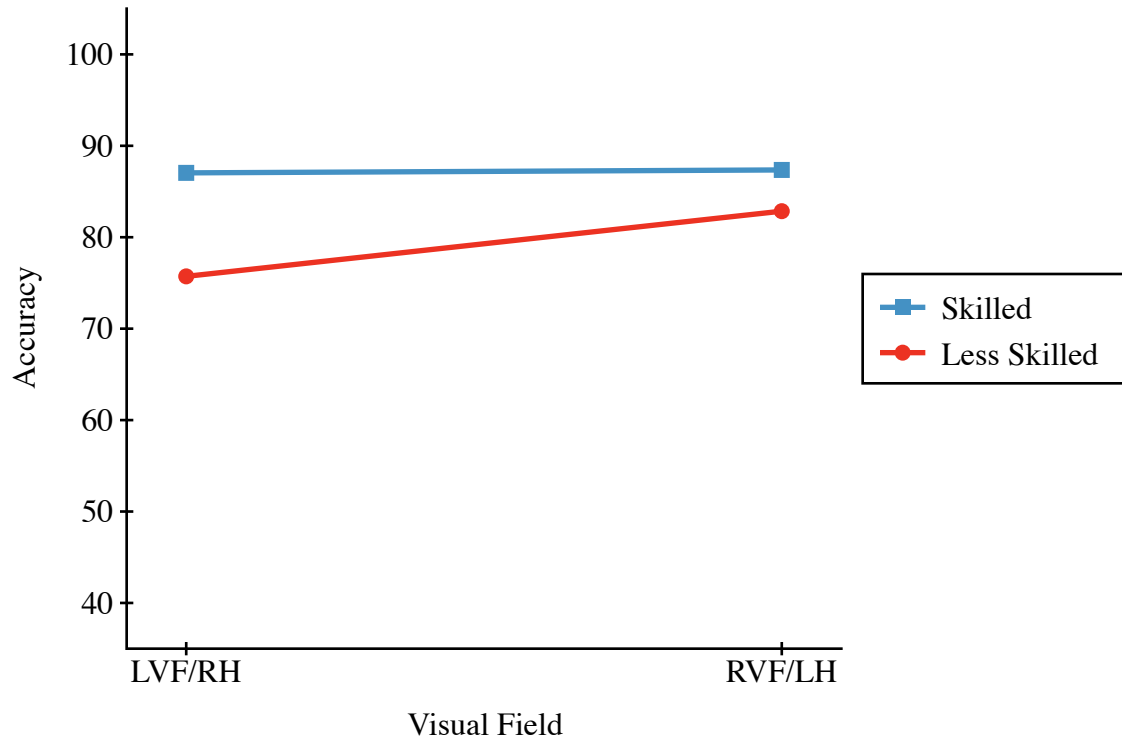


Figure 6. Sample distribution of Nelson-Denny reading comprehension scores (median indicated by green vertical line) for combined Experiment 1 and Experiment 2 participants.

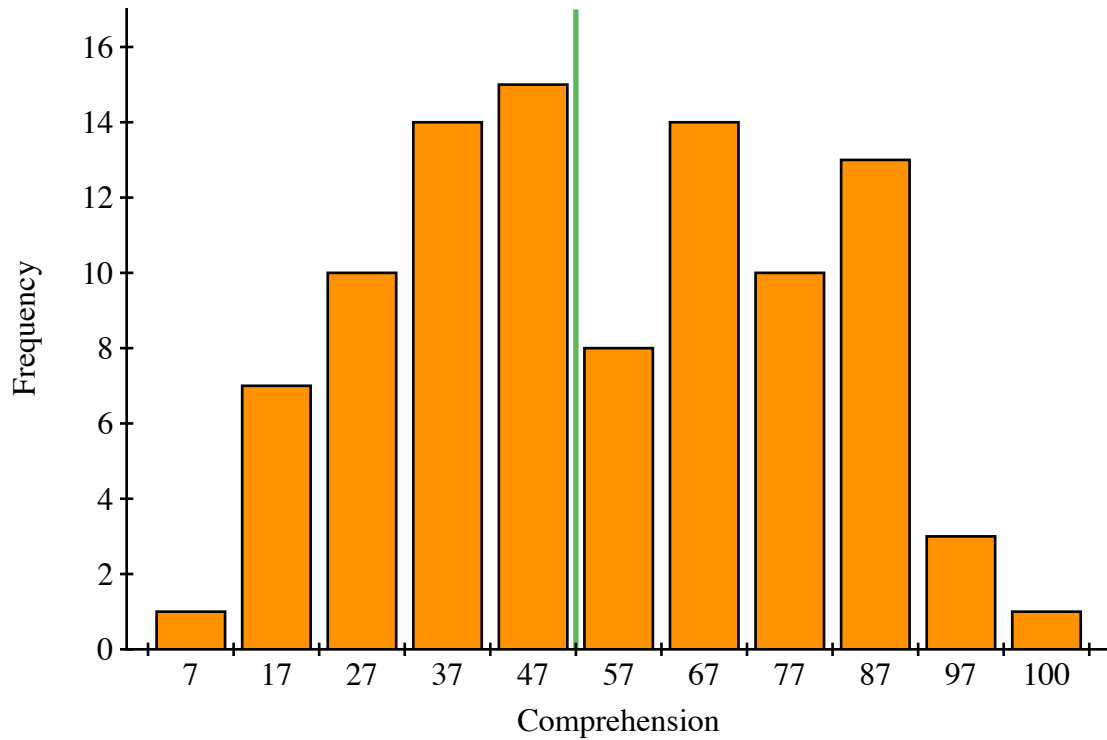


Figure 7. Exp. 1 & 2: Accuracy: Interaction between amount of experience and skill.

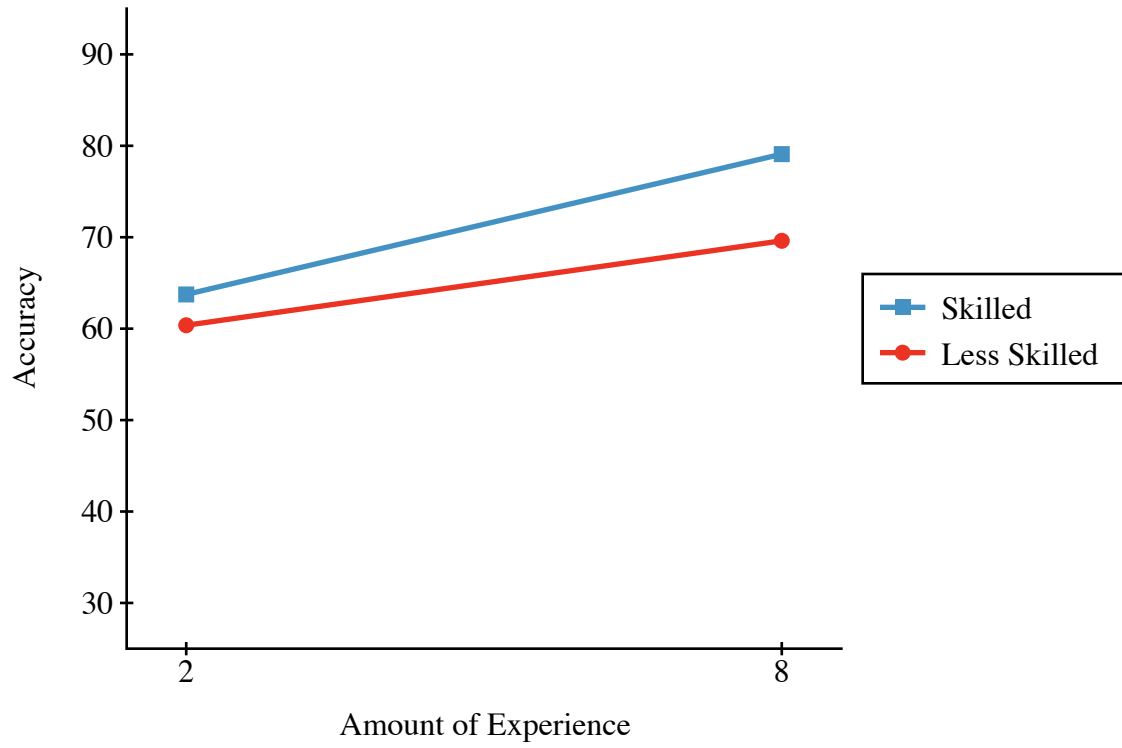


Figure 8. Exp. 1 & 2: Accuracy: Interaction between amount of experience and skill in RVF/LH.

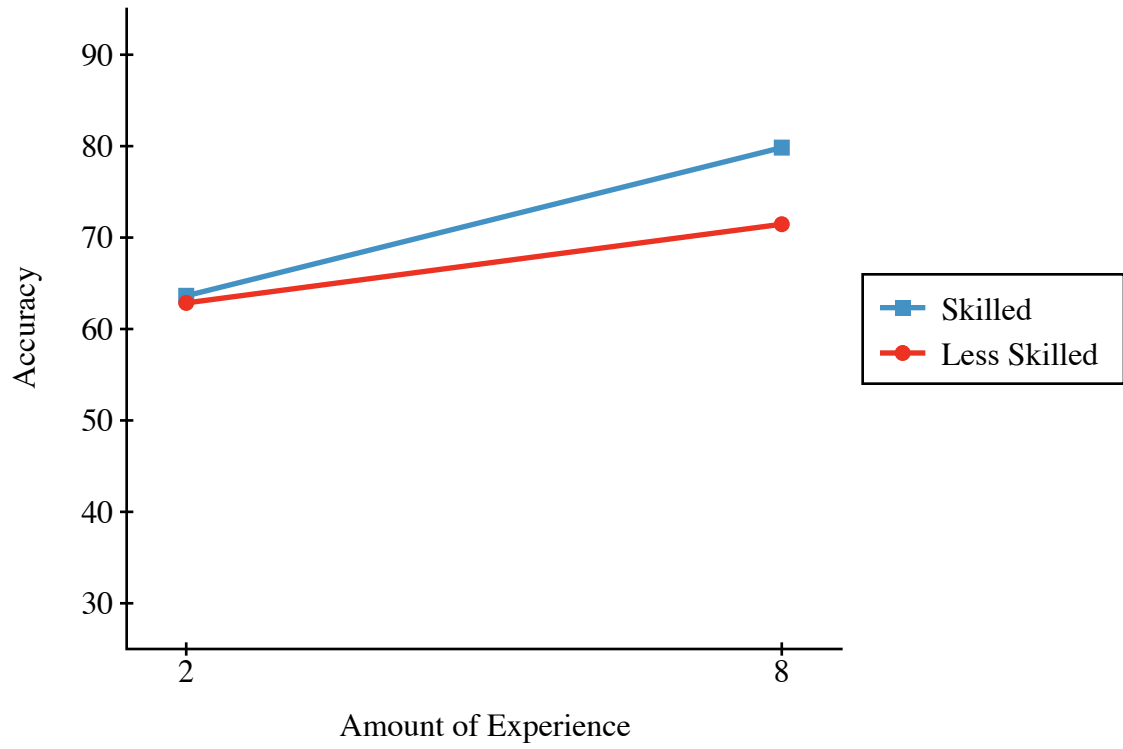


Figure 9. Exp. 1 & 2 – Top Bottom 25%: Accuracy: Interaction between visual field and skill for Lingo items.

