HEMISPHERIC CONTRIBUTIONS TO LANGUAGE COMPREHENSION

Word and Message-level Processing Mechanisms of the Right Cerebral Hemisphere.

by

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This thesis is presented for the degree of
Doctor of Philosophy
at Murdoch University.

2009

I declare that this thesis is my own account of my research and contains as its main content work which has not previously been submitted for a degree at any tertiary institution.

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ABSTRACT

Recent research into hemispheric differences in sentence comprehension has produced a puzzling disparity between the results from behavioral studies on neurologically normal individuals and studies utilizing other methods such as electrophysiology, neuroimaging and the investigation of neuropsychological patients. The former approach tends to produce results that indicate a restriction of the right hemisphere (RH) to lower-level processing mechanisms that are comparatively less sensitive to context than the left hemisphere (LH), while the combined findings of the latter approaches suggest that not only is the RH capable of processing language at a higher level, it is particularly sensitive to contextual information and, furthermore, this may form part of the special role of the RH in language tasks. Accordingly, the present series of studies employed a normal-behavioral approach to further investigate the underlying processing mechanisms of the RH during sentence comprehension tasks. In each of the four experiments, right-handed adult participants completed a computer-based lexical decision task where reaction time and error rates were recorded. Stimuli were always

centrally-presented, followed by a laterally-presented target word or non-word. In the first experiment, the sensitivity of the RH to message-level meaning was investigated by assessing whether it benefits from additional contextual information in sentences that was not the result of simple word-level associations. The remaining experiments aimed to examine several current models of RH language processing; specifically, they examined the applicability of the coarse-coding hypothesis (Beeman, 1993) and the integrative processing model (Federmeier, 2007) to RH sentence processing. The combined results of the four experiments lead to several conclusions. Firstly, this series of investigation consistently demonstrated that the RH does display a sensitivity to message-level processing that appears to be at least equivalent to that of the LH. This conclusion is uncommon in the normal-behavioral literature, but is consistent with evidence produced by other methodologies. Secondly, the coarse-coding hypothesis is insufficient in explaining RH language processing at the sentential level. Although there is considerable evidence in support of the coarse-coding model of RH processing of individual words, the findings of the present investigations do not support its applicability beyond this level. Thirdly, the integrative/predictive distinction between RH/LH language processing also appears to have limited applicability beyond sentence fragments and may instead be reflective of higher-level processing differences (e.g., wherein the RH may utilize a para-linguistic situation-model processing method whereas the LH may rely purely on a linguistic mechanism). Based on these conclusions, the present series of investigations appears to have resolved the inconsistent finding previously prominent in normal-behavioral literature and goes some way in determining the applicability of current models of RH language processing.

ACKNOWLEDGEMENTS

I wish to sincerely thank my primary supervisor, Jeffrey Coney, for his guidance, humour, enthusiasm and support throughout my postgraduate study. I could not have asked for a better mentor.

I also wish to acknowledge and thank my secondary supervisor, Marjorie Collins, for her extremely useful comments on the final drafts of several chapters, along with a number of anonymous reviewers whose thoughtful critiques (provided as part of the peer-review process for publication) were invaluable.

Finally, I would like to extend my gratitude to my family and friends for their unwavering support and encouragement.

LIST OF ORIGINAL PUBLICATIONS

This thesis comprises the following publications:

1. Gouldthorp, B. & Coney, J. (2009). Message-level processing of contextual information in the right cerebral hemisphere. *Neuropsychologia, 47,* 473-480.

2. Gouldthorp, B. & Coney, J. (2009). Right hemisphere language processing: The effects of summation priming. Submitted for publication.

3. Gouldthorp, B. & Coney, J. (in press). Integration and coarse-coding: Right hemisphere processing of message-level contextual information. *Laterality: Asymmetries of Body, Brain and Cognition.*

4. Gouldthorp, B. & Coney, J. (2009). Right hemisphere use of contextual information in predicting targets. Submitted for publication.

Publication of work undertaken prior to initiation of this thesis:

1. Gouldthorp, B. & Coney, J. (2009). The sensitivity of the right hemisphere to contextual information in sentences. *Brain and Language, 110,* 95-100.

CONTENTS

1. INTRODUCTION

1.1 Overview

The dominance of the left cerebral hemisphere (LH) in language processing and production has been repeatedly demonstrated over the past few decades, through studies of hemispherectomies, commissurotomies, and lateralized lesions (e.g., Dennis & Whitaker, 1976; Gazzaniga, 1970; Gazzaniga & Sperry, 1967; Zaidel & Peters, 1981), and through studies that have examined the intact brain by utilizing techniques such as brain-imaging, the measurement of event-related brain potentials (ERPs), and the lateralized presentation of stimuli (e.g., Faust & Babkoff, 1997). The early assumption that the RH plays a relatively minimal part in language processing is unsurprising given that a superficial examination of a patient with unilateral right hemisphere damage (RHD) would usually reflect limited language deficits; these individuals tend to have normal syntax and phonology, and appear able to converse relatively normally (Gardner, Brownell, Wapner, & Michelow, 1983). In more recent times, however, studies have also produced evidence for a distinct right hemisphere (RH) involvement in certain areas of language comprehension (e.g., Coulson, Federmeier, Van Petten, & Kutas, 2005; McDonald, 1996; St.George, Kutas, Martinez, & Sereno, 1999). In particular, the RH appears particularly important in utilizing context and deriving the meaning, or "gist", of language. Thus, a more detailed examination of a patient with RHD would often result in the observation of a range of deficits, including a difficulty in comprehending metaphoric relationships in language (Brownell, Simpson, Birhle, Potter, & Gardner, 1990), in extracting the theme or moral of a story or conversation

(Gardner et al., 1983), in integrating the elements of an account into a coherent narrative (Delis, Wapner, Gardner, & Moses, 1983; Wapner, Hamby, & Gardner, 1981), in comprehending the relationships between an utterance and its context (Joanette, Goulet & Hannequin, 1990), and in correctly interpreting jokes and sarcastic utterances (Birhle, Brownell, Powelson, & Gardner, 1986; Brownell, Michel, Powelson, & Gardner, 1983; McDonald, 1996). That the RH plays an integral, albeit less overt, part in language processing is thus rarely challenged in the contemporary literature. Instead, the current point of contention is how the hemispheres differ in regard to the underlying processing mechanisms that form the basis for their relative language capacities.

Intriguingly, the conclusions that are made relating to the processing capacities of each hemisphere differ considerably depending on the methodology utilized in the investigation. Behavioral[1] studies on neurologically normal individuals (hereafter referred to using the abbreviated term “normal-behavioral”) tend to produce results that indicate a restriction of the RH to lower-level processing mechanisms that are comparatively less sensitive to context than the LH (e.g., Faust, Babkoff, & Kravetz, 1995; Faust & Chiarello, 1998; Faust & Kravetz, 1998). Conversely, studies utilizing alternative methods such as electrophysiology, neuroimaging and investigation of neuropsychological patients paint quite a different picture. The combined findings of these alternative methodologies suggest that not only is the RH capable of processing language at a higher level, it is particularly sensitive to contextual information and,

[1] In view of the fact that the publications included in later chapters of this dissertation were required to use U.S. English this spelling convention was applied throughout all chapters, despite the dissertation being submitted at an Australian university, in order to preserve consistency of spelling.

furthermore, this may form part of the special role of the RH in language tasks (e.g., Coulson et al., 2005; Federmeier & Kutas, 1999).

The collective purpose of the present studies was thus to further investigate the role of the RH in sentence comprehension, particularly in regard to its use of contextual information, and reconcile the discrepant evidence produced by the normal-behavioral studies with the evidence produced by the alternative methodologies. While this may be partially attributable to the fundamental difference in the on-line status of these approaches (e.g., behavioral methodologies utilize off-line measures and are thus more likely to show null effects when the processing of interest occurs prior to the end-point measure), it is not a sufficient explanation given that hemispheric effects consistent with those observed in the other approaches *have* been observed in behavioral studies. An initial investigation (conducted prior to the initiation of the present Doctoral research program; Gouldthorp & Coney, 2009) indicated that the inconsistent evidence produced by studies utilizing a normal-behavioral approach is likely to have been, at least partially, due to the presence of confounding variables that have generally served to disadvantage, and therefore underestimate, the processing capacities of the RH. It provided an early demonstration that normal-behavioral research can reveal evidence of a RH sentence comprehension capacity that is more consistent with the results of other methodologies provided careful attention is paid to the simplicity and consistency of sentence structure, to the depiction of concrete and easily imagined scenarios, and to ensuring that sentence comprehension is probed with words that are known to be readily processed by the RH.

Accordingly, the present series of studies employed a normal-behavioral approach to further investigate the underlying processing mechanisms of the RH during sentence comprehension tasks. The first of the four experimental studies undertaken addressed the question of the relative use of sentential context by each hemisphere. The remaining studies investigated the underlying processing mechanisms employed by each hemisphere when utilizing sentential context and addressed the contradictory theoretical models of hemispheric language processing that have been proposed in the recent literature. The following subsections initially provide an exposition of the methods employed in this area, followed by a review of the empirical evidence of hemispheric differences derived from these various methodologies and a consideration of the applicability of this evidence to various theoretical models of RH text comprehension. This review of the language processing literature, particularly in relation to evidence of hemispheric differences, is thus intended to provide a rationale for the present series of investigations.

1.2 Methodologies used in the investigation of RH language processing

1.2.1 Normal-behavioral methodology

Investigations of hemispheric differences in language processing that employ behavioral measures (e.g., recording RT and accuracy) of neurologically-intact individuals ("normal-behavioral" methods) generally utilize a split visual field priming paradigm. The basic procedure involves a prime word or sentence being centrally presented on a screen, followed by the presentation of a target to the left or right visual field, while the participant maintains central fixation. Visual stimuli received by the retinas of both eyes to the right of the central fixation point (the right visual field (RVF)) are initially transmitted only to the LH via contralateral visual pathways, and vice versa (Beaumont, 1982). Although information can be transferred via the corpus callosum after 10-15ms (Hoptman & Davidson, 1994), evidence from a number of studies indicate that the callosal transfer is incomplete and does not always occur (for a review, see Federmeier, 2007).

The reliability of the split visual field paradigm in reflecting differential hemispheric processing is nonetheless contingent on a number of factors. Firstly, target eccentricity must be large enough to avoid any areas of bilateral projection (i.e., around the central fixation point); Young (1982) advises the use of target offsets of 2-6^{o} of visual angle. Secondly, target presentation times must be short enough so as to avoid saccadic eye movements bringing the laterally presented item into central vision; this varies as a function of target eccentricity as the distance of the necessary movement will affect the minimum presentation time needed (Bartz, 1962) but an exposure duration of 150ms is generally considered acceptable (Young, 1982). Thirdly, when making inferences about hemispheric processing based on behavioral measures from a group of participants, it is essential that the researcher is confident that the data is derived from consistent patterns of lateralization. Participants are thus usually restricted to right-handers, given that these individuals consistently display the lateralization of language dominance to the LH, whereas for left-handers the lateralization patterns are less consistent (Corballis, 1983).

A range of other factors have also been controlled for by some prior studies but their relative necessity is far more controversial than the above mentioned factors. For example, some studies will restrict their participant sample to include only males due to research that indicates females are less lateralized than males (Harris, 1980), although a number of meta-analyses on studies using visual-field paradigms (Boles, 1984; Fairweather, 1982; Hiscock, Inch, Jacek, Hiscock-Kalil, & Kalil, 1995) and functional-imaging (Sommer, Aleman, Bouma, & Khan, 2004; Sommer, Aleman, Somers, Boks, & Kahn, 2008) have failed to identify any consistent sex-differences in the lateralization patterns of language. Nonetheless, of those that have identified sex differences (e.g., Voyer, 1996), the LH advantage in language tasks was found to be less strong in females than in males. The use of a predominantly female sample in a language lateralization study is therefore unlikely to be problematic, providing a significant LH advantage for absolute RTs is identified. Another factor that receives some debate in the literature is the response task itself. Many studies utilize a lexical decision task (LDT), in either a go-nogo format (i.e., responses are only made for the identification that an item is a word) or go-go format (i.e., responses are made for the identification of both words and nonwords). Studies by Perea, Rosa, and Gomez (2002) and Gomez, Ratcliff, and Perea (2007) compared the go/no-go LDT with the 2-choice (yes/no) LDT and found that the core information on which decisions were based did not differ between them, indicating that there is no difference in the crucial cognitive operations involved in assessing lexical status. The rationale for selecting the go/no-go or go/go procedure thus rests on the theoretical questions under investigation (e.g., if RTs to nonwords are not relevant to the theoretical questions then the go/no-go LDT would involve no loss of data but would potentially minimize error variance associated with response programming and so produce significantly faster and less variable responses). Similarly, measurement of RTs and accuracy for vocal response naming of targets has been used as an alternative to manual-response LDTs. The use of this response task in studies investigating hemispheric processing is somewhat surprising given that vocal responses will nearly always be initiated by the LH (Young, 1982) and would thus be less sensitive to RH processing than LDTs (Gazzaniga, 1983). The use of a vocal response is also likely to have important implications for hemispheric arousal or, alternatively, hemispheric load. Nonetheless, despite the clear potential for confounding effects in relation to the use of vocal responses in laterality tasks, some investigators consider the naming task to be preferable (e.g., Beeman et al., 1994).

Despite some of these potential differences in methodology, behavioral studies of language comprehension commonly rely on the use of priming. Single-word semantic priming paradigms have been shown to produce significantly faster RTs and higher accuracy in the correct identification of a target word when it is preceded by a semantically associated prime word compared to when it is preceded by a neutral item or unrelated word (Meyer & Schvaneveldt, 1971; Neely, 1976). It is argued that presentation of the prime word leads to activation of that concept node within the semantic network in long term memory and this activation spreads to related concept nodes, with the strength of activation diminishing as a function of relatedness (i.e., distance within the network from the original concept node; Collins & Loftus, 1975). The excitation of the neurons that represent the target word therefore nears the recognition threshold prior to its actual presentation, resulting in very little additional excitation being needed in order to make a correct response following its presentation.

This process results in significantly faster RTs for these primed targets compared to targets preceded by a neutral item (i.e., a baseline condition); when the RT to respond to the primed (related) target is subtracted from the time take to respond to the same target following a neutral item, a positive difference is an indication of the amount of "facilitation" the related target exhibited. Alternatively, unrelated items are sometimes selected as the baseline measure in designs where a true "neutral" item is difficult to achieve. This is, however, only acceptable if inhibitory effects of the experimental items are either very unlikely or of no theoretical interest. The facilitation effect, via spreading activation, is proposed to occur pre-lexically and occurs without conscious awareness or strategic intention (Neely, 1991). Inhibition of responding to a target can also occur; this is reflected by a negative difference when the RT to respond to the primed target (often an unrelated word) is subtracted from the RT to respond to the same word preceded by the neutral item. In contrast to facilitation, however, inhibition is argued to reflect a strategic process in which the presented target is compared to an expected set of potential targets related to the prime (Neely, 1991). This suggests that the prime is used to form expectancies about possible target words and the occurrence of unexpected target words involves the redirection of attention and thus slows the response (Fischler & Bloom, 1985). Compound-cue theory proposes a quite different mechanism of priming to spreading activation or expectancy based processing. Ratcliff and McKoon (1988) and Dosher and Rosedale (1989) proposed that instead of information being temporarily activated in long-term memory, presented items (e.g., a "prime" and a "target") are joined together in short-term memory to form a compound cue which is then used to probe long-term memory. A correct response (e.g., in lexical decision) is then accomplished by means of matching the compound cue with all items in long-term memory. Facilitation of related targets therefore occurs due to the compound cue being highly familiar in long-term memory and therefore accessed more readily, whereas inhibition occurs due to the compound cue being much less familiar. McKoon and Ratcliff (1992) claim that the advantage of this model is that it accounts for mediated priming effects (where a prime is connected to a target only via a mediator) more readily than an automatic spreading activation account.

Although single-word semantic priming paradigms have been used to inform researchers on hemispheric differences in the processing of single words or pairs of words, sentence primes are commonly used as a means of investigating sentence-level processing and the effects of context. Schwanenflugel and Shoben (1985) proposed that sentences can produce different levels of facilitation in lexical decisions of single words due to varying levels of contextual constraint that, as outlined earlier, can be derived from both the semantic and syntactic information within the sentence. They argued that sentences that are highly constraining simultaneously increase expectations for certain words while decreasing expectations for other words. Constraint is often quantified as the probability of the dominant (i.e., the most frequent) response to the context in a completion task. This completion task is referred to as the "cloze" procedure (Taylor, 1953), where the sentence-final word is removed from a sentence to produce a fragment. These sentence fragments are then presented to participants who complete the sentence with the first word that comes to mind. The proportion of participants that produced the sentence-final word is the "cloze probability", wherein high probabilities reflect high sentential constraint for that sentence-final target and lower probabilities reflect weaker constraint. Nonetheless, the labeling of constraint categories appears quite variable in the literature; for example, Traxler and Foss (2000) defined low-constraint in their study as a cloze probability of less than 0.75, and Schwanenflugel and Shoben (1985) defined low-constraint as a cloze probability of 0.68. It appears, then, that the convention is to use relative labeling for the constraint conditions within a study rather than any consistent inter-study probability criterion. When the sentence-priming paradigm is used in studies investigating hemispheric language capacities, sentence fragments are usually presented centrally (either visually or aurally) and the visual target word or non-word is presented to either the LVF or RVF. In these instances, consistent with single word priming paradigms, the absolute lexical decision latencies are consistently higher for targets presented to the LVF/RH than to the RVF/LH, presumably reflecting a standard LH processing advantage for visual words. Thus, facilitation and inhibition effects are usually measured in order to make more direct comparisons between the hemispheres. That is, the increase or decrease in the absolute RT for each hemisphere relative to the corresponding neutral condition is compared, where neutral sentences such as “The next word is” provide a baseline measure of RT to the targets for each visual field. There has been some criticism in the literature of the validity of the assumption that the faster absolute RTs for targets presented to the RVF reflect the LH lexical processing advantage. For example, Kirsner and Schwartz (1986) argued that reading habits and directed attention might better account for the RVF superiority in lexical decision. This is presumably of particular concern for sentence fragments, as through learned reading behaviors participants may expect to see the sentence-final target presented to the right of where the sentence fragment had been. This argument has not, however, held against empirical testing. Faust, Kravetz, and Babkoff (1993a) presented participants with Hebrew sentence fragments which, given it is written and read from right to left, should not result in a RVF superiority given that attention should be directed to the LVF. They found a significant RVF superiority when absolute RTs were compared. As such, the use of sentences and sentence fragments as primes followed by laterally presented target words appears to be a valid means by which to investigate hemispheric differences in language processing at the sentence level.

1.2.2 Other methodologies

Early investigations into the contribution of each cerebral hemisphere to language tasks have studied the abilities and deficits of clinical populations, involving individuals who have, after childhood, undergone a commissurotomy (i.e., "Split-brain" patients, who have provided researchers with a unique opportunity to test each hemisphere in isolation; Taylor & Regard, 2003), hemispherectomy, or have acquired unilateral brain lesions (generally as a result of cerebro-vascular disease or brain tumor) (Gainotti, Caltagirone, & Miceli, 1983; Perecman, 1983). Split-brain research is generally interpreted with caution given that these patients might have unusual cerebral organization as a result of early brain damage from the epileptic seizures that necessitated the commissurotomy procedure (Gazzaniga & LeDoux, 1978). Investigations using patients with acquired brain-damage are more common as they are less susceptible to this difficulty (as most will confirm the unilateral nature of the lesions using CT scans as part of a pre-testing screening procedure), but nonetheless must take care to match the normal control-group for differences in age, sex, and education. A serious limitation of this methodological approach is the small sample size that often results from the careful exclusion criteria that must be applied to the participants

(Gainotti et al., 1983). Transcranial magnetic stimulation (TMS), however, can avoid this difficulty through simulating lesions on otherwise neurologically intact individuals. TMS is a non-invasive application of a strong, but relatively focused, magnetic field to the scalp that induces a depolarization or spiking of underlying neural tissues (Devlin & Watkins, 2002). This leads to a cortical disruption that is, in effect, a “virtual lesion” (Pascual-Leone, Walsh, & Rothwell, 2000) and can be used to draw causal inferences about the role of specific brain regions in individual cognitive tasks. Although TMS does not yet appear to have been used in specific attempts to investigate the role of the RH in sentence comprehension, there are a small number of studies that are beginning to utilize this method in related investigations (e.g., novel metaphor comprehension; Pobric, Mashal, Faust, & Lavidor, 2008). Despite TMS gaining popularity in the literature, there are questions relating to the methodology that remain unanswered and, as such, limit the extent to which the findings can be reliably interpreted. For example, the depth of the brain stimulation, and whether activity is always localized to the stimulus site or may spread through neural pathways, are unable to be determined (Devlin & Watkins, 2002). Additionally, Pascual-Leone et al. (2000) note that different neural elements in differing areas of the brain may vary in the level of sensitivity to the stimulation. Nonetheless, whether through the investigation of individuals with acquired brain damage or through “virtual lesions”, the observation of deficit (or retention) of specific language skills following lesions to specific areas of the brain provides useful insight into hemispheric functioning.

Unlike traditional neuropsychological studies, neuroimaging and electrophysiological studies are also able to assess “normal” individuals and therefore provide more weight to the applicability of generalizations about hemispheric functioning to neurologically intact populations. Neuroimaging studies rely on the fact that increased activation of a neuronal area is associated with increased blood supply, and vice versa (Rugg, 1999). Positron emission tomography (PET) and functional magnetic resonance imaging (fMRI) are methods of neuroimaging that are becoming more frequently encountered in the language processing literature. Images identifying areas of regional cerebral blood flow (rCBF) during different experimental conditions are compared to identify different areas of neural activity resulting from the experimental manipulations or behaviors (Rugg, 1999). As a result, inferences can be made as to the areas of the brain that are involved in particular language tasks. Despite the advances being made in neuroimaging techniques, they are nonetheless somewhat limited by the relatively poor temporal resolution (in the order of seconds, while many linguistic processes occur at the millisecond level). Other factors, such as equipment cost, sample sizes, and general methodological constraints, also reduce the widespread suitability of this technique.

A number of recent studies have used an electrophysiological approach which, unlike fMRI and PET, measures neural activity directly. A region of neurons oriented in roughly the same direction will, if polarized or depolarized simultaneously, produce an electromagnetic field as a result of the summation of their individual dipole moments (Kutas, Federmeier, & Sereno, 1999). Event-related potentials (ERPs) reflect scalp-recorded changes to the ongoing encephalogram (EEG; the electrical component of the electromagnetic field), which occur in a response to an external event (e.g., the presentation of a word) (Rugg, 1999). One of the common ERP measures used in language comprehension investigations is the N400, which is a negative voltage peaking at approximately 400ms following stimulus onset and has been shown to have a strong inverse relationship with priming resulting from the preceding stimulus or context (Federmeier, 2007).

1.2.3 Summary of methodologies

Although each provides a unique insight into hemispheric processing capacities, all of the methodological approaches have their limitations. No single method is suitable by itself; each provides a piece to the puzzle and it is the combination of these various pieces that allows us to build an informed understanding of the workings of the brain. Where inconsistent results are found across methodologies, it is essential that researchers examine why the discrepancy exists; to fail to do so runs the risk of further investigations being based on assumptions derived from the earlier findings that are, at best, questionable. The result of this is a body of literature wherein considerably different conclusions are being made depending on methodology.

1.3 Review of literature and current understanding

1.3.1 Models of text comprehension and hemispheric involvement

Early models of text comprehension focused on bottom-up vs. top-down processing, and proposed an analytic/holistic processing distinction between the hemispheres. Specifically, Taylor and Taylor (1983) proposed that the RH operates in a holistic manner, while the LH processes in an analytical manner. More recently, Faust et al. (1993b) proposed that a holistic processing strategy could be operationalized in reading as top-down processing whereas an analytical processing strategy would rely more on bottom-up processing. Facilitation resulting from context biasing a top-down processing strategy should thus be greater for targets processed by the RH than by the LH. Surprisingly, they found that increased amounts of contextual information contributed more to the speed and accuracy of target identification by the LH than it did for the RH. This finding suggested that top-down processing might not be a suitable operationalization of a holistic processing style and, furthermore, the increased syntactic and semantic constraint produced by the increased words in the contextual sentences may have produced an advantage for an analytical linguistic mechanism. Faust et al. (1995) thus proposed that the RH might operate in a modular manner (i.e., relying purely on the word-level information) whereas the LH operates interactively (i.e., utilizing information from both the word-level and the message-level derived from the sentence context).

This distinction between word and message-level processing appears to have taken precedence in the recent literature over the traditional modular vs. interactive models, particularly in relation to hemispheric processing differences. Word-level processing is proposed to utilize lexical information and basic relations between individual words in sentences to produce context effects. That is, facilitation can occur as a result of the combination of content words in a sentence rather than the integration of the message-level sentence meaning (Duffy, Henderson, & Morris, 1989). Nonetheless, the contextual basis derived from these word-level processes would be somewhat limited due to the restriction of processing to associations between combinations of words as opposed to higher-level meaning. In contrast, message-level mechanisms operate by combining syntactic, semantic, and pragmatic information in order to build a conceptual representation of the meaning of the sentence (Morris, 1994). Faust et al. (1995) suggested that, while in a neurologically intact brain these processes work in conjunction, the RH is predominantly restricted to the word-level mechanisms whereas the LH is also able to interpret contextual information by using message-level mechanisms.

Although this distinction underpins much discussion in the recent lateralization literature as to the relative contributions of each cerebral hemisphere to language processing, current psycholinguistic models often conceptualize text comprehension in terms of a textbase-situation model distinction. Johnson-Laird (1983) argued that discourse can be formed by two different kinds of representations. A propositional representation represents the basic meaning explicitly represented in the text (i.e., the *textbase*), whereas additional information based on prior knowledge and experience (extracted from long-term memory) may be integrated with the textbase to form the *situation model*. As a result, the situation model can contain not only the propositional information given explicitly in the text, but also implicit information that is inferred based on the reader's background knowledge (Therriault & Rinck, 2007). These two representations are also reflected in Van Dijk and Kintsch's (1983) propositional representation-discourse model distinction. Long and Baynes (2002) attempted to investigate whether the propositional representation and the discourse model may be differentially constructed by, or represented in, each of the hemispheres. They argued that, given the RH has been consistently demonstrated to have difficulty in utilizing the syntactic information necessary to construct a propositional representation, this may be either wholly stored or at least initially constructed by the LH. They further suggested that, in contrast, the RH may represent the discourse model. While their study produced strong results that the propositional representation resides in the LH, their findings related to the RH's involvement in the discourse model were less clear. They suggested that processing differences at the word-level, in which lexical access by the RH is coarsely-coded whereas for the LH it is finely-coded (Beeman, 1993), may explain the hemispheric differences that they observed in relation to the discourse model.

The word/message-level hemisphere distinction would appear to suggest that the LH processes and constructs representations of text at both the propositional/text-base and at the discourse/situation model level, wherein the contribution of the RH is limited to the word-level associations that the LH then applies when extracting meaning or, perhaps more importantly, when revision or maintenance of an initial construction is required. This implies that the RH does not construct a representation of the text per se; it simply uses automatic spreading activation to identify associations with presented words (i.e., those in the sentence). For neurologically intact individuals, the LH is then able to utilize the RH's broader lexical activation in building the discourse model. This conclusion is, however, intuitively difficult to reconcile with evidence that suggests the RH is essential for integrating information presented implicitly in the sentence with world knowledge. That is, if the RH is processing purely at the word-level then, by definition, it is not able to access broader world-knowledge information that would enable the construction of a discourse-model. Nonetheless, the evidence in the literature regarding the RH's ability to process at the message-level is inconsistent and has led to several contradictory models being developed that attempt to explain the special role of the RH at either the word- or the message-level.

1.3.2 The role of the RH in language processing: Review of current evidence

1.3.2.1 Evidence from electrophysiological, neuropsychological and neuroimaging methodologies

The evidence produced by studies utilizing electrophysiological, neuropsychological and neuroimaging methodologies are considerably more consistent with one another than the findings produced by the majority of behavioral studies on normal participants ("normal-behavioral"). The evidence from these approaches appears to converge on the conclusion that that the RH uses contextual information during language processing and appears to do so at a level that is equivalent, and in some instances superior, to the LH; this is inconsistent with the proposition that the RH is unable to utilize message-level processing or at least uses word-level processing preferentially.

Some of this evidence comes from studies on individuals with RH brain damage. As reviewed earlier, these individuals typically find it difficult to comprehend metaphoric relationships in language; to extract the theme or moral of a story or conversation; to integrate the elements of an account into a coherent narrative; to comprehend the relationships between an utterance and its context; or to correctly interpret jokes and sarcastic utterances. These sorts of studies suggest that the RH plays an important role in comprehending and integrating language and also in the application of contextual information. It seems the LH is far more literal in its interpretation of language, whereas the RH is able to use context to identify the overall meaning. Furthermore, Leonard, Waters, and Caplan (1997) found that, for patients with either unilateral LHD or RHD, both groups responded faster to sentences preceded by a supportive linguistic context than sentences presented in isolation, indicating that the RH does indeed make significant use of contextual information. Additionally, Brownell, Potter, Bihrle, and Gardner (1986) found evidence that the RH is important for reinterpreting and thus correctly comprehending contextual information. They found that, compared to the normal control group, patients with RHD demonstrated an impairment in reinterpreting their initial processing of the contextual information in order to integrate new information presented within a second sentence. That is, the RHD patients appeared to have difficulty in cohering the contextual information across the sentences in order to make an appropriate inference. More recently, Grindrod and Baum (2005) used a cross-modal procedure to present brain-damaged participants with four-sentence discourse passages ending in ambiguous words, followed by a visual target related to a meaning of the final word. They found that patients with RHD exhibited an impairment in the use of context, leading to the activation of word meaning on the basis of word frequency rather than on the contextual information provided by the passages.

Neuroimaging studies are generally consistent with the neuropsychological findings. In fact, imaging studies focusing on the comprehension of complex narratives or on non-literal language have sometimes found not just bilateral activation patterns, but a *predominance* of right hemisphere activity (e.g., Bottini, Corcoran, Sterzi, & Paulesu, 1994; St.George et al., 1999). For example, St.George et al. (1999) found a considerable RH involvement (as shown by fMRI) in the comprehension of untitled paragraphs of otherwise semantically vague propositions, providing evidence that the way in which the RH is able to integrate information into a coherent context means it may be particularly important in processing at the discourse level. Additionally, a meta-analysis on fMRI studies investigating higher-level text-comprehension found consistent activation of a number of areas within the RH (Ferstl, Neuman, Bogler, & Yves von Cramon, 2008). The findings of these sorts of studies suggest that the RH plays an important role in comprehending and integrating language and in the application of contextual information.

Electrophysiological results have added further weight to the findings of the previous two approaches. For example, Coulson and Wu (2005) measured ERPs to laterally-presented target words that were preceded by either funny sentences or non-funny controls (e.g., Nonfunny Control: "Everyone had so much fun jumping into the swimming pool, we decided to put in a little platform" compared to Funny: "Everyone had so much fun jumping into the swimming pool, we decided to put in a little water"). The results indicated that funny sentences compared to controls led to greater priming of LVF/RH target words than RVF/LH target words. Coulson and Wu concluded that the RH is better able to extract the humorous context from the sentences than the left. Moreover, a number of electrophysiological studies have provided strong evidence that not only does the RH utilize contextual information, it does so via message-level processing (e.g., Coulson et al., 2005; Federmeier & Kutas, 1999; Federmeier, Mai, & Kutas, 2005; Van Petten, 1993; Wlotko & Federmeier, 2007). For example, Federmeier and Kutas (1999) found evidence of greater RH semantic selectivity and more adherence to message-level plausibility than the LH. Federmeier et al. (2005) specifically tested the claim that the RH does not benefit from contextual information at the message-level. In their ERP study, sentence contexts (primes) provided different levels of message-level constraint on what were otherwise entirely plausible sentence-completion targets. They argued that if the RH was insensitive to message-level information, then no difference in facilitation should be observed between sentence contexts reflecting weak, as compared to high, message-level constraint. Their results, however, revealed more facilitation for LVF/RH targets following primes with high message-level constraint than those with low-constraint. Furthermore, the magnitude of facilitation was comparable to that observed in the RVF/LH. In another ERP study, Coulson et al. (2005) found that not only did both hemispheres process message-level information, but that they also did so in preference to word-level information when both were available. They further concluded that, although both hemispheres are primarily driven by message-level congruity during sentence reading, they utilize this information in different ways. This finding was replicated in a similar study by Wlotko and Federmeier (2007) in which facilitation for expected, as compared to unexpected, items in high-constraint sentences was equivalent across hemispheres, providing strong evidence against the proposition that the RH is wholly or partially insensitive to message-level meaning.

1.3.2.2 Evidence from normal-behavioral methodologies

In contrast, behavioral studies on normal participants have often suggested that the RH has little capacity for comprehension of sentences at the message-level of meaning, other than that which might be gleaned from activation of individual word meanings in the sentence (i.e., word associations). These results are in distinct contrast with the previous approaches that have been described. The proposition that the RH relies solely (or, in more recent research, predominantly) on word-level mechanisms is supported by several studies that have found that it is only in the LH that normal sentences are much more effective primes than the same words presented in a scrambled list (Faust et al., 1995; Faust & Chiarello, 1998). Furthermore, increasing the amount of context from one to three to six words produced larger priming effects when presentation was to the RVF/LH but not the LVF/RH (Faust et al., 1993b). Additionally, lexical decision latencies were increased for implausible compared to plausible sentence-final words when presented to the RVF/LH but not the LVF/RH. Faust and Babkoff (1997) take these findings as evidence that the LH is more sensitive than the RH to linguistic information conveyed at the sentence message-level. Furthermore, they argue that while the LH is able to suppress contextually inappropriate words or meanings, the RH's comprehension ability is compromised as a result of the "flooding" of irrelevant information due to its sustained activation of multiple meanings and associations.

Although the behavioral data provides some evidence that the RH is limited in its use of context and message-level processing, the data appears to be somewhat inconsistent. For example, Faust et al. (1995) reported that, although accuracy of responses for RH targets relative to left was not significantly affected by sentence anomaly, accuracy for both hemispheres was lower in the incongruent sentences than for an un-constraining neutral sentence. Furthermore, as RT measures were not reported, some doubt must be placed on the validity of inferences made by the authors about the underlying processes observed in the experiment (e.g., due to possible speed-accuracy trade-offs or, of more concern, if the reported effects were only present in the secondary measure (accuracy) and not in the primary measure usually used in speeded-response tasks (RT)). Chiarello, Liu, and Faust (1999) attempted to clarify some of these findings by appending an adjective to the subject of the sentence in order to strengthen the semantic relationship with the sentence-final target word. A baseline condition of neutral sentences was also included, against which the level of priming in each condition was assessed. The results were again inconclusive. While the experiment showed, as expected, that target words presented to the LH were primed by normal sentences but not by anomalous sentences, the RH displayed inconsistent priming across testing sessions. This inconsistency of priming resulted in the study failing to obtain a clear RVF/LH advantage for lexical decisions. In a more recent study by Chiarello, Liu, and Faust (2001), the lexical decision latencies for the final words of congruous and incongruous sentences, with and without a lexical associate, were compared. In the condition where lexical associates were present, facilitation for congruous targets was observed in both hemispheres. Conversely, when lexical associates were absent, no facilitation was observed for congruous targets and additionally, inhibition was observed in both hemispheres for incongruous targets. A study by Faust, Bar-lev, and Chiarello (2003) produced a similar pattern of effects. These results are inconsistent with the claim that the RH is sensitive only to word-level information (Faust & Chiarello, 1998). Long and Baynes (2002) investigated the prediction that the LH constructs a propositional representation of text whereas the RH constructs a discourse representation. Their results supported this notion and, moreover, indicated that the LH appeared to be encoding a message-level representation (that had a propositional structure) whereas the RH appeared to be constructing an associative network representation based on links between individual lexical items and related semantic concepts within the sentences. A follow-up study (Long, Baynes, & Prat, 2005), however, indicated that lexical-semantic priming was not sufficient to explain their RH priming results, although they were not able to rule out some contribution of the overlap of semantic relationships.

Notably, several behavioral studies of normal individuals have, in fact, demonstrated a RH sensitivity to context under certain circumstances. For example, Titone (1998) investigated hemispheric priming effects of dominant and subordinate meanings of homonyms using a cross-modal, divided visual field lexical decision task where sentences provided a context that supported either peripheral or central semantic features related to only the subordinate meaning. Results showed that following a neutral sentence context, only the dominant meaning was primed for both hemispheres. Both the dominant and subordinate meanings were primed for both hemispheres following sentences biasing the central semantic features of the subordinate homonym meaning. Following sentences biasing the peripheral semantic features of the subordinate homonym meaning, however, only the contextually-appropriate subordinate meaning was activated in the RH while the contextually-inappropriate dominant meaning was activated in the LH. This provides some evidence that the RH was making better use of contextual information than the LH. As noted by Titone, however, this finding could be explained by a RH sensitivity to weakly-associated words (Beeman, 1998) leading to activation of the subordinate meaning in the peripheral condition. In contrast, the LH was presumably unable to activate these weak associations and therefore effectively treated the peripheral-context as neutral (thus resulting in priming of the inappropriate, dominant meaning). Similarly, Faust and Kravetz (1998) found that greater priming occurred for the RH in high- rather than low-constraint sentences. They explained this, however, by arguing that as the high-constraint sentences had more words highly associated with the target than did the low-constraint sentences, the RH sensitivity to constraint/context most likely resulted from word-level processing mechanisms only. This tendency to assume the RH is relying purely on word-level processing is, although common in this area (e.g., Beeman, 1998; Chiarello, 1991), surprising; firstly, this assumption cannot be made without including a baseline measure of word-level priming (e.g., scrambled sentences) in order to show that processing beyond this level (i.e., at the message-level) is not occurring and, secondly, it is inconsistent with the results produced by studies in other methodologies demonstrating a RH use of message-level processes. Although some researchers in the normal-behavioral field now concede that the RH is not restricted solely to word-level processing they nonetheless maintain that it is far less sensitive to message-level information than the LH and that it relies mainly on the intra-lexical mechanisms (Faust et al., 2003; Faust, Barak, & Chiarello, 2006).

1.3.3 The role of the RH in language processing: Review of current theory

The discrepant evidence produced by the different methodologies has lead to two quite different and seemingly contradictory theoretical models being pursued. Based on the assumption that the RH is restricted (at least predominantly) to word-level mechanisms, the coarse-coding model (Beeman, 1998) of RH language processing is prominent in the normal-behavioral literature. In contrast, based on the assumption that the RH is able to utilize message-level processing to much the same extent as the LH, Federmeier (2007; Federmeier & Kutas, 1999) argued that hemispheric differences in language processing are better explained by the relative processes each uses when processing message-level information. This led to the proposal that the RH processes message-level information using an “integrative” strategy whereas the LH uses a “predictive” strategy. These models are clearly at odds given the former assumes a RH restriction to word-level processing and the latter assumes a full message-level processing capacity of the RH.

1.3.3.1 RH word-level processing: The coarse-coding hypothesis

Beeman (1998) proposed that the RH uses a “coarse coding” processing strategy that relies purely on word-level processing. This model suggests that the RH weakly activates a large field of both close and distantly associated words, resulting in extensive semantic overlap. In contrast, the LH uses “fine coding” wherein only highly related meanings are activated, resulting in activation of a narrower and more focused semantic field and there therefore being less chance of overlap between words. This model also assumes that the RH is restricted (at least predominantly) to word-level processing, whereas the LH is also able to use message-level processing. Evidence for this model comes primarily from summation priming experiments. Beeman et al. (1994) presented participants with three-word primes that were weakly related to a target and found more facilitation occurring for targets presented to the LVF/RH than for targets presented to the RVF/LH. Furthermore, they found that for targets presented to the LVF/RH, a single highly associated prime only produced facilitation equivalent to the three weakly associated summation primes. In contrast, for targets presented to the RVF/LH, far more facilitation was produced by the single highly associated prime than by the summation primes. There is, however, more recent evidence that suggests the special role of the RH for certain language tasks is not just by an initial coarse coding of the distantly related words, but rather the maintenance of this activation (Tompkins, Scharp, Meigh, & Fassbinder, 2008).

A number of authors (e.g., Anaki, Faust, & Kravetz, 1998: Beeman, 1998; Burgess & Chiarello, 1996) argue that evidence of a special role for the RH in tasks such as metaphor comprehension, cohering extended discourse, appreciation of humor, and making certain types of inferences (as reviewed earlier), can be explained by the RH's use of coarse-coding at the word-level. For example, Beeman, Bowden, and Gernsbacher (2000) found that participants named targets presented to the LVF/RH faster if they were related to predictive inferences but this did not occur for targets presented to the RVF/LH. They argued that the RH's activation of larger semantic fields would result in a greater likelihood that a concept that provides an inferential connection would be activated. Evidence of RH use of context has thus often been explained in the literature as resulting from the more diffuse activation of a wider range of meanings, therefore advantaging the RH as it permits a greater appreciation, and thus comprehension, of less usual relationships between words (Beeman 1998; Beeman et al., 2000). Conversely, Coulson and Wu (2005) suggested that instead of coarse-coding in the RH reflecting simply a sensitivity to word-level associations, it might activate a broader range of thematic and relational information. If this is the case, then a special role of the RH for discourse coherence (e.g., St. George et al., 1999) could be explained not just by an initial coarse coding at the word-level but by a general, overlapping activation of concepts at a message-level. The applicability of the coarse-coding hypothesis to more extended language tasks (e.g., across several sentences) therefore requires further investigation.

1.3.3.2 RH message-level processing: The Integrative vs. Predictive model

In direct contrast to the word-level coarse coding hypothesis of RH language processing, Federmeier's (2007; Federmeier & Kutas, 1999) model of language processing differences assumes both hemispheres utilize message-level processing of sentences. This model suggests that the LH utilizes an essentially top-down processing in order to predict upcoming words, whereas the RH utilizes an interactive bottom-up processing in order to integrate the new stimuli into the message-level representation. Evidence for this model comes originally from Federmeier and Kutas' (1999) ERP study in which pairs of sentences providing contextual information were presented, followed by sentence-final targets that were unexpected given the sentence context. For example, while the expected completion of the sentence context: "They wanted to make the hotel look more like a tropical resort. So along the driveway they planted rows of" would be "*palms*", unexpected targets ("*pines*" or "*tulips*") were also presented. The unexpected targets were either "within-category violations", meaning that they were from the same semantic category as the expected target (e.g., pines and palms are both methods types of trees), or "between-category violations", meaning that they were from a different semantic category to the expected target (e.g., tulips are flowers while palms are trees). All targets were possible completions (i.e., all can be planted) unless considered in terms of the situational context. If the RH were simply processing at the word-level, using a coarse-coding mechanism, then both of the unexpected targets should have been facilitated to a greater extent than the LH, which due to fine-coding should only have facilitated the appropriate, expected word. Instead, Federmeier and Kutas (1999) found that the RH appeared sensitive to both violations, whereas the LH only appeared sensitive to the between-category violations; that is, the LH demonstrated priming for the within-category violation targets (e.g., the target "*pines*" was facilitated even though it was not consistent with the context). This suggests that while the RH was influenced by congruency of the target to the contextual information, the LH was influenced not only by the contextual congruency but also by the semantic relatedness of the target to the expected sentence completion (e.g., "*pines*" was facilitated because it is semantically related to "*palms*", not because it was an appropriate sentence completion). As a result, Federmeier (2007; Federmeier & Kutas, 1999) argued that the LH uses *predictive* processing in which incoming words are combined with current information to produce a message-level meaning that is then used to activate semantic features of the item most consistent with the context. The extracted meaning is therefore utilized to generate specific predictions without the contextual information itself being maintained. The features of the presented target (e.g., pines) are then matched against the features of the expected target (e.g., palms) rather than the sentence context itself, leading to facilitation of within-category violations. In contrast, the RH is proposed to use *integrative* processing, where the previous context must not only be kept active but must be flexible to account for changes of interpretation based on the new incoming information. The presented target (e.g., pines) is then compared directly with the context itself; the within-category violations were inconsistent with the context and therefore could not be readily integrated, leading to a lack of facilitation. This model therefore accounts for the majority of the findings from the alternative methodologies (as reviewed earlier) in which a special role of the RH can be explained by a sensitivity to context that is made particularly apparent by the ability to extract and maintain activation of contextual information in order to revise initial interpretations.

Moreover, the summation priming findings of Beeman et al. (1994) that provided much of the impetus for the coarse coding hypothesis appear to be largely accounted for by Federmeier's (2007) model. Federmeier and Kutas (1999) argued that summation primes involving individual words would not produce a sufficient basis from which consistent predictions could occur, particularly when compared with a single, strong-associate, thus resulting in the observed finding that the LH was facilitated significantly more by the single, strong-associate than by groups of weakly related words. In contrast, integrative processing would support facilitation in both conditions and therefore also account for the observed results. Nonetheless, evidence in support of Federmeier's (2007; Federmeier & Kutas, 1999) model comes predominantly from studies using sentence fragments. Thus, as noted in relation to the coarse-coding model, it is unclear how applicable the proposed integrative and predictive processes are to instances of more extended discourse (e.g., across several sentences).

1.4 Different methodology, different conclusions: Why the discrepancy?

As outlined in this review of the literature, there is a distinct disparity between the results from the normal-behavioral approach and the alternative approaches (i.e., neuropsychological, electrophysiological, and neuroimaging). The alternative approaches suggest an important role for the RH in utilizing context and message-level mechanisms for sentence comprehension. In fact, a number of studies actually suggest that the RH may be *more* important than the left in the comprehension of at least some aspects of high-level meaning. The normal-behavioral approaches, however, rarely provide evidence that the RH is capable of utilizing message-level processes, much less to the same extent as the LH. Instead, these studies suggest the RH is limited to deriving sentence meaning from word-level mechanisms such as word associations.

In addition to there being such a disparity between the conclusions made in the alternative approaches and those made in the normal-behavioral approaches, there has been a significant amount of inconsistency in the results of studies using behavioral approaches. It is not unusual for these sorts of behavioral studies to produce unexpected and, to a degree, unexplainable results although there seems to be no good reason why behavioral studies of normal individuals should not return veridical findings in this area. This experimental approach has been applied to other hemispheric questions in thousands of studies over several decades, with a good record of success in terms of consistency with conclusions derived from other methodologies. It is possible that the inconclusive nature of the results of these studies with respect to the capabilities and mechanisms of the RH in language comprehension may be the result of several methodological problems. For example, as outlined earlier, much of the past behavioral research that has investigated the effect of context on RH language comprehension has done so by preceding the same target word with different sentences designed to have different levels of constraint. The sentences that precede each target word tend to vary quite considerably in terms of their grammatical construction and linguistic typology. For example, rather than following a consistent, canonical structure, they are often comprised of different combinations of noun and verb phrases (e.g., Faust and Kravetz (1998)'s sentence examples for High constraint: "The monkey ate the BANANA"; Medium constraint: "I mashed a *banana* for the baby"; Low constraint: "Today I ate a BANANA."). Admittedly, Faust and Kravetz's study used Hebrew sentences and the structure of those sentences may be presumed to differ from the translated examples provided in their English report on the study. It is not common in the literature, however, for researchers to carefully match sentence structures across each level of constraint, presumably because of the very considerable difficulties that such matching entails. As a result, there remains the possibility that although these studies purport to be investigating the effect of varying levels of contextual information on hemispheric comprehension, the variation in sentence structure may confound any attempt to properly compare the performance of the two hemispheres.

Nonetheless, studies that have attempted to manipulate context by increasing the number of words (e.g., Faust et al., 1993b) have still failed to produce results that are consistent with the findings of neuropsychological, electrophysiological, and neuroimaging studies. As such, the confound of sentence structure observed in studies manipulating context through the use of constraint does not fully account for the inconsistencies seen in behavioral research. Other uncontrolled variables may also contribute to the inconsistencies. For example, the studies by Faust et al. (1995) and Chiarello et al. (1999) were potentially confounded by the grammatical category of the words used in their investigations. In both of these studies, determining the message-level content of the sentence was contingent on appreciating the linguistic function of the verb or verb phrase (e.g., congruent: “The patient *swallowed* the MEDICINE” vs. incongruent: “The patient *parked* the MEDICINE”). There is a substantial body of research that suggests the RH has difficulty in processing verbs (e.g., Damasio & Damasio, 1992; Day, 1979; Gazzaniga, 1970; Sereno, 1999). This is scarcely surprising in view of the psycholinguistic status of verbs as fundamentally more abstract entities than nouns, representing functional relationships between more concrete entities in text. As such, the dependence of previous studies on the critical role of the verb in simple sentences could have partially masked any evidence of RH sentence comprehension. Chiarello, Shears, Liu, and Kacinik (2002), however, suggest that much of the research showing hemispheric differences in the processing of nouns and verbs has been confounded by other considerations such as imagability, concreteness, and lexical ambiguity. The results of their study suggest that the noun/verb distinction is better accounted for by differences in imagability than grammatical class itself. A number of psycholinguistic studies have also provided evidence for the superior cognitive processing of the RH for concrete, as opposed to abstract, nouns (e.g., Coney, 2002; Day, 1979; Ellis & Shepherd, 1974; Gazzaniga, 1970; Gazzaniga & Hillyard, 1971; Schwanenflugel, Harnishfeger, & Stowe, 1988; Villardita, Grioli, & Quattropani, 1988). Dual-coding theory claims that the processing of abstract nouns relies on verbal code representations of the LH, whereas concrete nouns additionally access a second image-based processing system in the RH (Jessen et al., 2000). Furthermore, Nieto, Santacruz, Hernandez, Camacho-Rosales, and Barroso (1999) found that the RH disadvantage for processing verbs could be removed when imagability was controlled. Their results indicated that the RH only had difficulty in processing verbs of relatively low-imagability; high imagery verbs appeared to be processed equally well by both hemispheres. Conversely, it has been postulated that evidence of different neural substrates for the processing nouns and verbs (e.g., Caramazza & Hillis, 1991; Federmeier, Segal, Lombrozo, & Kutas, 2000) may derive from the relationship between verbs and their meanings as actions. Several TMS studies have found that the role of the LH in processing verbs is related to the role of the left dorso-lateral prefrontal cortex in representing actions (Cappa, Sandrini, Rossini, Sosta, & Miniussi, 2002; Devlin & Watkins, 2007). Differences in the imagability of nouns and verbs may therefore not be entirely sufficient for explaining the RH disadvantage for processing verbs. Despite these findings, there continues to be a general failure in the literature to control for imagability in lieu of, or in addition to, grammatical class. Given the critical role of the verb phrase in demonstrating a sensitivity to the message-level information in the sentence in the studies by Faust et al. (1995) and Chiarello et al. (1999), it is likely that the failure to control for imagability and/or grammatical class resulted in an underestimation of RH processing. Furthermore, word length has been shown to affect lexical decision latencies to words presented in the LVF/RH but not to words presented in the RVF/LH. This result has been found for both concrete and abstract nouns (Bub & Lewine, 1988; Ellis, Young, & Anderson, 1988).

Based on these observations, it is possible that much of the inconsistency observed in previous research in relation to the RH's sensitivity to contextual information in sentences might be avoided by controlling the aforementioned methodological difficulties. Indeed, Baynes and Eliassen (1998) and Federmeier (2007) contend that behavioral studies have underestimated RH comprehension abilities. The assertion that the RH relies purely on word-level mechanisms therefore needs to be tested using stimuli that are less likely to mask the possibility that the RH utilizes message-level mechanisms, particularly given the contradictory evidence from alternative methodologies (e.g., Federmeier, 2007). For example, target words should comprise only short, concrete, highly imageable nouns in order maximize the likelihood that they can be processed appropriately by the RH. Although not all factors that might disadvantage the RH can be easily addressed (e.g., the lexical decision task is in itself a limitation), the inconsistency of results suggests that changes to the methodology employed within this paradigm must be applied in order to bridge the gap between the findings of normal-behavioral studies and the findings of other approaches.

In an initial investigation of these proposed methodological amendments, Gouldthorp and Coney (2009)[2] reported results that support the view that earlier normal-behavioral studies have underestimated RH sentence processing abilities. This study investigated the relative sensitivity of each hemisphere to the extra contextual information provided by long compared to short sentences that were identified as strongly and weakly constraining, respectively. Although this study by no means eliminated all of the potential limitations to RH processing, it appears from the results that the type of target words employed elicited more genuine and unconfounded RH responses than some previous research. Target words were restricted to highly imageable, concrete, four-letter nouns; the impact of this can be clearly observed in the observation that the RVF/LH generated lexical decision latencies that were, on average, 19ms less than the LVF/RH. In contrast, Faust et al. (2003) reported a corresponding RVF/LH advantage of 103ms; although target words were short (4-5 letters), imagability or concreteness were not reported to be controlled for and, as noted earlier, comprehension of the message-level information relied on processing of the critical verb within the sentence context. Furthermore, participants in the preliminary study responded considerably faster (mean RTs for all conditions were below 500ms) and

[2] Note that the study upon which this article was based was carried out in the context of a thesis project that formed part of the requirements of an Honors degree in Psychology completed by the first author. As such, this study is not submitted as part of the original research presented in this doctoral dissertation.

more accurately than has been reported in the majority of laterality studies in this area (where mean RTs above 900ms are frequently reported) (e.g., Faust et al., 2006; Faust & Kravetz, 1998; Faust & Babkoff, 1997). These observations suggest that the task employed in this study significantly enhanced the capacity of the RH to respond to word targets rather than "lose out" to the LH. More compellingly, a comparison between normal and scrambled sentences provided a means by which to determine the effects of context beyond those produced by word-level information. That is, normal sentence primes differed from the scrambled sentence primes in that they provided message-level information (i.e., through syntactic, semantic, and pragmatic analysis) in addition to word-level information (i.e., through lexical processes) (Morris, 1994). Therefore, the difference between lexical decision latencies for normal and scrambled sentences can be taken as a measure of the priming attributable to message-level processes. In the preliminary study, increasing the length of the sentences resulted in a markedly greater increase in priming in the LVF/RH than the RVF/LH for the normal sentences, but had no effect upon visual field differences in priming for the scrambled sentences. This might suggest that the RH was not only utilizing the message-level information contained in normal sentences, but was doing so to a greater extent than the LH (although, admittedly, it is not clear whether this apparent difference was an artefact of the LH reaching ceiling, or perhaps the LH gaining more from the short, weakly constraining sentences than the RH).

The possible finding that the LVF/RH gained greater benefit from increased contextual information than the RVF/LH may be indicative of a RH role in sentence comprehension that has generally only featured in neuropsychological, electrophysiological and neuroimaging studies. These studies (e.g., Delis et al., 1983; Wapner et al., 1981, as reviewed earlier) show strong evidence that the RH is capable of utilizing message-level processes and is important in the integration of contextual information, particularly in extended discourse. It appears that the earlier study (Gouldthorp & Coney, 2009), through the simplicity and consistency of the priming sentences used, the concrete and easily imagined scenarios that they depicted, and the use of highly imageable nouns as probe words, provided a conceptual environment that the RH could readily comprehend (e.g., Short: *The boy used the* SOAP; Long: *The boy washed his hands and used the* SOAP). That is, an environment that allowed the RH to reveal an early indication of the global language skills that have been repeatedly demonstrated in alternative methodological approaches.

1.5 Aims

The present series of investigations therefore aimed to reconcile the discrepant evidence found between the different methodological approaches in relation to RH language processing by using a normal-behavioral methodology that would reduce the likelihood of an inherent underestimation of RH processing capacities. The four studies were centered around the RH use of contextual information embedded in sentences with the specific aims of, firstly, clarifying to just what extent the RH utilizes message-level rather than simply word-level information present in sentences and, secondly, investigating the relative applicability of the “coarse vs. fine coding” and “integration vs. prediction” models of hemispheric processing differences to higher levels of language processing (i.e., beyond single sentences).

2. EXPERIMENT 1

Due to the considerable inconsistency in the literature in regard to the RH's use of message-level, as opposed to word-level, mechanisms during language comprehension (reviewed in Chapter 1), the first study in the present program of research was designed to specifically test the sensitivity of the RH to contextual information present in sentences at the message-level compared to the word-level. The rationale for Experiment 1 was derived from a critique of earlier work by Faust and Kravetz (1998), in which participants were presented with sentences of varying levels of context. Although Faust and Kravetz found that both hemispheres benefited more from high compared to low levels of context, they assumed that the RH derived facilitation of targets preceded by sentences due to word-level processes whereas the LH also utilized message-level processes. Experiment 1 therefore aimed to disentangle the facilitatory effects of word-level compared to message-level processing by including a baseline measure of the priming created by the word-level associations.

Participants were centrally presented with sentence fragments followed by either the sentence-final word or a non-word presented to either the LVF or RVF, on which they were required to make a lexical decision. The constraint that the sentence fragments placed on the sentence-final target was classified as either high (i.e., high probability that the target would be provided as the sentence completion) or low (i.e., low probability that the target would be provided as the sentence completion). Given that all word targets were syntactically valid completions, it was argued that the constraint of the sentence fragment reflected the contextual information provided by either the word-level or the message-level information, or a combination of the two. In order to differentiate between the effects of word-level and message-level contextual information, participants also received scrambled versions of the sentence fragments in which the order of the words was randomly altered in order to reduce the sentences to essentially strings of words. The scrambled sentence fragments therefore provided a baseline measure of word-level priming. It was argued that the difference in facilitation of targets preceded by the normal sentence fragments and those preceded by the scrambled sentence fragments would reflect the amount of additional priming obtained through message-level processing.

The manuscript describing Experiment 1 has undergone peer review and has since been published in the journal *Neuropsychologia*. The following section presents the manuscript in the form that it was published.

2.1 Message-level processing of contextual information in the right cerebral hemisphere.

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Abstract

Recent research into right hemisphere (RH) sentence comprehension has produced a number of inconsistent results, particularly in relation to the types of processing used. The present study investigated whether the RH utilizes message-level mechanisms during sentence comprehension and whether it benefits from additional contextual information that is not the result of simple word-level associations. Thirty-six right-handed Murdoch University undergraduate psychology students participated in a computer-based lexical decision task where reaction time and error rates were recorded. Normal and scrambled versions of sentences with high, low, and neutral levels of constraint were presented centrally, with the sentence-final word presented to either the left or right visual field. The results demonstrated that the RH was facilitated by increases in context to at least the same extent as the left hemisphere (LH) and, furthermore, that this was not simply due to increased word-level associations. These findings are in contrast to previous behavioral research that suggests the RH is less sensitive to message-level processing than the LH.

KEYWORDS: sentence comprehension, hemisphere, visual field, priming, context, constraint

Introduction

Recent research into hemispheric differences in sentence comprehension has produced a puzzling disparity between the results from studies that have utilized behavioral measures in samples of normal individuals (normal-behavioral approaches), and those derived from alternative approaches (i.e., neuropsychological, electrophysiological, and neuroimaging). The alternative approaches suggest an important role for the right hemisphere (RH) in the comprehension of high-level meaning in sentences (e.g., Federmeier, 2007). In contrast, the normal-behavioral approaches rarely provide evidence that the RH is capable of utilizing message-level processes. Instead, these studies suggest the RH is limited to deriving sentence meaning from word-level mechanisms such as word associations (e.g., Faust & Kravetz, 1998).

In the normal-behavioral approaches, participants are often required to complete a lexical decision task. A sentence fragment is presented centrally and reaction times to targets presented to either the left (LVF) or right visual field (RVF) are recorded. For example, Faust and Kravetz (1998) compared lexical decision latencies for target words presented to the left and right visual field following centrally presented sentence fragments of neutral, low, medium, and high constraint. They found a decrease in reaction time for both visual fields following high constraint compared to neutral sentences, although this difference was considerably larger for the RVF/left hemisphere (LH) than for the LVF/RH. While significant differences in reaction time were also found between all levels of constraint for the RVF/LH (except between neutral and low), no further differences were significant for the LVF/RH. Faust and Kravetz argue that while these results suggest the RH does take advantage of some degree of constraint, it may utilize a different form of processing.

A major point of contention in the literature is the type of processing mechanisms utilized by each hemisphere. It has been theorized that sentential information can be derived using “word-level” mechanisms (i.e., by using associations between individual words in the sentence) as well as from “message-level” mechanisms (i.e., by building a conceptual representation of the meaning of the sentence through the combination of syntactic, semantic and, pragmatic information) (Morris, 1994). Much of the normal-behavioral research indicates that the RH is only capable of utilizing word-level information. For example, several studies have found that for targets presented to the LVF/RH normal sentences were no more effective as primes than the same words presented in a scrambled list. Targets presented to the RVF/LH, however, were greatly facilitated by normal as compared to scrambled sentences (Faust, Babkoff & Kravetz, 1995; Faust & Chiarello, 1998). In addition, the RH appears to be far less affected by incongruity of ambiguous word meanings compared to the LH (Burgess & Simpson, 1988). Faust and Kravetz (1998) used these findings to suggest that the RH is only capable of utilizing intralexical processing and therefore, in effect, treats sentences as strings of single words. More recently, Faust and colleagues have conceded that the RH does appear to use some message-level processing; they do, however, maintain that the RH relies more on word-level than on message-level processing and is far less sensitive to message-level information than is the LH. For example, Faust, Bar-Lev and Chiarello (2003) conducted a divided visual field study on normal participants in which sentence fragments permitted an initial message-level interpretation that was either congruent with the target (i.e., produced a meaningful completion) or incongruent (i.e., violated the message-level interpretation). They also included random sentences (i.e., a scrambled word order) and sentences that were syntactically correct but meaningless. Sentences also contained a word that was either semantically associated or unassociated to the target. Their results indicated that, for both hemispheres, associated target words presented to the corresponding visual field were facilitated in the congruent condition and inhibited in the incongruent condition. This reflected a sensitivity of both hemispheres to the message-level information. They also found that, in the LVF/RH, random sentences (i.e., a disrupted syntactic structure) facilitated targets to the same extent as congruent sentences if they contained a word highly associated with the target. Faust et al. (2003) argued that this implies an insensitivity of the RH to word order constraint. In the light of these findings, Faust et al. (2003) argued that although the RH appears to have access to message-level information, it is less sensitive to such information than the LH. Faust, Barak, and Chiarello (2006) also concede that both hemispheres appear to be able to use message-level as well as intralexical information in a sentence to facilitate word recognition, but they maintain that the RH relies mainly on intralexical information.

This proposition is, however, difficult to reconcile with the literature that has emerged from alternative approaches, which generally suggests that not only does the RH use message-level processing, but that this seems to occur to roughly the same extent as in the LH and, furthermore, that both hemispheres appear to use message-level processing in preference to word-level processing. A number of recent studies have used an electrophysiological approach in which event-related brain potentials (ERPs) were measured. One of the common measures is the N400, which is a negative voltage peaking at approximately 400ms following stimulus onset and has been shown to have a strong inverse relationship with priming resulting from the preceding stimulus or context (Federmeier, 2007). For example, Coulson, Federmeier, Van Petten, and Kutas (2005) conducted an ERP study using similar priming stimuli to Faust et al. (2003) (i.e., sentence fragment primes containing a critical word that was either highly associated or unassociated to the sentence-final target, which in turn was either congruent or incongruent with the message-level interpretation of the sentence). Their results indicated that both hemispheres seemed to preferentially use message-level over word-level information when both were available. Similarly, Federmeier and Kutas (1999) found evidence of greater RH semantic selectivity and more adherence to message-level plausibility than the LH. Federmeier, Mai, and Kutas (2005) specifically tested the hypothesis that the RH predominantly uses word-level context and that the LH is superior at constructing a message-level representation, by using sentence contexts that were designed to vary the message-level constraint placed on a target. They observed significant N400 effects for both the LH and RH, indicating that both hemispheres were making use of contextual information in the sentences beyond simple word-associations. Furthermore, they found no evidence that the amount of message-level priming differed between the LH and RH. This finding was replicated in a similar study by Wlotko and Federmeier (2007) in which facilitation for expected, as compared to unexpected, items in high-constraint sentences was equivalent across hemispheres, providing strong evidence against the proposition that the RH is wholly or partially insensitive to message-level meaning.

Interestingly, some normal-behavioral research is starting to emerge that is consistent with the findings of the alternative approaches in relation to RH processing mechanisms. Liu (2002) compared normal sentences to sentences containing anomalous meanings as well as to scrambled sentences. The results indicated that both hemispheres were sensitive to message-level meaning. In addition, a recent study in our laboratory investigated the relative sensitivity of each hemisphere to the extra contextual information provided by long compared to short sentences (Gouldthorp & Coney, 2008). This study used differing sentence lengths to manipulate constraint, rather than the more commonly used method of varying types of grammatical construction, or by including a strong lexical associate of the target in the sentence. It was argued that these methods could potentially confound results. In studies such as Faust and Kravetz (1998), the effect of context on RH language comprehension has been investigated by preceding the same target word with sentences designed to have different levels of constraint, with the sentences varying quite dramatically in terms of their grammatical construction. Gouldthorp and Coney attempted to address the possibility that many normal-behavioral studies have not properly assessed the RH's sentence comprehension abilities, by manipulating constraint through sentence length instead of structure. Our results suggested that not only was the RH making use of the extra contextual information provided by the long sentences, but that this occurred to a greater extent than for the LH. Furthermore, the response times in the LVF/RH were faster for normal compared to scrambled sentences, thus evidencing message-level mechanisms in the RH. A limitation of this study was that, while sentence constraint and grammatical structure were controlled, the length of the sentence was a potential confound. Nonetheless, the study demonstrated that when careful attention is paid to

RH processing abilities (e.g., through the use of consistent and grammatically-simple sentences and the restriction of targets to short, concrete nouns), results that are consistent with those found in the alternative approaches can be obtained.

Similarly, Faust and Kravetz (1998) demonstrated a decrease in reaction time for the LVF/RH following sentences of high compared to neutral constraint. However, they argued that this may have been the result of the presence of single words in the sentences that were highly associated with the target word. Beeman (1998) proposed a model wherein the RH uses coarse semantic coding whereas the LH uses relatively fine semantic coding. As a result, the RH maintains weak activation of several meanings of the word as well as distantly-related features while the LH only maintains activation of a single meaning or limited relevant features (Coney & Evans, 2000). Beeman suggests that the RH's importance in drawing inferences, maintaining coherence, and integrating complex discourse is the result of semantic overlap of words sharing distant semantic features. This provides some support for Faust and Kravetz's contention that the RH's contribution to sentence comprehension relies predominantly on word-level processes. In Faust and Kravetz's study, they found that their high constraint sentences contained a high level of associated words whereas their medium and low constraint sentences did not. As they pointed out, a definitive test of the suggestion that their results were due to the presence of associated words would be produced by using highly constraining sentences that do *not* contain such words. In addition, scrambled sentences could be used in order to provide a baseline measure of the intralexical effects. If it was found that the RH responds faster following normal sentences compared to scrambled sentences, then this would suggest the RH is not processing the sentences as a string of single words. If effects of constraint were also found for the RH, then this could only be attributable to some amount of message-level processing.

Thus, the aim of the present study was to investigate the extent to which the RH utilizes message-level mechanisms during sentence comprehension and whether it benefits from additional contextual information that is not the result of simple word-level associations. The study used sentences of high, low and neutral levels of constraint as well as scrambled sentences. Although some sentences contained words associated to the target, this was balanced across each category of constraint. By implementing these controls, the results of the present study were expected to show whether Faust and Kravetz's (1998) findings were indeed indicative of message-level processing or simply a result of the presence of associated words and, hopefully, demonstrate results that would be comparable with those observed in alternative methodologies. Based on the findings of Gouldthorp and Coney (2008) and Faust and Kravetz (1998), it was hypothesized that the LVF/RH would respond more quickly to words following highly constraining sentences as compared to low constraint or neutral sentences. Additionally, under the assumption that the RH is not restricted to word-level processing mechanisms, it was hypothesized that the LVF/RH would respond more quickly to words following normal compared to scrambled sentences. Finally, based on the evidence from alternative methodologies that both hemispheres utilize message-level processing to approximately the same degree, it was expected that the LH would exhibit the same pattern of results as the RH.

Method

Participants

Thirty-six undergraduate university students participated in this study, with the majority of participants receiving course credits. Thirty-two of the participants were female and 4 were male (*M*=25.5 years, *SD*=8.9 years). All participants possessed English as a first language and normal or corrected-to-normal vision. Participants were all right-handed, as assessed by a rating of .40 or above (*M*=0.90, *SD*=0.16) on the Bryden's Simplified Hand Preference Questionnaire (Bryden, 1982), on which the scale ranges from +1.00 (extreme right-handedness) to -1.00 (extreme left-handedness).

Design & Stimulus Materials

A 2x2x3 repeated measures design was used, manipulating the independent variables of visual field (left or right), sentence type (normal or scrambled) and sentence constraint (neutral, low, or high). The dependent variables were reaction time and error rate, with reaction time being the primary experimental measure.

Stimulus Construction

One hundred and fifty target words were selected, based on the requirements that they were short (3-5 letters, *M*=4.15 *SD*=0.64), highly imageable (*M*=592, *SD*=34), concrete (*M* = 593, *SD* = 33) nouns, as derived from the MRC Database (1987) collated ratings (Coltheart, 1981). Three sentences were constructed for each target word, where the target was always the sentence-final word. The three sentences were designed to be of neutral, low, or high constraint for the sentence-final word. Neutral sentence fragments were always of the form "*The next word that you will see is*". Lists of the low and high constraint sentence fragments were given to two panels of 15 and 17 participants respectively (recruited from the same population as the experimental sample), who were required to complete each fragment with the word they felt was most suitable. Using the "cloze" procedure (Taylor, 1953), the level of constraint of each sentence was quantified by determining the probability of the target word being used as a completion. The Cloze probabilities were used to eliminate 30 target words and their associated sentence fragments, whereby the Cloze probability for the low-constraint fragment for a target had to be at least 0.2 below the Cloze probability of the high-constraint fragment for the same target. As a result, the remaining 120 high-constraint sentences had a mean Cloze probability of 0.96 (*SD*=0.10, range=0.69-1.00) and the 120 low-constraint sentences had a mean Cloze probability of 0.42 (*SD*=0.24, range=0.25-0.75). Sentence length was kept fairly constant, with the mean length of high-constraint sentence fragments being 8.0 words (*SD*= 2.0), the mean length of low-constraint sentence fragments being 7.4 words (*SD*=1.8) and the length of the neutral sentence fragments always being 8 words.

The nouns in each sentence fragment were assessed for association with the sentence-final word using the University of South Florida association norms database (Nelson, McEvoy & Schreiber, 2004), in order to remove any highly associated words and to ensure that remaining word associations occurring within the high and low constraint sentences were kept relatively constant. Of the 100% of target words present in the database, the high-constraint sentence fragments contained individual words with a mean forward associative strength rating of 0.04 (*SD*=0.11) and the low-constraint sentence fragments had a rating of 0.03 (*SD*=0.12). In order to further account for any effects of word associations, the 360 sentence fragments were scrambled (i.e., their word order was randomly changed) to produce an additional control set of 360 scrambled sentence fragments. This was designed to remove the structure of the sentences, essentially reducing them to lists of apparently unrelated words and thus providing a baseline measure of priming resulting from word-level associations. The result was a stimulus set for each target word, containing normal and scrambled sentences of high, low, and neutral constraint, as in the following example (further sample sentences and targets appear in Appendix A):

High Constraint Normal: *The girl scrubbed her hands with lavender scented (SOAP)*

High Constraint Scrambled: *Lavender hands scrubbed the scented with her girl (SOAP)*

Low Constraint Normal: *The boy washed his hands and used the (SOAP)*

Low Constraint Scrambled: *Used hands washed the the and his boy (SOAP)*

Neutral Normal: *The next word that you will see is (SOAP)*

Neutral Scrambled: *See you word the is will that next (SOAP)*

An additional 120 sentences were constructed with the sentence-final word being a non-word. Forty of these sentence fragments took the “neutral” form and the remaining 80 sentence fragments were designed to mimic the style of the high and low constraint sentence fragments. The 120 non-words were generated by taking the 120 real-word targets and non-systematically changing a single letter so that the resulting letter string was a pronounceable, orthographically-legal pseudo-word. Any resulting pseudo-homophones were identified and replaced with alternate non-words. The 120 non-word sentence fragments were also scrambled to produce an additional set of 120 scrambled non-word sentence fragments.

Six separate stimulus sets were constructed from the pool of 960 sentence fragments so that, firstly, each participant would only be presented with one version of the high, low, or neutral constraint sentence fragment for each sentence-final target word and, secondly, would have equal numbers of the target word or nonword for each condition presented to each visual field. As the non-word sentences were not constructed in groups of three (i.e., all had a different sentence-final non-word), all of the participants saw the same non-word sentences but half were presented to the opposite visual field. As such, participants would only see a target word or non-word twice (i.e., preceded once by the normal and once by the scrambled sentence fragment) and to the same visual field. In order to minimize any repetition priming effects, each stimulus set was divided across two sessions (resulting in twelve stimulus sets altogether), whereby the normal version and the scrambled version of each sentence fragment was presented to each participant in a different session at least one week apart. This was designed to maximize the time between the first and the second presentation of the same word or non-word. Each session, however, contained equal numbers of normal and scrambled sentences, and the presentation of the normal or scrambled version in the first or second session was balanced across participants. An additional 12 sentences (of a similar style to the test stimuli) were produced for use in the practice tasks. Finally, a list containing

18 sentence fragments was generated for each of the twelve stimulus sets, nine of which were present in the corresponding set and nine of which were not present. The lists were designed to test the participants following completion of each session, to ensure the sentences were being read in full.

Apparatus

All programs associated with running both sessions were run on an Intel Pentium 4 processor with a Windows 98 SE operating system and 256 MB Ram. The monitor on which stimuli were displayed was a Mitsubishi Diamond Plus 71 with a screen area of 800x600 pixels, 32-bit color and a refresh rate of 75 hertz. A 2-button micro-switch response box was used to record the participants' responses. Participants rested their chin on a chin-rest that was 60cm away from the monitor and could be individually adjusted for height. Ear defenders were used to ensure exclusion of any possible extraneous noise. Finally, a CCTV system was used to monitor participants' eye movements. One of each participant's eyes was enlarged so as to fill a large portion of the CCTV monitor screen, from which the comparison of the location of the participant's eye with a calibrated central point on the monitor screen allowed for even minor deviations from central fixation to be readily detected.

Procedure

Prior to each session, the order of presentation of trials was randomized on-line within each discrete set of 24 experimental conditions. Participants attended two, one-hour sessions approximately one week apart (aimed at minimizing practice effects across sessions) and were tested individually. Testing was conducted in a laboratory illuminated by both fluorescent and natural lighting. Prior to commencing the first session, participants completed the Bryden's Simplified Hand Preference Questionnaire (Bryden, 1982). Participants were then read instructions and any questions answered.

In both sessions, participants first participated in a supervised practice task. This task involved 12 trials and was included to ensure the participant understood the task prior to the commencement of data collection. These sentence fragments were presented centrally on the computer screen in black letters with a grey background and in Courier font approximately 1cm high (0.95 degrees of visual angle). Sentences were presented for 60ms per letter, which allowed participants to read at a natural pace while still comprehending each word in the sentence. Following each presentation, a black fixation cross appeared centrally on which participants were instructed to focus their gaze. Shortly following the presentation of the fixation cross, the target was flashed to either the left or right side of the screen, with the innermost boundary located at 2.1 degrees of visual angle from the central fixation point. Targets were presented in black uppercase letters, using the Verdana font, for 150ms. The participant then made a decision as to whether they believed the target was a word or a non-word. Participants were instructed to depress both micro-switches simultaneously with the index finger of each hand if they believed the target was a word. Participants were instructed to withhold any response if the target was a non-word. If participants responded to a non-word or failed to respond within 1500ms to a word, an error message (consisting of the word “ERROR”) was presented briefly on the screen. Following completion of each trial was a gap of two seconds prior to commencement of the next trial.

Following completion of the practice task, it was reiterated that participants must maintain central fixation during target presentation. Participants were also advised that their eye movements would be monitored on a CCTV linked to a camera above the computer screen to ensure they were reverting to a central fixation following the sentence fragment presentation. It was also emphasized that they must read each word in the sentence (i.e., not “skim read”). They were informed that following the task they would be given a list containing some of the sentences that they were presented with and they would need to identify which they could recall. Participants were advised that this did not mean they should concentrate on memorizing the sentences, but rather that they should simply ensure that they read each sentence carefully.

Participants were then presented with one of the twelve balanced stimulus sets of 240 sentences (i.e., ten cycles of the 24 conditions per session), divided into five blocks. Presentation of the sentence fragments, targets, and the method of response were the same as in the practice task. Participants were given a rest break between each block, during which feedback relating to their reaction times and errors for the preceding block of trials was provided.

On completion of the lexical decision task in each session, each participant was given a list of 18 sentence fragments (nine of which had been presented) and they were asked to identify which had been presented during the session. This task was designed to motivate participants to attend to the sentences carefully, and to provide an indication of their success in following this instruction.

Results

A rejection criterion of 50% accuracy was implemented for the recognition task; however, no participants scored equal to or less than this cut-off. It was therefore assumed that since all participants performed at better than chance they had read the sentence fragments with at least reasonable care.

Reaction Time

Reaction time data for correct responses were initially screened utilizing a deletion criterion of +/- 2.0 standard deviations from each individual's mean response times for each condition. An additional screening procedure was applied to the data, whereby a rejection criterion of +/- 2.0 standard deviations for the mean of each experimental condition resulted in 3.2% of mean responses being replaced with a response equivalent to 2 standard deviations above or below the sample mean for the respective condition. Data were also carefully examined for any evidence of speed-accuracy tradeoffs and no evidence of this was found. A preliminary analysis of variance indicated that there was a main effect of session ($F(1,35)=13.6$, MSe=15463.0, $p<.001$) attributable to practice; however, there were no significant interactions between session and other variables. Data was therefore collapsed across sessions prior to performing subsequent analyses.

An overall 2x3x2 repeated-measures analysis of variance was performed on the screened reaction time data (summarized in Table 1).

Table 1. Mean RT (ms) as a function of target visual field, sentence constraint, and sentence type. Standard deviations (ms) appear in parentheses.

	LH/RVF		RH/LVF	
	Normal Sentences	Scrambled Sentences	Normal Sentences	Scrambled Sentences
High Constraint Sentences	432 (106)	469 (100)	441 (105)	480 (86)
Low Constraint Sentences	469 (99)	483 (87)	486 (90)	518 (82)
Neutral / No Constraint Sentences	526 (79)	524 (76)	548 (87)	544 (83)

The analysis revealed a significant main effect of visual field ($F(1,35)=34.0$, MSe=1578.8, $p<.001$), whereby a fairly standard LH advantage for lexical decisions of 19ms was observed. A Mauchley's Test of Sphericity was violated for the main effect of constraint as well as for the interaction between visual field and sentence constraint, resulting in the Huyn-Feldt Epsilon correction being used for these two cases. The effect of constraint was significant ($F(1.3, 47.1)=148.6$, MSe=2348.2, $p<.001$), reflecting the fact that participants responded most quickly to high constraint and slowest to neutral sentences. A significant main effect of sentence type was identified ($F(1,35)=34.5$, MSe=1183.7, $p<.001$), where responses were faster for normal sentences than for scrambled sentences.

There was a significant interaction between visual field and level of sentence constraint ($F(1.6,55.3)=3.8$, MSe=1298.0, $p=.039$). For neutral sentences there was a 21ms difference between the left and right visual field, approximating the overall difference observed in the main effect of visual field. A difference of 26ms occurred for the low constraint sentences while, interestingly, there was only a 10ms difference for high constraint sentences. There was a significant interaction between level of constraint and sentence type ($F(2, 70)=21.1$, MSe=749.0, $p=.001$), where increases in constraint appeared to reduce RT more for normal than for scrambled sentences. There was little difference between normal and scrambled sentences at the neutral level, which was expected given that the neutral fragment should have no impact on the time taken to make a lexical decision.

Although these absolute RT effects are of interest, facilitation effects are of critical importance to this study as they allow a direct comparison between the visual fields. These effects are presented in Figure 1. An additional analysis of variance was conducted on the facilitation observed in each condition (i.e., the mean RT for the condition subtracted from the mean RT for the corresponding neutral condition).

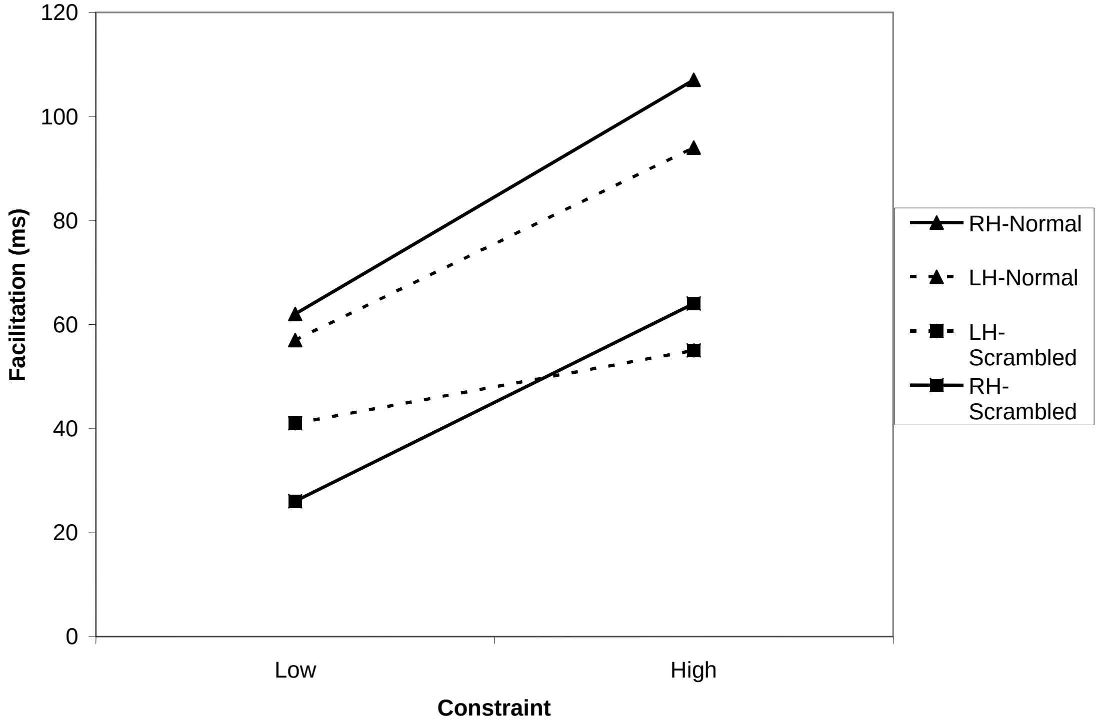

Figure 1. The relative facilitation (ms) of each visual field/hemisphere presentation as a function of constraint for normal compared to scrambled sentences.

As expected, there was a significant main effect of sentence type ($F(1,35)=34.1$, MSe=2433.2, $p<.001$), with more facilitation occurring overall for normal (M=81ms) than for scrambled (M=47ms) sentences. Similarly, a significant effect of constraint was observed ($F(1,35)=108.5$, MSe=746.9, $p<.001$), with facilitation greater for high (M=80ms) than for low constraint (M=47ms). There was not, however, a significant main effect of visual field. Although visual field and sentence type did not interact significantly, there was a significant interaction between visual field and constraint ($F(1,35)=12.7$, MSe=370.7, $p=.001$) as well as between sentence type and constraint ($F(1,35)=1.87$, MSe=687.0, $p=.023$). Although a three-way interaction between visual field, sentence type and constraint was not significant, planned comparisons of the normal conditions as separate to the scrambled conditions were carried out. While the two-way interaction between constraint and visual field was not significant for the normal sentences, it was significant for the scrambled sentences (F(1,35)=13.971, MSe=384.9, p=.001). Targets presented to the RVF/LH following scrambled, low constraint sentence fragments were facilitated 15ms faster than those presented to the LVF/RH (t(35)=2.492, p=.018), but there was no significant difference in facilitation following high constraint scrambled fragments. This indicates that there was a greater relative increase in facilitation of the RH from low to high constraint scrambled sentences than for the LH; indeed, high constraint scrambled sentence fragments resulted in an additional 38ms facilitation for the LVF/RH, compared to the additional RVF/LH facilitation of only 14ms (t(35)=3.738, p=.001).

Error Rates – Word Targets

A repeated-measures analysis of variance was conducted on error rates for word-target trials. As in the reaction time analyses, there was a main effect of session (F(1,35)=8.4, MSe=69.0, p=.007), with fewer errors occurring overall in the second than in the first session. As there was no significant interaction between session and other variables, data was once again collapsed across sessions prior to performing subsequent analyses. The relevant error rate data are summarized in Table 2.

Table 2. Mean error responses (%) to target words as a function of target visual field, sentence constraint, and sentence type. Standard deviations appear in parentheses.

	LH/RVF		RH/LVF	
	Normal Sentences	Scrambled Sentences	Normal Sentences	Scrambled Sentences
High Constraint Sentences	0.42 (1.84)	2.94 (4.85)	2.24 (3.89)	4.18 (5.43)
Low Constraint Sentences	1.67 (3.16)	3.08 (4.58)	2.53 (3.93)	5.17 (6.95)
Neutral / No Constraint Sentences	7.71 (7.44)	8.11 (6.45)	10.99 (7.25)	12.69 (8.10)

A significant main effect of visual field ($F(1, 35)=9.5$, MSe=60.4, $p=.004$) was consistent with the RT data, with a greater error rate exhibited in the LVF/RH ($M=6.3\%$) than in the RVF/LH ($M=4.0\%$). As with the RT data, a Mauchley's Test of Sphericity was violated for the main effect of constraint as well as for the interaction between visual field and sentence constraint, resulting in the Huyn-Feldt Epsilon correction being used for these two cases. Significant main effects of both constraint ($F(1.6, 56.4)=10.4$, MSe=30.09, $p<.001$) and sentence type ($F(1,35)=12.4$, MSe=27.4, $p=.001$) paralleled the RT data, indicating that more errors occurred when sentences were less constraining than when of high constraint, and when scrambled compared to normal. In contrast to the RT data there was not, however, a significant interaction between visual field and constraint ($F(1.6,56.7)=2.3$, MSe=38.6, $p=.122$), although the non significant interaction of visual field and sentence type ($F(1,35)=.58$, MSe=19.6,

p=.452) was consistent with the RT data. Given the consistency of the error rate data with the RT data, it is unlikely that any speed/accuracy trade off effects were impacting the results.

Error rates – Nonword targets

A repeated-measures analysis of variance was also conducted on error rates for nonword-target trials (i.e., false alarms) with the effect of constraint being of particular interest. The relevant error rate data are summarized in Table 3.

Table 3. Mean error responses (%) (false alarms) to target non-words as a function of target visual field, sentence constraint, and sentence type. Standard deviations appear in parentheses.

	LH/RVF		RH/LVF	
	Normal Sentences	Scrambled Sentences	Normal Sentences	Scrambled Sentences
High Constraint Sentences	6.53 (5.45)	9.44 (8.43)	7.92 (6.59)	9.58 (8.31)
Low Constraint Sentences	13.47 (9.17)	13.89 (7.57)	7.22 (6.70)	10.42 (8.57)
Neutral / No Constraint Sentences	8.47 (8.26)	8.06 (6.01)	16.25 (10.91)	18.61 (11.93)

A significant main effect of constraint (*F*(2,70)=12.8, MSe=57.7, *p*<.001) reflected the fact that the rate of false alarms decreased in order of neutral sentence fragments (M=12.8%), low-constraint fragments (M=11.2%), and high-constraint fragments (M=8.37%). A significant main effect of sentence type was also observed (F(1,35)=11.438, MSe=26.963, p=.002), where more false alarms occurred in the context of scrambled (M=11.7%) rather than normal sentences (M=9.9%). Additionally, a significant main effect of visual field (*F*(1, 35)=6.65, MSe=46.5, *p*=.014) indicated that more false alarms occurred for nonword targets presented to the LVF/RH (*M*=11.7%) than to the RVF/LH (*M*=10.0%). The interaction between visual field and constraint was also significant (F(2,70)=51.897, MSe=34.572, p<.001), with follow-up analyses showing that significantly more false alarms occurred in the context of nonword targets presented to the LVF/RH (M=17.4%) than to the RVF/LH (M=8.3%) (t(35)=5.668, p<.001). These results provide a good indication that faster reaction times and lower error rates to word-targets associated with increasing constraint were not simply due to high-constraint invoking a stronger expectation that a word would be presented. Indeed, the opposite effect occurred, with the highest rate of false alarms occurring in neutral sentences, suggesting that participants were better able to reject a target when it did not match their expectation. This was particularly the case for targets presented to the LVF/RH, which may be related to the relative inferiority of RH lexical processing.

Discussion

There has been much discussion in the recent literature regarding the ability of the RH to utilize message-level processing. Although commonplace in alternative methodologies, few behavioral studies of normal individuals have succeeded in demonstrating the use of message-level processing in the RH. This has been due partly to the difficulty in disentangling the facilitatory effects of word-level associations from message-level processing. By controlling for the presence of word-level associations, the present study aimed to determine whether Faust and Kravetz's (1998) findings were indicative of RH message-level processing or simply a result of the presence of associated words. The major finding of this study is that the RH utilized message-level information derived from the sentences at a level comparable to the LH. The results supported the hypothesis that the RH would respond more quickly to words following highly constraining sentences as compared to low constraint or neutral sentences; this is a clear demonstration that the RH was benefiting from increased context. Additionally, the hypothesis that the RH would respond more quickly to normal compared to scrambled sentences was supported by the results, indicating that the increased facilitation from high constraint sentences was not simply due to an increased number of word-level associations.

These findings are in distinct contrast to Faust & Kravetz's (1998) suggestion that the RH is only capable of utilizing intralexical processing, effectively treating sentences as strings of single words. They are also inconsistent with Beeman's (1998) model, which suggests that the RH only benefits from contextual information due to the semantic overlap of words that share distant semantic features. In the present study, the scrambled sentences provided a baseline measure of these intralexical effects and, as a result, confirmed that the RH is indeed utilizing processing mechanisms beyond simple word-level information. If, as in Beeman's (1998) model, the RH's ability to utilize contextual information was simply the result of a semantic overlap of individual words in the sentence, there should not have been the clear difference between the scrambled and normal sentences that was observed. The present findings, then, also place Faust and Kravetz's (1998) results in a different perspective. They proposed that their observation of a decrease in reaction time for targets presented to the LVF/RH following sentences of high compared to neutral constraint was simply due to the presence of highly associated words in the high-constraint condition. The results of the present study provide strong evidence that the RH is not simply processing the sentences as a string of single words and that the effects of constraint can therefore be attributed to message-level processing. As such, Faust and Kravetz's results may indeed reflect RH message-level processing.

Furthermore, the findings of the present study are consistent with those found in another study recently conducted in our laboratory (Gouldthorp & Coney, 2008), in which it was shown that the LVF/RH benefited more than the RVF/LH from the increased context provided by longer sentences. We have argued in that article that our results were at least partially due to the careful attention paid in stimulus construction to produce simple and consistent priming sentences, along with the use of short, highly imageable nouns as probe words. That is, we set out to moderate the presence of variables that have generally served to disadvantage the processing capacities of the RH.

In this context, Federmeier (2007) noted the potential for tasks used in behavioral studies (such as lexical decision) to be disadvantageous to RH processing, resulting in RH comprehension abilities being underestimated (Baynes & Eliassen, 1998). Given that the present study followed the same general guidelines in stimulus construction as Gouldthorp and Coney, the consistency of these results supports the contention that RH processing has indeed been previously underestimated by behavioral studies due to the use of stimuli that are inherently disadvantageous for RH processing.

These results of the present study are also consistent with a number of studies utilizing alternative approaches. For example, in an ERP study in which sentences of varying levels of constraint were presented to participants, Federmeier et al. (2005) found that message-level information impacted on the semantic processing of stimuli presented to the RH and, furthermore, that this was not affected to any greater extent than in the LH by the presence of conflicting word-level information. A number of additional studies by Federmeier and colleagues (see Federmeier, 2007, for a review) have suggested that the RH may be as sensitive to message-level information in sentences as the LH.

Despite strong evidence indicating that at least under some circumstances both hemispheres benefit from contextual information to roughly the same extent, it remains unclear as to whether the hemispheres use the information in the same way. For example, a difference in the way the hemispheres processed scrambled sentences was evident in the present study. Visual field and constraint interacted in these sentences (see Figure 1) such that the differential effect of constraint in facilitating responses, while significant in both visual fields, was greater for the LVF/RH. A possible explanation for this finding assumes the use of different processes by each hemisphere. For example, the RH may rely on word-level processing when message-level processing is disrupted (as occurred in the scrambled sentences). Federmeier (2007) suggests that while both hemispheres benefit from word-level mechanisms generally (e.g., Federmeier & Kutas, 1999), RH facilitation at the word-level occurs due to the specific semantic overlap of the individual words (i.e., summation priming). Given the nature of the sentences, it would be expected that fewer low-level associations between the words would be present in the low-constraint condition than in the high-constraint condition. (It is important to note that this is quite different to the presence of highly-associated words; these were removed during pre-experimental stimulus construction with the remaining single-word priming effects balanced across levels of constraint). The sentences will always, however, unavoidably contain words such that different combinations result in different levels of summation priming (Beeman et al., 1994). Given that the contextual information (and thus constraint) in the sentence fragments tends to rely on world-knowledge and common scenarios, it is a logical extension that high-constraint sentences would result in greater summation priming than low-constraint sentences. The pattern of facilitation of targets presented to the LVF/RH is consistent with this; the greater facilitation from the high-constraint scrambled sentences suggests that there must have been more word-level information available in the high-constraint than in the low-constraint condition. In contrast, targets presented to the RVF/LH were not facilitated more by high-constraint scrambled sentences than the low-constraint scrambled sentences. This suggests that the LH did not resort to word-level processing when the message-level was disrupted. This finding is not initially surprising, given

Beeman et al. (1994) found that summation priming had a greater effect in the LVF/RH than the RVF/LH, and it would therefore follow that the LH would be less facilitated by the semantic overlap of distantly related words in the scrambled sentences. Interestingly, however, the targets to the RVF/LH were facilitated in the low-constraint scrambled condition to a greater extent than the LVF/RH. It is possible that, rather than relying on the automatic process of summation priming, the LH was using some form of controlled processing that allowed it, on at least some proportion of trials, to predict the upcoming word or to partially reconstruct the message-level information. Although the mechanisms by which this might be accomplished are unclear, it certainly appears that the LH was able to extract more information from the low-constraint scrambled sentences than the RH and that, furthermore, this did not appear to be due to word-level processing as a result of the semantic overlap of distantly related words.

Interestingly, the relative increase in facilitation from low to high constraint scrambled sentences was much less for the RVF/LH than for the LVF/RH. Although this is consistent with the view that the RH utilized word-level processing in the scrambled sentences, the processing mechanism used by the LH in the scrambled conditions must have been relatively less affected by constraint or less able to utilize the extra information in the high-constraint sentences. A similar finding was also observed in normal sentences by Federmeier, Wlotko, De Ochoa-Dewald, and Kutas (2007); there was only slightly less facilitation in the RVF/LH for weak compared to high constraint sentences. Federmeier (2007) also noted that targets presented to the RVF/LH were facilitated by low to moderate constraint sentences to a greater extent than those presented to the LVF/RH. Wlotko and Federmeier (2007) explained their findings by suggesting that the use of prediction would produce an advantage for the LH in processing expected words in relatively weak contexts. These findings were, however, in relation to normal sentences and it is not clear how the LH could use predictive processing in scrambled sentences unless it partially reconstructed the sentence at the message-level. Additionally, a similar pattern was not observed in the normal sentence condition which is therefore not consistent with the predictive processing explanation. Nonetheless, although the results suggest that the hemispheres were using quite different processing mechanisms, the nature of these processes (particularly in relation to the LH) remains speculative. Further research is needed to determine the underlying processes and how they differ in each hemisphere.

In summary, the present study aimed to resolve previous discrepancies in the literature in relation to RH use of contextual information at the message-level. The normal-behavioral research findings of the present study reinforce mounting evidence from other methodologies that suggests that, under at least some circumstances, both hemispheres utilize message-level information. While word-level processes as described by Beeman (1998) are highly relevant (and, as indicated by the scrambled sentences in the present study, the RH may well make greater use of them than the LH given no or limited message-level support), the present results do not suggest that the RH is restricted to such processes, or necessarily uses them preferentially. As such, further investigation is warranted, not into *whether* message-level processing is used, but *how* each hemisphere uses it.

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Appendix A

Table 1. Example stimuli

Sentence Type	Constraint	Sentence Fragment	Target
Normal	High	The boy was smelly and needed to take a	
	Low	The lady was relaxed as she sat in the warm	BATH
Scrambled		Take needed smelly boy the a to and was	
		The sat as was warm in she relaxed lady the	
Normal	High	The boy liked to walk his two	
	Low	The lady cuddled her two pet	DOGS
Scrambled		His to boy two walk liked the	
		Cuddled two her lady pet the	
Normal	High	The lady was washing the dishes in the	
	Low	The lady turned on the water to fill up the	SINK
Scrambled		The was dishes washing lady the the in	
		Up to the turned the the fill water on lady	
Normal	High	The sailor tied the rope in a complicated	
	Low	The man couldn’t loosen the	KNOT
Scrambled		A rope tied the complicated in the sailor	
		Loosen man the couldn’t the	
Normal	High	The chips were flavoured with lots of vinegar and	
	Low	The chef tasted the sauce then added some more	SALT
Scrambled		Vinegar lots flavoured chips and of with were the	
		Some then the chef more added sauce tasted the	

Sentence Type	Constraint	Sentence Fragment	Target
Normal	High	The girl scrubbed her hands with lavender scented	
	Low	The boy washed his hands and used the	SOAP
Scrambled		Lavender hands scrubbed the scented with her girl	
		Used hands washed the the and his boy	
Normal	High	The walls needed a second coat of	
	Low	The artist had run out of	PAINT
Scrambled		Coat a walls of second needed the	
		Out had the of run artists	
Normal	High	The gifted musician played a chord on the concert	
	Low	The boy was getting lessons to play the	PIANO
Scrambled		The chord played gifted concert on a musician the	
		Play lessons was the to getting boy the	
Normal	High	The girl shielded her eyes from the glare of the	
	Low	The workers protested at having to work in the	SUN
Scrambled		Of the eyes shielded the the glare from her the	
		In to at workers the work having protested the	
Normal	High	The athlete’s forehead was dripping with	
	Low	The hot worker used a rag to wipe away the	SWEAT
Scrambled		Dripping the athlete’s with was forehead	
		Away to a worked the the wipe rag used hot	

3. EXPERIMENT 2

The results of Experiment 1 showed that participants responded significantly faster to targets preceded by high-constraint sentence fragments than low-constraint sentences, regardless of visual field presentation. Furthermore, this increase in facilitation as a function of constraint was found to be significantly greater in the normal sentence condition than in the scrambled sentence condition. This result was observed for targets presented to either visual field. On the basis of these findings, it was concluded that both hemispheres utilize message-level processing mechanisms during sentence comprehension. The major finding of Experiment 1 was thus that the RH benefits from increased context by utilizing both word and message-level information derived from the sentences, at a level comparable to the LH. This provided an important contribution to the literature because, as reviewed in subsection 1.3.2.2, the majority of normal-behavioral studies of this sort have tended to assume that observations of a RH use of contextual information in sentences occurs primarily due to word-level associations. Experiment 1 demonstrated that the RH uses the message-level information when it is available, to an extent that produces facilitation of targets that is greater than that produced by the word-level information.

Although originally incorporated in Experiment 1 purely as a means of demonstrating whether facilitation of targets occurred due to message-level rather than simply word-level processing, the scrambled sentence fragments produced some unexpected results. In particular, the finding that the low constraint, scrambled sentences produced higher levels of facilitation for targets presented to the LH than to the RH was initially quite surprising. In order to explain this finding, it was suggested that the LH was using some form of controlled processing, while the RH was using summation priming derived from the word-level associations. Nevertheless, inconsistent findings in the literature relating to whether hemispheric differences in the use of summation priming can be explained in terms of a coarse/fine coding distinction necessitated further investigation of the conclusions made in Experiment 1 relating to the scrambled sentences. Accordingly, the second study in the present program of research aimed to examine whether these scrambled sentence results were reflective of the RH's use of coarse coding leading to a summation priming effect, while the LH utilized controlled processing to extract information beyond the word-level.

In Experiment 2, the scrambled sentences from Experiment 1 were reduced to only their content words in order to ensure that there remained no information from which a message-level representation could be reconstructed. These content words were presented centrally, one at a time, followed by the lateralized presentation of the corresponding target word or non-word. In addition to allowing the further investigation of the scrambled sentence findings of the first experiment, Experiment 2 provided a rigorous test of the underlying processing mechanisms of word-level information of each hemisphere. Specifically, as reviewed in Subsection 1.3.3.1, Beeman (1998) proposed that the RH utilizes a coarse semantic coding while the LH uses a finer coding. This model would predict that a greater increase in facilitation for the LH than for the RH should be observed as a function of increases to word-level constraint.

The manuscript describing Experiment 2 has been submitted for publication and is currently under peer review. The manuscript is presented in the following subsection in the form that it has been submitted for publication.

3.1 Right hemisphere language processing: The effects of summation priming.

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Running head: Summation priming and the right hemisphere

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Abstract

Evidence in support of the coarse coding hypothesis is, although substantial in the literature, not always consistent. The present study was designed to test claims made in a previous study (Gouldthorp & Coney, 2009) that, rather than relying purely on the word-level associations present in scrambled (i.e., syntactically disrupted) sentences, the left hemisphere (LH) used some form of controlled processing. Fortuitously, the design of the experiment permitted a rigorous test of the basic mechanisms of word-level processing proposed by Beeman (1998); namely, fine and coarse semantic coding. The present study presented only the content words from Gouldthorp and Coney's (2009) scrambled sentences to 30 right-handed participants who performed lexical decisions on laterally presented targets. The facilitation produced by each hemisphere for targets preceded by low or high constraint word groups was compared and, in strong support of the coarse/fine coding model of hemispheric processing, a significantly greater increase in facilitation from low to high constraint was observed for targets presented to the right visual field (RVF)/LH than to the left visual field (LVF)/RH. Additionally, the LH advantage in the low-constraint condition observed in Gouldthorp and Coney (2009) was eliminated in the present study when only the content words were presented. The results therefore lend strong support to the proposition that the LH utilizes a fine-coding mechanism in order to focus on the most predictable upcoming target when only word-level information is available, but also appears able to utilize controlled processing to extract some message-level information from syntactically disrupted sentences.

KEYWORDS: coarse coding, hemisphere, visual field, summation priming, constraint

Introduction

Recent investigations in the literature have often expressed the differences between the left hemisphere (LH) and the right hemisphere (RH) processing mechanisms in terms of fine and coarse semantic coding, respectively (Beeman et al., 1994). Coarse-coding involves the weak activation of a large field of both close and distantly associated words, resulting in an extensive semantic overlap occurring for the RH. Conversely, fine-coding involves the activation of only highly related meanings and thus results in a narrower and more focused semantic field for the LH, creating less chance of overlap between words.

A substantial body of evidence in support of the coarse coding hypothesis of RH processing is present in the literature. For example, Beeman et al. (1994) presented participants with three-word primes that were weakly related to a target and found more facilitation occurring for targets presented to the LVF/RH than for targets presented to the RVF/LH. Furthermore, they found that for targets presented to the LVF/RH, a single highly associated prime only produced facilitation equivalent to the three weakly associated summation primes. In contrast, for targets presented to the RVF/LH, far more facilitation was produced by the single highly associated prime than by the summation primes. Similarly, Chiarello, Burgess, Richards, and Pollock (1990) found that word targets preceded by a strongly associated word prime from the same semantic category were facilitated to roughly the same extent for RVF/LH and LVF/RH presentation. Conversely, when preceded by a weakly associated word prime, also from the same semantic category, the targets were facilitated only when presented to the

LVF/RH. Additionally, Titone (1998) investigated hemispheric priming effects of dominant and subordinate meanings of homonyms using a cross-modal, divided visual field lexical decision task where sentences provided a context that supported either peripheral or central semantic features related to only the subordinate meaning. Results showed that following a neutral sentence context, only the dominant meaning was primed for both hemispheres. Both dominant and subordinate meanings were primed for both hemispheres following sentences biasing the central semantic features of the subordinate homonym meaning. Following sentences biasing the peripheral semantic features of the subordinate homonym meaning, however, only the contextually-appropriate subordinate meaning was activated in the RH while the contextually-inappropriate dominant meaning was activated in the LH. Titone argued that this finding resulted from a RH sensitivity to weakly-associated words leading to activation of the subordinate meaning in the peripheral condition. In contrast, the LH was presumably unable to activate these weak associations and therefore effectively treated the peripheral context as neutral (thus resulting in priming of the inappropriate, dominant meaning).

Although a large number of studies support the proposition that the RH uses coarse coding, inconsistent results from a number of mediated priming and ambiguity resolution studies cast some doubt on this conclusion. For example, Richards and Chiarello (1995) argued that, based on the coarse coding hypothesis, mediated priming should be seen primarily with LVF/RH presentation given that these primes are inherently more distantly related to the targets than direct associates (i.e., a mediated prime is only related to the target through an additional word; e.g., soap-drink, via water). There was not, however, any evidence to support this, even across a varying range of stimulus onset asynchronies (SOAs) (50, 250 and 750ms). Livesay and Burgess (2003) also found equivalent levels of mediated priming for both hemispheres, which does not support the proposition that the activation of more distantly related words occurs more for the RH than for the LH. Conversely, Faust and Lavidor (2003) found results that supported the conclusion that the RH is especially sensitive to mediated priming. They presented two single word primes followed by an ambiguous target presented to either the left or right visual field. The word prime pairs were both either related to the dominant meaning of the target, to the subordinate meaning of the target, or included one related to the dominant and one to the subordinate meaning. They found that for targets presented to the LVF/RH the largest facilitation occurred for the condition in which the word primes diverged in meaning.

Kandhadai and Federmeier (2007) argue, however, that it is difficult to directly compare the findings obtained by Faust and Lavidor (2003) with those of Richards and Chiarello (1995) and Livesay and Burgess (2003) due to substantial differences in their use of stimuli, task parameters and analysis strategies. As such, Kandhadai and Federmeier further investigated hemispheric differences in mediated priming, including the question of whether the observed priming effects differed for ambiguous compared to unambiguous targets. They presented two primes that were either related or unrelated to the target, the former of which either converged on a single meaning of an unambiguous target (e.g., LION – STRIPES – TIGER), or diverged across different meanings of an ambiguous target (e.g., KIDNEY – PIANO – ORGAN). They did not find significant differences in facilitation across the two hemispheres in either the lexical decision or in the semantic judgement task; there were no differences in the amount of facilitation produced for either ambiguous or unambiguous targets presented to either visual field when preceded by two related primes. Given their failure to observe greater summation priming for the RH compared to the LH for mediated primes, they concluded that their findings did not support the coarse coding hypothesis.

Similarly, Kelpousniotou and Baum (2005) argued that the coarse semantic coding hypothesis has not garnered clear support in regard to its ability to account for the deficits following RH damage and they therefore set out to specifically test the predictions it made in regard to the processing of ambiguous words. They presented, at varying inter-stimulus intervals (ISIs), ambiguous words that were classified as either homonymous (a lexical item with two or more distinct and unrelated meanings) or metonymous (a lexical item with several different meanings that all have strong featural overlaps and are thus related). It was hypothesized that, if the coarse coding explanation was correct, RHD patients would not be impaired in processing the alternative meanings of metonymous words (due to the strong featural overlap between meanings) but would demonstrate an impairment for the homonymous words. These predictions were not, however, reflected in the results and thus failed to support the coarse semantic coding hypothesis; no processing differences in the RHD patients were found between homonymous and metonymous words.

The inconsistent conclusions derived from the literature in relation to RH coarse coding are problematic for researchers attempting to apply this model to experimental findings of their own. For example, in a previous study conducted in our laboratory

(Gouldthorp & Coney, 2009) we compared the relative facilitation obtained by each hemisphere from normal compared to scrambled sentences at varying levels of constraint. The scrambled sentences were designed to disrupt the syntactic structure and thus provide a measure of facilitation obtained from word-level processing. Surprisingly, we found that while the RH had quite low facilitation from low constraint, scrambled sentences and higher facilitation from high constraint, scrambled sentences, the LH had moderate levels of facilitation in both low and high constraint, scrambled sentences. In order to explain how the LH gained more facilitation than the RH from low constraint scrambled sentences, we argued that it must be using some sort of controlled processing, possibly to extract a modicum of message-level information by inferring some approximation of the structure of the unscrambled sentence; the RH, on the other hand, was presumably using summation priming as this would explain the increase in facilitation from low to high constraint scrambled conditions. Nonetheless, due to the inconsistency in the literature regarding the coarse coding hypothesis, our conclusions require further investigation.

Although the present study was initially designed to examine the hypotheses raised in Gouldthorp and Coney (2009) relating to the scrambled sentences, it also allowed us to mount a rigorous test of Beeman's (1998; Beeman et al., 1994) coarse/fine coding model. In the present study, all function words (articles, prepositions, conjunctions, etc.) were removed from the scrambled sentences used in Gouldthorp and Coney (2009), leaving only the content words. The removal of all function words should, we reasoned, seriously impair the ability of the LH to reconstruct the syntax of the original unscrambled sentence, and thus force a reliance on word-level information. This, in turn, should eliminate the LH advantage in the low constraint scrambled condition. Furthermore, on the basis of the mechanisms proposed by Beeman, the restriction of displays to content words should encourage the LH's fine coding mechanism to operate optimally in the high constraint condition due to a greater ability of the LH to focus on a single, expected target. As such, the fine coding hypothesis of LH processing would predict a greater increase in facilitation from low to high constraint conditions (i.e., a steeper slope of facilitation as a function of constraint) for targets presented to the RVF/LH than to the LVF/RH.

Results

Reaction time

RT data were initially screened using an outlier deletion criterion of +/- 2.5 standard deviations from each individual's mean response times for each condition. This resulted in 4.48% of the total observations being excluded. A further screening procedure was then applied to the sample as a whole, involving a winsorization process in which sample outliers for each condition were replaced with a value corresponding to 2.0 standard deviations above or below the sample mean for that condition. A total of 0.03% of means were replaced in this screening process. These data are summarized in Table 1.

Table 1. Mean RT as a function of target visual field and word group constraint. Standard deviations appear in parentheses.

	LH/RVF	RH/LVF
High Constraint Word Group	463 (74)	518 (91)
Low Constraint Word Group	503 (76)	532 (75)
Neutral / No Constraint Word Group	524 (64)	560 (79)

An initial 2x3 repeated measures analysis of variance was performed on the absolute RT data. The main effect of visual field was significant ($F(1,29)=34.7$, MSe=2055.7, $p<.001$), where targets presented to the RVF/LH were responded to 40ms faster on average than those presented to the LVF/RH. The main effect of constraint was also significant ($F(2,58)=27.4$, MSe=1446.0, $p<.001$) reflecting a decrease in RT as constraint increased from neutral (M=542ms), to low (M=518ms), to high (M=491ms). Although the interaction between visual field and constraint was not significant, planned comparisons were carried out to determine whether the facilitation produced by each hemisphere at each level of constraint was significant. Targets preceded by low constraint word groups were responded to significantly faster than when preceded by neutral word groups, for both the RVF/LH ($t(29)=2.697$, $p=.012$) and the LVF/RH ($t(29)=2.763$, $p=.010$). The high-constraint word groups also resulted in significantly faster RTs than neutral word groups for targets presented to the RVF/LH ($t(29)=6.331$, $p<.001$) and to the LVF/RH ($t(29)=4.270$, $p<.001$).

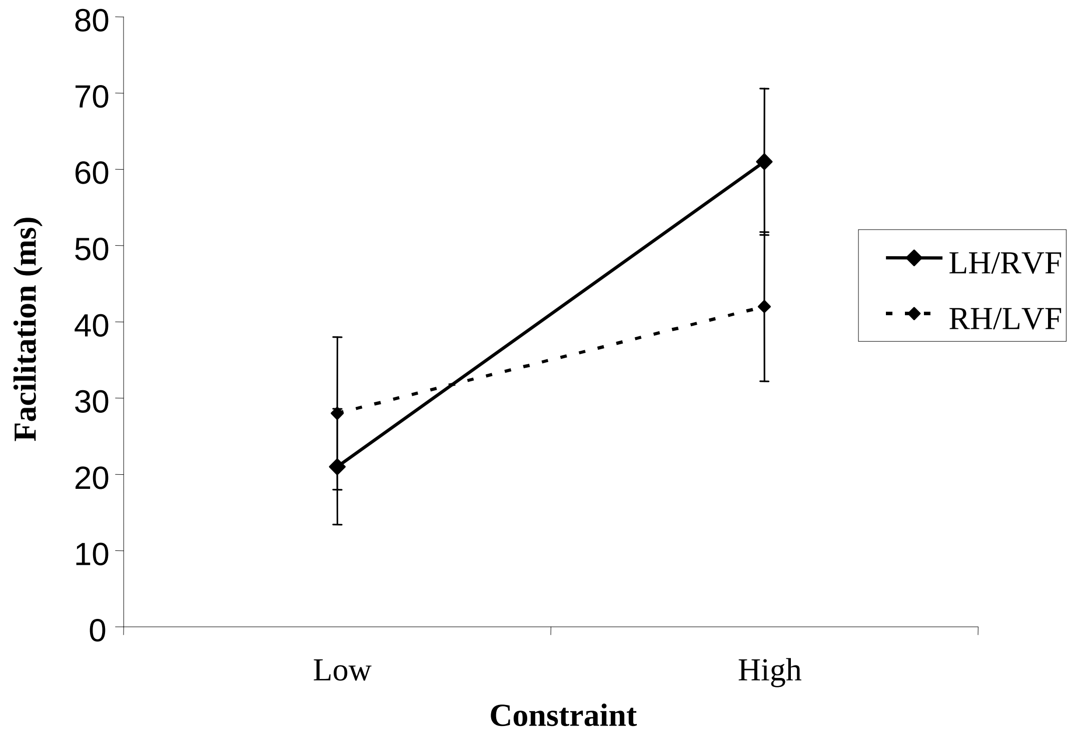

Figure 1. The relative facilitation (ms) of each visual field/hemisphere presentation as a function of constraint. Error bars represent +/- 1 standard error from the mean.

An additional 2x2 repeated measures analysis of variance was performed on the facilitation data, calculated by subtracting the mean RT of each condition from the mean of the corresponding neutral condition. These data are presented in Figure 1. The main effect of visual field was not significant, indicating that facilitation for responses was, overall, approximately equal for both hemispheres. The main effect of constraint was significant ($F(1,29)=14.3$, MSe=4008.8, $p=.001$), reflecting more facilitation for targets preceded by high constraint word groups (M=51ms) than by low constraint word groups (M=24ms). The interaction between visual field and constraint was also significant ($F(1,29)=6.16$, MSe=814.7, $p=.019$). Follow-up paired samples t-tests indicated that facilitation was significantly higher in the high constraint condition than in the low constraint condition for targets presented to the RVF/LH (t(29)=5.654, *p*<.001), but not for those presented to the LVF/RH. Although facilitation did not differ significantly between targets presented to the RVF/LH and RVF/RH in either the low constraint or high constraint condition, the increase in facilitation from low to high constraint was significantly greater for targets presented to the RVF/LH (*M*=40ms) than to the LVF/RH (*M*=14ms) (t(29)=2.061, *p*=.04).

Errors

A 2x3 repeated measures analysis of variance was conducted on the error rates word target trials. These data are presented in Table 2.

Table 2. Mean error responses (%) to target words as a function of target visual field and word group constraint. Standard deviations appear in parentheses.

	LH/RVF	RH/LVF
High Constraint Word Group	4.0 (5.2)	6.8 (7.3)
Low Constraint Word Group	3.8 (5.5)	13.1 (12.2)
Neutral / No Constraint Word Group	10.3 (7.6)	19.9 (14.1)

As in the RT analysis, the main effect of visual field was significant (*F*(1,29)=14.67, MSe=160.05, *p*=.001), reflecting fewer error responses to word targets presented to the RVF/LH (*M*=6%) than to LVF/RH (*M*=13%). The main effect of constraint was also significant (*F*(2,58)=35.2, MSe=41.9, *p*<.001), with the most errors occurring in response to targets preceded by neutral word groups (M=15%) and decreasing as constraint increased from low (M=8%) to high (M=5%). Additionally, the interaction between visual field and constraint was significant ($F(2,58)=5.35$, MSe=41.12, p=.007). Follow-up paired samples t-tests determined that there were significantly fewer errors for targets presented to the RVF/LH than to the LVF/RH in the neutral condition ($t(29)=3.175$, p=.004) and in the low constraint condition ($t(29)=4.184$, p<.001) but did not differ significantly in the high constraint condition. Given the consistency of the error rate data with the RT data, and that there was an inverse relationship between accuracy and speed as constraint increased, it is unlikely that any speed/accuracy trade off effects were impacting the results.

Discussion

In light of the inconsistency in the literature relating to the coarse coding hypothesis, the present study set out to determine whether the results observed in Gouldthorp and Coney (2009) relating to the scrambled sentences were reflective of the RH's use of coarse coding whereas the LH used a different processing mechanism altogether (perhaps by reconstructing some level of syntactic information from the scrambled sentences in order to extract a higher level of meaning in the low-constraint condition than would otherwise have been produced by purely word-level mechanisms). By presenting only the content words from these sentences in the present study, we were able to test these conclusions by comparing the facilitation derived by each hemisphere in the context of a form of the summation priming paradigm. The results provided strong support for the proposition that the RH utilizes coarse-coding at the word-level, while the LH is able to utilize a finer coding in order to focus on the most likely, or predictable, upcoming word. The results also support the conclusion made in Gouldthorp and Coney (2009) that, when the scrambled sentences also contained all of the function words, the LH was utilizing controlled processing to at least partially reconstruct the message-level meaning. As expected, the LH advantage in the low constraint scrambled condition observed in Gouldthorp and Coney (2009) was eliminated in the present study as a result of the LH having to utilize purely word-level information.

Furthermore, it appears that the removal of words that were superfluous to word-level processing (i.e., function words) allowed the fine coding of the LH to operate more effectively. Consistent with the mechanisms proposed by Beeman (1998; Beeman et al., 1994), a significantly greater increase in facilitation from low to high constraint was observed for targets presented to the RVF/LH than to the LVF/RH. It therefore appears that where the constraint imposed by the prime set was relatively high, the LH was able to select and amplify the likely meaning of the upcoming target, while the low condition yielded no more facilitation than that available in the RH. The RH, on the other hand, with an inclination toward only weakly activating relatively large semantic fields, was much less able to take advantage of an increase in constraint offered by the prime set.

Although the increase in facilitation from low to high constraint for the LVF/RH was considerably less than that observed in Gouldthorp and Coney (2009), the present results are, on reflection, more consistent with Beeman et al.'s (1994) coarse coding model of RH processing. For example, Beeman et al. (1994) found that the facilitation for the RH for targets preceded by a single highly associated prime was equivalent to the facilitation derived from three weakly associated primes. The LH, however, gained significantly greater facilitation from the highly associated prime compared to the weakly associated primes. This suggests that the RH may not benefit as much as the LH from increases in constraint and, further, that the RH advantage only becomes apparent when presenting very weakly related primes (i.e., very weakly constraining). Thus, the finding in the present study that the increase in facilitation from low to high constraint was comparatively minimal for the RH is consistent with Beeman et al.'s (1994) finding, particularly given that these labels reflect their relationship relative to one another, rather than reflecting an absolute measure of constraint. Notably, examination of Figure 1 suggests that extrapolation of the LH and RH functions to lower levels of constraint (and thus very weakly related words) could eventually yield a significant RH superiority in facilitation if even lower levels of constraint were to be presented. That is, the divergence in the functions representing hemispheric facilitation occurs in a direction that is consistent with the coarse coding model of RH processing.

Based on these findings, it appears that although the present study was fundamentally driven by the aim to examine hypotheses in Gouldthorp and Coney (2009) relating to the scrambled sentence findings, the variation of the summation priming paradigm used in the present study provided a rigorous test of the basic mechanisms of word-level processing proposed by Beeman (1998; Beeman et al., 1994). Notably, there were several variations from Beeman et al.'s paradigm that were incorporated into the present study. Firstly, the prime words were presented serially, and relatively slowly, rather than in parallel; secondly, the stimulus sets varied dynamically from 1-6 words due to their derivation from “real” sentences as opposed to being artificially constructed word groups; thirdly, a lexical decision task was used, which has not previously produced results that are consistent with Beeman et al.’s findings (see Joss & Virtue, 2008, for review). Thus, given the major departure from the paradigm used by Beeman et al. (1994), the present results represent an impressive confirmation of Beeman’s model.

Method

Participants

The 30 participants were undergraduate university students who had not already participated in Experiment 1 and were comprised of 6 males and 24 females (mean age=25.3 years, *SD*=4.9 years). All participants were right-handed, as assessed by a rating of .40 or above (*M*=0.97, *SD*=0.07) on the Bryden’s Simplified Hand Preference Questionnaire (Bryden, 1982). All participants possessed English as a first language and normal or corrected-to-normal vision.

Design and Stimulus Materials

A 2x3 repeated measures design was used, manipulating the independent variables of visual field (left or right) and constraint (neutral, low, or high). The dependent variables were reaction time and error rate, with reaction time being the primary experimental measure.

The stimuli used in this experiment were derived from the scrambled sentence fragments used in Gouldthorp and Coney (2009). The nouns, verbs and adjectives of each of the sentence fragments were used to form a “word group” and these were categorized according to the level of constraint created by the sentence fragment it was derived from. For example, word groups derived from high-constraint sentence fragments were identified as “high constraint” in the present study. The number of words in each resultant group ranged from 1-6 for the high-constraint condition (*M*=3.6, *SD*=1.0) and 1-5 for the low-constraint condition (*M*=3.3, *SD*=1.0). The sentence-final target from Gouldthorp and Coney (2009) remained the target word for the respective word group. Although the target words were identical to those used in Gouldthorp and Coney (2009), each target was only presented once per participant in the present study due to the removal of the normal sentences condition (i.e., each target was presented twice to each participant in Gouldthorp and Coney (2009), but only once per session). See Table 3 for example stimuli.

Table 3. Example stimuli associated with the target “SOAP”.

	Gouldthorp & Coney (2009) sentence fragment		Present-study word group
Constraint	Normal	Scrambled	
High	*The girl scrubbed her hands with lavender scented*	*Lavender hands scrubbed the scented with her girl*	Lavender; hands; scrubbed; scented; girl
Low	*The boy washed his hands and used the*	*Used hands washed the the and his boy*	Used; hands; washed; boy

Neutral	*The next word that you will see is*	*See you word the is will that next*	See; word; next

The process of extracting stimulus word-groups from Gouldthorp and Coney's (2009) scrambled sentences was also conducted for the non-word target conditions so that half of the final stimulus set comprised word targets, and the remaining half comprised non-word targets. The final stimulus set was comprised of 720 word groups in total (3 word groups for each of the 120 word targets; 3 word groups for each of the 120 nonword targets). Each participant received one of the 3 word groups per target, producing 20 observations per condition per participant. An additional 12 word groups (of a similar style to the test stimuli) were constructed for use in the practice task.

Apparatus

The apparatus was identical to that described in Gouldthorp and Coney (2009).

Procedure

Prior to each session, the order of presentation of trials was randomized on-line within each block of 24 experimental conditions. Participants attended a single one-hour session and were tested individually. Testing was conducted in a laboratory illuminated by both fluorescent and natural lighting. Prior to commencing the first session, participants completed the Bryden's Simplified Hand Preference Questionnaire (Bryden, 1982). Participants were then read instructions and any questions answered.

Prior to commencing the experiment participants first participated in a supervised practice task. This task involved 12 trials and was included to ensure the participant understood the task prior to the commencement of data collection. Individual prime words were presented centrally, one at a time, on the computer screen in black letters with a grey background and in Courier font approximately 1cm high (0.95 degrees of visual angle). Each word was exposed for a duration calculated on the basis of 60ms per letter, in order to cater for varying word lengths. Following the presentation of all prime words in a trial set, a black fixation cross appeared centrally on which participants were instructed to focus their gaze. Shortly following the presentation of the fixation cross, the target was flashed to either the left or right side of the screen, with the innermost boundary located at 2.1 degrees of visual angle from the central fixation point. Targets were presented in black uppercase letters, using the Verdana font, for 150ms. The participant then made a decision as to whether they believed the target was a word or a non-word. Participants were instructed to depress both micro-switches simultaneously with the index finger of each hand if they believed the target was a word. Participants were instructed to withhold any response if the target was a non-word. If participants responded to a non-word or failed to respond within 1500ms to a word, an error message (consisting of the word “ERROR”) was presented briefly on the screen. Following completion of each trial was a gap of two seconds prior to commencement of the next trial.

Following completion of the practice task, it was reiterated that participants must maintain central fixation during target presentation. Participants were also advised that their eye movements would be monitored on a CCTV linked to a camera above the computer screen to ensure they were reverting to a central fixation following the sentence fragment presentation. Participants were then presented with one of the three balanced stimulus sets of 420 word groups (i.e., twenty blocks of the 12 conditions). Presentation of the word groups, targets, and the method of response were the same as in the practice task. Participants were given a rest break between each block, during which feedback relating to their reaction times and errors for the preceding block of trials was provided.

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3.2 Experiment 2: Additional Discussion

Although it was argued in the preceding paper that the results from Experiment 2 provided support for Beeman's (1998; Beeman et al., 1994) model of hemispheric processing at the word-level, there were some alternative interpretations of the results that were not addressed. Indeed, the ambiguous nature of the results presented a considerable difficulty in producing a coherent account of the results in a manner that might be acceptable for publication; thus, the account presented in the paper is only one of several alternative theoretical interpretations.

In the preceding subsection, the argument that Experiment 2 provided support for Beeman's (1998) coarse/fine coding distinction of hemispheric processing at the word-level rested predominantly on the observation that there was significantly greater facilitation for the LH in the high-constraint condition than in the low-constraint condition. It was argued that this result reflected a fine-coding mechanism, in which greater facilitation was produced in the high constraint condition for the LH due to its ability to focus on and amplify the most likely meaning. Conversely, the finding that there was no significant difference in facilitation between the hemispheres in the low-constraint condition did not initially appear to be consistent with a coarser-coding mechanisms of the RH (i.e., the coarse coding hypothesis predicts that the RH is facilitated more than the LH where there are a number of weakly related associates). Further consideration of the results, however, suggested that one possible explanation is that the words presented in the low-constraint condition were not weakly related enough to reveal the RH advantage. As argued in the paper, the presentation of lower levels of constraint may have yielded significantly greater RH facilitation.

Nevertheless, the ambiguity of the results in relation to the processes occurring in the low-constraint condition invites consideration of an alternative interpretation of the results. For example, contrary to the argument presented in the paper in the preceding subsection, the results could alternatively be interpreted as *not* providing support for Beeman's (1998) model. If the words included in the low-constraint condition were, in fact, considered to be weakly-related enough to reveal a RH processing advantage, then the finding in Experiment 2 that there were not any significant hemispheric differences in facilitation in the low-constraint condition is inconsistent with the coarse coding hypothesis. According to the coarse coding hypothesis, there should have been significantly greater facilitation for the LVF/RH in the low constraint condition due to a greater chance in semantic overlap between each of the weakly related words in each group.

Another explanation of the results in Experiment 2 is that the hemispheres may be differentially sensitive to the predictability of upcoming words. For example, a number of researchers (e.g., Federmeier & Kutas, 1999; Virtue, van den Broek, & Linderholm, 2006) have found that the predictability of a target due to a preceding context influences hemispheric processing, with significantly greater priming observed for predictable targets for the LH than for the RH. The low and high constraint word groups used in Experiment 2 are also likely to have reflected low and high target predictability, respectively, due to measurement of constraint used in Experiment 1 as being the cloze probability of the required target. Thus, when targets were preceded by the high constraint word groups they would also have been considered to be more highly predictable than when preceded by the low constraint word groups. As such, rather than reflecting effects of fine coding, the observation in Experiment 2 that the LH benefited more from the increase from low to high constraint than the RH may instead reflect a LH advantage for processing predictable words given a context. Furthermore, Joss and Virtue (2008) found that although for the LH targets preceded by strongly or weakly related primes were responded to more accurately than unrelated targets, no difference was observed for the RH. This suggests that the LH may be more effective at controlled processing than the RH and thus better able to utilize a strategy to search for a relation between the primes and the target.

This explanation would also account for why the constraint effect on scrambled sentences was not also observed for the LH in Experiment 1. When the content words were embedded in sentences it is likely that the inclusion of the additional function words reduced the ability to focus on potential relationships between the relevant primes (i.e., the content words) and the target, thus eliminating an advantage in the high constraint condition. Alternatively, the change in results regarding the effect of constraint on facilitation following the removal of the function words in Experiment 2 may be interpreted as an indication that the presence of message-level information alters the way in which the semantic information is processed and thus overrides the possible alternative meanings derived from the semantic information alone.

The ambiguity of the results produced in Experiment 2, and the various interpretations available, thus create some difficulty in drawing specific conclusions from these findings. Nevertheless, the account presented in the paper in the preceding subsection, as submitted for publication, supports Beeman et al.'s (1994) conclusion that the coarse/fine coding model of hemispheric processing is applicable when applied to the word-level. Whether one favors this particular interpretation of the present results or one of the alternatives, it is undisputable that the fine/coarse coding model maintains prominence in the hemispheric language processing literature. Thus, further investigation of this model is worthwhile, particularly in regard to the possibility of its extrapolation beyond individual words in order to explain language comprehension on a broader level.

4. EXPERIMENT 3a AND 3b

Although the results of Experiment 1 provided strong evidence that the RH is sensitive to message-level contextual information and is therefore not restricted to word-level processing, the results of Experiment 2 suggest that there is nevertheless some applicability of the coarse/fine-coding distinction between right and left hemisphere processing. The combination of these findings therefore points to the possibility that the RH may utilize a coarser coding of message-level concepts than the LH. Accordingly, the third study in the present program of research aimed to build on the findings of both Experiment 1 and 2 by investigating, firstly, whether the RH integrates contextual information across several sentences and, secondly, whether there is any evidence for a "coarse" processing mechanism of the RH at the message-level.

To address these aims, participants in Experiment 3a and 3b made lexical decisions about laterally presented target words or non-words preceded by one of four sentence prime conditions. Constraint was manipulated from low to medium to high through the addition of an extra sentence. For example, the target "PLANE" was preceded by a sentence prime condition that was either: i) neutral (e.g., *I am a neutral sentence*.); ii) low constraint (e.g., *I am made from paper*.); iii) medium constraint (e.g., *I am made from paper. I am folded*.); iv) high constraint (e.g., *I am made of paper. I am folded. I can fly*.). As in the first experiment in this program of research, a scrambled condition for each level of constraint was also included in order to provide a baseline measure of the effects of word-level associations. It was argued that the sentence primes, when considered individually, presented message-level information that was only weakly related to the target. Thus, if the coarse coding model of RH processing can be applied to message-level concepts, significantly greater facilitation for targets presented to the LVF/RH than to the RVF/LH should be observed due to the greater chance of overlap between the otherwise weakly related concepts.

The manuscript describing Experiments 3a and 3b has undergone peer review and has been accepted for publication in the journal *Laterality: Asymmetries of Body, Brain and Cognition*. The following subsection presents the manuscript in the form that it will be published. As such, Experiment 3a and 3b are referred to in the following manuscript as "Experiment 1" and "Experiment 2", respectively.

4.1 Integration and coarse-coding: Right hemisphere processing of message-level contextual information.

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Running head: Right Hemisphere and Context

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Abstract

A number of different models have been proposed in order to explain the underlying processing mechanisms of each hemisphere for contextual information in sentences. While the coarse-coding hypothesis (Beeman, 1998) remains prominent in the literature, it is inconsistent in its current form with strong evidence suggesting that the RH has a capacity for comprehension that extends beyond word-level processing. Experiment 1 set out to investigate the proposed special role of the RH for integrating broad concepts by centrally presenting one, two, or three sentences followed by an associated word or non-word target to either the left or right visual field. Each sentence, in itself, provided only minimal cues to the nature of the target, but in combination with others created a much more powerful context. Thirty-two right-handed undergraduate psychology students participated in a computer-based lexical decision task where reaction time and error rates were recorded. In contrast to expectations based on the coarse-coding hypothesis, targets presented to the RVF/LH were as strongly facilitated as targets presented to the LVF/RH at all levels of contextual support. Due to some ambiguity in the results as to the level of processing of each hemisphere, an additional experiment was conducted which aimed to resolve this difficulty through a modification to the scrambled sentence condition. Experiment 2 provided a clear demonstration that the equality of facilitation observed in both experiments occurred as a result of message-level processing. This finding indicates that the coarse/fine-coding distinction between left and right hemisphere processing cannot be applied to message-level processing.

Keywords: sentence comprehension, hemisphere, visual field, priming, context

Introduction

The right cerebral hemisphere (RH) has been shown in recent research into language comprehension capacities to be able to utilize contextual information embedded in sentences to facilitate target recognition (Gouldthorp & Coney, 2009; Gouldthorp & Coney, in press; Titone, 1998). Furthermore, there is strong evidence that the RH has a special role in deriving meaning from an integration of contextual information over a number of sentences (Delis, Wapner, Gardner, & Moses, 1983; Gardner, Brownell, Wapner, & Michelow, 1983; St. George, Kutas, Martinez, & Sereno, 1999; Wapner, Hamby, & Gardner, 1981). A number of researchers have attributed this integration to a RH sensitivity to message-level processes (e.g., Coulson, Federmeier, Van Petten, & Kutas, 2005; Gouldthorp & Coney, 2009; Gouldthorp & Coney, in press); that is, the syntactic, semantic, and pragmatic information embodied in sentences and texts (Morris, 1994). An alternative explanation, which appears to be particularly prominent in the literature derived from behavioral measures in normal individuals, is that the RH relies simply on word-level processes (i.e., the basic lexical relationships between individual words in sentences; Morris, 1994) (Beeman, 1998). The conflict between these two explanations remains puzzling and, as yet, few studies have attempted to reconcile the discrepant evidence.

The word-level processing explanation of the RH's appreciation of context is often related to Beeman's (1998) model of RH coarse-coding of words. This model suggests that the RH weakly activates a large field of both close and distantly associated words, resulting in extensive semantic overlap. In contrast, the left hemisphere (LH) strongly activates only highly related meanings, resulting in activation of a narrower and more focused semantic field, and there is thus less chance of overlap between words. A number of authors (e.g., Anaki, Faust, & Kravetz, 1998: Beeman, 1998; Burgess & Chiarello, 1996) argue that evidence of a special role for the RH in tasks such as metaphor comprehension, appreciation of humor, and making certain types of inferences, can be explained by the RH's use of coarse-coding at the word-level. They argue that the fine semantic coding of the LH allows for quick selection of relevant meanings which are then incorporated into higher level processes. This provides an advantage to the LH in most language tasks, as it facilitates rapid language processing. The proposed RH use of coarse coding is therefore not as efficient as the LH and, as a result, the RH tends to be inferior to the LH in a number of language tasks. There are, however, some circumstances in which the more diffuse activation of a wider range of meanings advantages the RH as it permits a greater appreciation, and thus comprehension, of less usual relationships between words. For example, Beeman, Bowman, and Gernsbacher (2000) found that participants named targets presented to the left visual field (LVF)/RH faster if they were related to predictive inferences. The same finding did not occur for targets presented to the right visual field (RVF)/LH. Predictive inferences refer to the prediction of upcoming sequences or likely events based on the preceding context even though the inference is not required for coherence of the text (as in a coherence, or bridging, inference). Beeman et al. (2000) argued that the RH's activation of larger semantic fields would result in a greater likelihood that a concept that provides an inferential connection would be activated. Other evidence for this explanation comes primarily from summation priming experiments. Beeman et al. (1994) presented participants with three-word primes that were weakly related to a target and found more facilitation occurring for targets presented to the LVF/RH than for targets presented to the RVF/LH. Furthermore, they found that for targets presented to the LVF/RH, a single highly associated prime only produced facilitation equivalent to the three weakly associated summation primes. In contrast, for targets presented to the RVF/LH, far more facilitation was produced by the single highly associated prime than by the summation primes. Tompkins, Scharp, Meigh, and Fassbinder (2008) found that individuals with RH damage (RHD) appear to have a deficit in sustaining the activation of peripheral features of nouns. This therefore supports the presumption that the RH relies on word-level processing, but rather than suggesting that only the RH initially activates the distantly related associations, it suggests that it is only the RH that *maintains* activation of them. If this is the case, then a special role of the RH for certain language tasks could be explained not just by an initial coarse coding of distantly related words, but also the maintenance of this activation.

Although there certainly appears to be strong evidence in support of the RH coarse coding model in relation to sentence processing at a word-level, it is unclear how the hemispheres differ when processing sentential information at the message-level. Indeed, most authors using this model as an explanation for RH advantages in inference generation, metaphor comprehension, discourse integration, etc., appear to assume that the RH is only using word-level processing; that is, through activation of distantly related words (Tompkins et al., 2008). For example, Faust and Babkoff (1997) investigated the priming effects of scripts for each cerebral hemisphere using a lexical decision task. They argued that if greater facilitation was observed for targets presented to the LVF/RH than to the RVF/LH, then this could be explained by greater summation priming capability in the RH than the LH, due to the priming ability of a script deriving mainly from the accumulated associations of the relevant single words of which it was composed (Sharkey & Mitchell, 1985). Their results, instead, showed facilitation for both hemispheres (although greater in the RVF/LH). Based on the assumption that the RH is restricted to word-level processing, they argued that the RVF/LH facilitation effects resulted from message-level processing, whereas the LVF/RH facilitation effects resulted from word-level processing. A similar conclusion was reached in Faust and Kravetz's (1998) study, where LVF/RH as well as RVF/LH facilitation was observed following sentence primes; however, given that no baseline measure of word-level primes was used (e.g., strings of single words or scrambled sentences) the assumption that the facilitation observed for the RVF/LH resulted from message-level processing while the facilitation observed for the LVF/RH resulted from word-level, rather than message-level, processing appears unsubstantiated. The assumption presumably stems from Faust, Babkoff, and Kravetz's (1995) study in which no difference in facilitation was observed for the LVF/RH between normal and scrambled sentences. This result has not, however, been replicated and there is some doubt as to its reliability given the effect was only reported in the secondary measure of accuracy and not in the primary measure of RT. Despite the frequent assumption that the RH relies predominantly on word-level processing (e.g., Chiarello, Liu, & Faust, 2001; Faust, Bar-Lev, & Chiarello, 2003), few authors appear to have reliably demonstrated that the RH is insensitive to message-level information or that it uses word-level information preferentially (for a review, see Wlotko & Federmeier, 2007).

Conversely, evidence from a growing number of studies (e.g., Coulson et al., 2005; Gouldthorp & Coney, 2009; Gouldthorp & Coney, in press; Federmeier & Kutas, 1999; Federmeier, Mai, & Kutas, 2005; Van Petten, 1993; Wlotko & Federmeier, 2007) strongly suggests that *both* hemispheres use message-level processing. For example, Federmeier et al. (2005) set out to specifically test the claim that the RH does not benefit from contextual information at the message-level. In their ERP study, sentence contexts (primes) provided different levels of message-level constraint on what were otherwise entirely plausible sentence-completion targets. They argued that if the RH was insensitive to message-level information, then no difference in facilitation should be observed between sentence contexts reflecting weak, as compared to high, message-level constraint. Their results, however, revealed more facilitation for LVF/RH targets following primes with high message-level constraint than those with low-constraint. Furthermore, the magnitude of facilitation was comparable to that observed in the RVF/LH. In another ERP study, Coulson et al. (2005) found that not only did both hemispheres process message-level information, but that they did so in preference to word-level information when both were available. They presented participants with sentences for which the context was either congruous or incongruous with the sentence-final target and, additionally, either contained a word associated to the target or did not contain any associated words. Word-level priming was therefore measured by those sentences containing an associated word, while message-level priming was measured by those without the associated word. Furthermore, the sensitivity of each hemisphere to message-level compared to word-level information was compared by examining facilitation in the incongruous, associated condition (i.e., where facilitation would only be observed if the word-level information overrides the incongruous message-level information) and facilitation in the congruous, unassociated condition (i.e., where facilitation would only be observed if the message-level information of the sentence is used to prime the target). Contrary to the presumption that the RH relies predominantly on word-level processes, the results indicated that sentence congruity and not the presence of an associated word was the primary determinant of facilitation for both hemispheres. That is, both hemispheres used the message-level sentential context preferentially to the word-level associations. These findings are supported by a previous investigation in our own laboratory using a behavioral methodology in which the relationship between sentence context and a sentence-final target word was manipulated to produce varying levels of target constraint. A scrambled-sentence condition was included in order to differentiate between word and message level processing (Gouldthorp & Coney, 2009). Interestingly, the results indicated that the RH was perhaps using coarser processing when information was only available at the word level (as in the scrambled sentences), but when message-level information was available (as in the normal sentences) the RH was facilitated to at least the same extent as the LH. We obtained similar results in another study (Gouldthorp & Coney, in press) in which the amount of contextual information in a sentence was varied by manipulating sentence length; both hemispheres utilized the additional contextual information present in the longer sentences and, furthermore, did so in a way that could only be attributable (through comparison of normal and scrambled sentences) to message-level processing.

It would therefore appear that the coarse-coding model of RH language processing is insufficient in accounting for evidence of RH message-level processing. Beeman's (1998) account of the coarse-coding model proposes that RH language processing occurs from the overlap of broad semantic fields resulting from automatic spreading activation, which inherently presumes a restriction to word-level processing. Given that evidence for the coarse coding model comes predominantly from the summation of single-word priming (Beeman et al., 1994), evidence that the coarse coding model can be applied at a sentential level remains to be demonstrated. For example, St George et al. (1999) found a considerable RH involvement (as shown by fMRI) in the comprehension of untitled paragraphs of otherwise semantically vague propositions; that is, there appeared to be a special involvement of the RH in developing “global coherence”. Although St George et al. suggested that this special role of the RH in developing and maintaining coherence may be a result of coarse coding processes, the individual sentences were of such a vague and disconnected nature (e.g., see the horse-back riding example provided in St. George et al., 1999) that it is not at all clear how meaning could be derived from word-level processing alone. The coarse-coding model therefore needs to be extended beyond the word level in order to account for evidence of RH message-level processing. For example, the RH may be extracting the message-level meaning from the individual sentences and then weakly activating a wide range of concepts related to the message-level meaning.

Federmeier (2007) presented an alternative model in which hemispheric differences at the message-level were conceptualized as a “predictive” capacity of the LH and an “integrative” capacity of the RH. Federmeier argues that the LH uses top-down processing to predict upcoming information which, although allowing for fast and detailed processing, can distort the bottom-up signal of incoming stimuli. In contrast, the RH maintains the stimulus-specific information for a longer period of time, allowing for revision and reinterpretation of previous signals in order for integration with later stimuli to occur. This model therefore does not assume that the RH relies on coarse-coding but rather develops a higher-level contextual basis and new incoming information is then integrated with this context, even if this requires a reinterpretation of the previous context. This proposition is supported by the finding that the RH is better able to maintain activation of concepts related to the contextual information, whereas the LH only activates the features of a concept that are predicted by the context (Federmeier & Kutas, 1999).

The proposed special role of the RH for cohering broad concepts, whether as a result of coarse-coding (Beeman, 1998) or “integrative” processing (Federmeier, 2007), was investigated in the present study by presenting one, two, or three sentences followed by a word or non-word target. Each sentence individually provided minimal contextual information, but in combination served to generate significant context. Just as Beeman et al. (1994) found that the RH was facilitated more by summation priming from three distantly related single words, so we expected that if the RH is using coarse coding to provide coherence across sentences (as proposed in St George et al., 1999) rather than across individual words then it should be facilitated to a greater extent than the LH by the integration (or “summation”) of three distantly related sentential contexts. In line with Faust and Babkoff’s (1997) study, we used complete sentences rather than fragments. As noted by Sharkey and Mitchell (1985) and Faust and Babkoff, sentence fragment primes, by their very nature, constrain the target to that which is consistent with the syntactic structural composition of the sentence. Complete sentences, on the other hand, allow targets to be based on more diffuse associations with the primes.

Given this, complete sentence groups should provide a means by which to investigate the “coarse” processing of the RH at a message-level. The present study also included scrambled sentences in order to provide a baseline measure of word-level mechanisms.

Based on the findings of St. George et al. (1999) and the assumption that the RH uses a coarser, more global processing mechanism than the LH (Beeman, 1998), we hypothesized that the presentation of three sentences would generate greater facilitation for targets presented to the LVF/RH than to the RVF/LH. It was also hypothesized that both hemispheres would evidence message-level processing by exhibiting greater facilitation from normal sentences than from scrambled sentences.

Experiment 1

Method

Participants

Thirty-two undergraduate university students participated in the experiment, with the majority of participants receiving course credits. The sample was comprised of 7 males and 25 females (mean age=29.6 years, *SD*=10.5 years). All participants were right-handed, as assessed by a rating of .40 or above (*M*=0.90, *SD*=0.13) on the Bryden’s Simplified Hand Preference Questionnaire (Bryden, 1982), on which the scale ranges from +1.00 (extreme right-handedness) to -1.00 (extreme left-handedness). All participants possessed English as a first language and normal or corrected-to-normal vision.

Design and stimulus materials

The basic experimental task required a lexical decision to be made in respect of laterally-presented targets which were primed by centrally-presented sentences intended to establish a context. The target set was divided equally between words and non-words, and three additional variables were manipulated as repeated measures in the design: (i) the nature and number of sentences was varied in order to manipulate the degree of context relative to the target (neutral = neutral sentence only, low = one context sentence, medium = two context sentences, and high = three context sentences), (ii) visual field of target presentation, and (iii) sentence type (normal or scrambled). Thus, each trial in the experiment consisted of the sequential presentation of from 1 to 3 normal or scrambled sentences, followed by the lateral exposure of a letter-string representing a word or nonword target. A total of 640 such trials (with 20 observations per condition), distributed over two sessions, were presented to each participant in the course of the experiment.

Stimuli associated with degree of context consisted of groups of three sentences based around a single target word, constructed so that: (i) a neutral condition (that always took the form of “This is a neutral sentence.”) produced a baseline measure of priming; (ii) low-context for the target would be produced by each sentence when presented individually, (iii) medium-context would be produced when two sentences were presented, and (iv) high-context would be produced when all three sentences were presented. That is, increased context would occur through the integration of two or more low-context sentences rather than simply by the addition of a single highly-contextual sentence. Target words were short (3-5 letters, *M*=4.3, *SD*=0.7), highly imageable (*M*=580, *SD*=44), concrete (*M*=580, *SD*=60) nouns, as derived from the MRC Database (1987) collated ratings (Coltheart, 1981). Initially, 180 targets with corresponding groups of three sentences were generated, and these were then subjected to a test of association in order to remove unsuitable stimuli. Lists of either one, two, or all three of the sentences corresponding to each target were given to five panels of 10 participants (recruited from the same population as the experimental sample) who were required to write down the first one or two words that came to mind after reading the sentence/s. The level of association (context) of each sentence was quantified by determining the probability of the target word being produced. If the probability produced for one or more of the sentences in the group was not consistent with the anticipated level (e.g., if a single sentence produced a probability above 0.35; if two sentences produced a probability below 0.36 or above 0.75; if three sentences produced a probability below 0.76) then that target and sentence group was eliminated. Targets and their corresponding sentences were also eliminated if a noun in any of the three sentences was determined by the University of South Florida association norms database (Nelson, McEvoy & Schreiber, 2004) to be a primary associate of the target. The final, total stimulus set comprised 160 word targets, each with sentence groups of one, two, or three sentences. For each target, all three sentences presented together (i.e., the "high-context" sentence group) generated a mean probability of 0.88 (*SD*=0.09); two sentences presented together (i.e., the "medium-context" sentence group) generated a probability of 0.67 (*SD*=0.21); one sentence presented individually (i.e., the "low-context" sentence group) generated a probability of 0.24 (SD=0.18). Following this, the word order of all of the sentences was randomly changed to produce an additional control set of 160 scrambled sentence groups. This was designed to remove the structure of the sentences, essentially reducing them to lists of apparently unrelated words and thus providing a baseline measure of priming resulting from word-level associations. The set of potential stimuli for each target word therefore contained normal and scrambled sentence groups of high (three sentences), medium (two sentences), low (one sentence) and neutral context. Table 1 shows an example sentence group; the second sentence in each pair is the scrambled version of the first, normal sentence.

Table 1. Example stimulus sets for the targets "*HONEY*" and "*PLANE*", respectively.

Context	First sentence	Second sentence	Third sentence
Neutral	*This is a neutral sentence.* *Neutral is sentence a this.*		
Low	*I taste sweet.* *Taste sweet I.*		
Medium	*I taste sweet.* *Taste sweet I.*	*I can be put on toast.* *On be I toast put can.*	
High	*I taste sweet.* *Taste sweet I.*	*I can be put on toast.* *On be I toast put can.*	*I am made by an insect.* *An made I insect by am.*
Neutral	*This is a neutral sentence.* *Neutral is sentence a this.*		
Low	*I am made of paper.* *Made I paper of am.*		
Medium	*I am made of paper.* *Made I paper of am.*	*I am folded.* *Am folded I.*	

High	*I am made of paper.*	*I am folded.*	*I can fly.*
	Made I paper of am.	*Am folded I.*	*Can fly I.*

An additional 160 sentence groups were created in order to be paired with a non-word target. Forty of these sentence groups took the neutral form and the remaining 120 sentence groups were designed to mimic the style of the high, medium, and low context sentence groups. Non-word targets were generated by taking the 160 real-word targets and non-systematically changing a single letter so that the resulting letter string was a pronounceable, orthographically-legal pseudo-word. Any resulting pseudo-homophones were identified and replaced with alternate non-words. The non-word sentences were also scrambled to produce a set of 160 scrambled non-word sentence groups.

With the addition of these sentences, the final stimulus ensemble comprised 640 items counterbalanced over eight different stimulus sets so that, firstly, each participant would only be presented with one sentence group (i.e., either the neutral, low, medium, or high context group) for each target and, secondly, would have equal numbers of target words and non-words for each condition presented to each visual field. Additionally, each stimulus set was divided across two sessions (conducted at least one week apart) so that, for each target word or non-word, the normal version of the sentence group was presented in a different session to the scrambled version. Each session, however, contained equal numbers of normal and scrambled sentences, and the presentation of the normal or scrambled version in the first or second session was balanced across participants. Finally, an additional 12 sentence groups (of a similar style to the test stimuli) were produced for use in the practice task.

Apparatus

All programs associated with running both sessions were run on an Intel Pentium 4 processor with a Windows 98 SE operating system and 256 MB Ram. The experimental control program was a custom-written FORTRAN application compiled by a Salford Software compiler and real-time library system. The monitor on which stimuli were displayed was a Samsung SyncMaster 931c with a screen resolution of 1280 x 1024 pixels, 32-bit color and a refresh rate of 75 hertz. A 2-button micro-switch response box was used to record the participants' responses. Participants rested their head on a chin-rest that was positioned 60cm from the monitor and could be individually adjusted for height. Ear defenders were used to ensure exclusion of any possible extraneous noise. Finally, a CCTV system was used to permit the experimenter to monitor participants' eye movements in an adjoining room. A zoom lens was used to project an enlarged image of one of the participant's eyes on a CCTV monitor, and the position of the pupil during central fixation was marked on the screen. This permitted even minor deviations from central fixation to be readily detected during the experiment.

Procedure

Prior to each session, the order of presentation of trials was randomized on-line within each block of 32 experimental conditions. Participants attended two, one-hour sessions approximately one week apart (aimed at minimizing repetition priming across sessions) and were tested individually. Testing was conducted in a laboratory illuminated by both fluorescent and natural lighting. Prior to commencing the first session, participants completed the Bryden's Simplified Hand Preference Questionnaire (Bryden, 1982). Participants were then read instructions and any questions answered.

In both sessions, participants first participated in a supervised practice task. This task involved 12 trials and was included to ensure the participant understood the task prior to the commencement of data collection. Each sentence was presented centrally on the computer screen in black letters with a grey background and in Courier font approximately 1cm high (0.95 degrees of visual angle). The exposure duration of each sentence was computed on the basis of allowing 60ms per letter, which provided sufficient time for participants to read at a natural pace while still comprehending each word in the sentence. Where there were two or three sentences in the group, each sentence was presented individually on the screen. The display screen was cleared after each sentence and remained blank for a period of 1000ms. Following presentation of the final sentence, a central fixation cross appeared on which participants were instructed to focus their gaze. Nine hundred milliseconds after the presentation of the fixation cross, the target was flashed to either the left or right side of the screen, with the innermost boundary located at 2.1 degrees of visual angle from the central fixation point. Targets were presented in black uppercase letters, using the Verdana font, for 150ms. Participants then decided whether the target was a word or a non-word, and were instructed to depress both micro-switches simultaneously with the index finger of each hand if the target was a word. Participants were instructed to withhold any response if the target was a non-word. If participants actively responded to a non-word or failed to respond within 1500ms to a word, an error message (consisting of the word

“ERROR”) appeared briefly on the screen. The completion of each trial was separated by two seconds from the commencement of the next trial.

Following completion of the practice task, it was reiterated that participants must maintain central fixation during target presentation. Participants were also advised that their eye movements would be monitored on a CCTV camera positioned above the computer screen, in order to ensure they were correctly fixating prior to target presentation. It was also emphasized that they must read each sentence carefully (i.e., not “skim read”).

Participants were then presented with one of the eight balanced stimulus sets of 640 trials. Each stimulus set was divided into two halves, each containing 10 full iterations of the 32 conditions in the design. An untimed rest break was allowed between each block of 32 trials, during which feedback relating to their RT and errors for the preceding block of trials was provided.

Results

Reaction Time

RT data were initially screened using an outlier deletion criterion of +/- 2.5 standard deviations from each individual’s mean response times for each condition. This resulted in 2.9% of the total observations being excluded. A further screening procedure was then applied to the sample as a whole, involving a winsorization process in which sample outliers for each condition were replaced with a value corresponding to 2.5 standard deviations above or below the sample mean for that condition. A total of 1.6% of means were replaced in this screening process. Data from the two sessions were collapsed prior to analysis, as each session only contained half of the total number of observations required for statistical reliability.

Table 2. Mean RT (ms) as a function of target visual field, sentence context, and sentence type. Standard deviations (ms) appear in parentheses.

	LH/RVF		RH/LVF	
	Normal Sentences	Scrambled Sentences	Normal Sentences	Scrambled Sentences
High Context	415 (61)	418 (62)	442 (64)	461 (83)
Medium Context	461 (65)	467 (64)	501 (81)	513 (73)
Low Context	512 (76)	507 (63)	552 (78)	560 (84)
Neutral / No Context	533 (78)	527 (68)	564 (75)	563 (68)

An overall 4x2x2 repeated-measures analysis of variance was initially performed on the RT data (summarized in Table 2). The assumption of sphericity was violated for the main effect of context. The Huynh-Feldt correction was used in this instance. The ANOVA revealed a significant main effect of context ($F(2.6, 78.7)=130.5$, MSe=3030.6, $p<.001$). RT was longest for targets following a neutral sentence (*M*=547ms) and decreased as context increased from low (*M*=533ms), medium (*M*=485ms), to high (*M*=434ms). The analysis of sentence type indicated that targets following normal sentences (M=497ms) were not responded to faster than those following scrambled sentences (M=502ms) (although this effect approached significance; $F(1,31)=3.95$, MSe=721.4, $p=.056$). There was a significant main effect of visual field ($F(1,31)=60.1$, MSe=3320.4, $p<.001$), where targets presented to the RVF/LH (M=480ms) were responded to faster than targets presented to the LVF/RH (M=519ms). The interaction between visual field and sentence type also approached significance ($F(1,31)=3.94$, MSe=798.7, $p=.056$), but none of the remaining interactions were significant (highest F=2.07, for the interaction between context and sentence type).

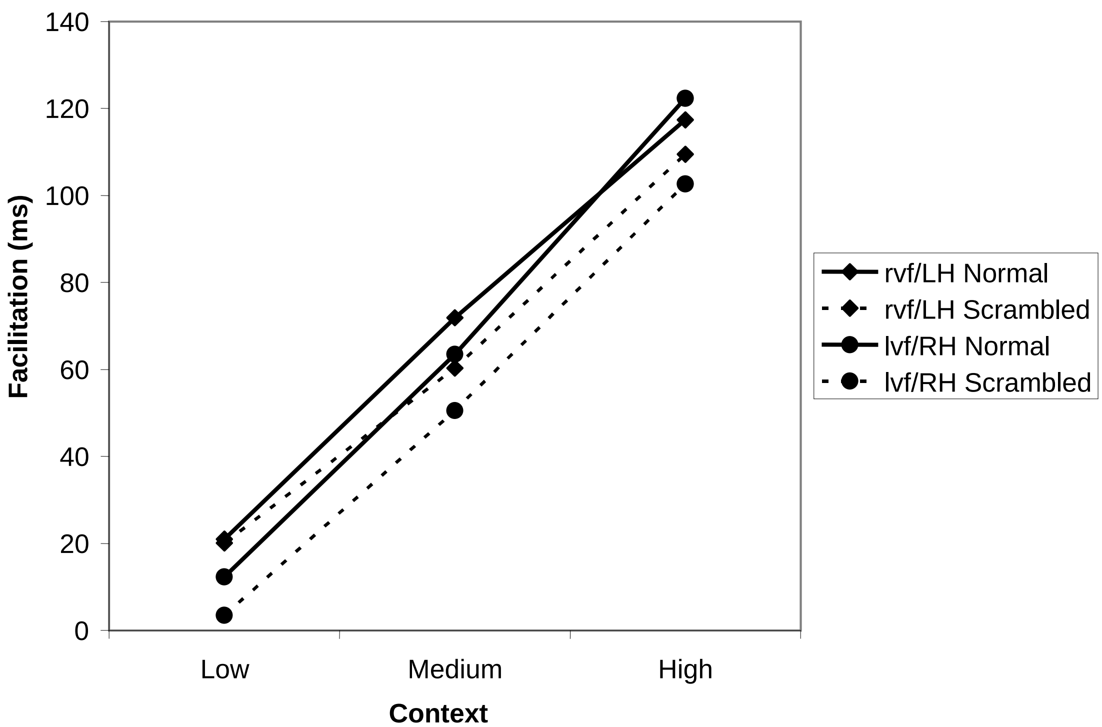

Figure 1. The relative facilitation (ms) of each visual field/hemisphere presentation as a function of context for normal compared to scrambled sentences.

A further repeated-measures ANOVA was conducted on the facilitation effects computed by subtracting RT of the low, medium, and high context conditions from the neutral condition (see Fig.1). The assumption of sphericity was violated for the main effect of context and the interaction of context and visual field, and the Huynh-Feldt correction was applied in these instances. The main effect of context was significant ($F(1.6, 48.9)=128.3$, MSe=3084.7, $p<.001$), reflecting the fact that increasing context from low (M=14ms) to medium (M=61ms) to high (M=113ms) resulted in a large and essentially linear increase in facilitation. Interestingly, the main effect of sentence type was marginally significant in this analysis ($F(1,31)=4.62$, MSe=2243.5, $p=.04$), where normal sentences (M=68ms) generated more facilitation than scrambled sentences (M=58ms). The main effect of visual field was not significant ($F(1,31)=.869$, MSe=6445.4, $p=.358$), and there were no interactions between visual field and any other variable (F=1.065, for the interaction between context and sentence type, was the highest F obtained over all interactions).

Errors

A repeated-measures analysis of variance was conducted on error rates for word-target trials. The relevant error rate data are summarized in Table 3.

Table 3. Mean error responses (%) to target words as a function of target visual field, sentence context, and sentence type. Standard deviations appear in parentheses.

	LH/RVF		RH/LVF	
	Normal Sentences	Scrambled Sentences	Normal Sentences	Scrambled Sentences
High Context	0.9 (2.0)	1.1 (2.5)	2.3 (4.0)	2.0 (2.8)
Medium Context	2.7 (3.8)	2.8 (4.0)	5.7 (6.7)	6.7 (6.8)
Low Context	5.7 (5.4)	5.2 (4.1)	10.2 (9.0)	9.4 (7.8)
Neutral / No Context	12.4 (9.3)	9.9 (8.3)	19.7 (10.6)	20.3 (13.5)

As with the RT data, sphericity was violated for the main effect of context as well as the interactions, resulting in the Huynh-Feldt Epsilon correction being applied in these instances. A significant main effect of context (F(1.95, 60.52)=72.8, MSe=98.41, p<.001) indicated error rates decreased as context increased from neutral (M=15.6%) to low (M=7.6%), to medium (M=4.5%) to high (M=1.6%). As this suggests that there was an inverse relationship between accuracy and RT (i.e., accuracy increased and reaction time decreased with more contextual support) it is therefore unlikely that a speed-accuracy trade-off occurred. As in the RT data, the main effect of sentence type (F(1,31)=.285, MSe=28.5, p=.537) was not significant. A significant main effect of visual field (F(1, 31)=64.4, MSe=39.6, p<.001) was consistent with the RT data, with a greater error rate exhibited in the LVF/RH (M=9.6%) than in the RVF/LH (M=5.1%). In contrast to the RT data, a significant interaction was observed between visual field and context ($F(1.7, 52.4)=5.18$, MSe=114.3, $p=.012$). Follow-up paired-samples t-tests, incorporating a Bonferroni adjustment to alpha=.0125, revealed higher error rates in the LVF/RH than RVF/LH for neutral sentences ($t(31)=4.329$, $p<.001$), low context sentences ($t(31)=3.198$, $p=.003$), medium context sentences ($t(31)=3.603$, $p=.001$), and (marginally) for high context sentences ($t(31)=2.124$, $p=.042$).

Discussion

The present study set out to investigate the proposed special role of the RH for maintaining activation of and/or integrating broad concepts in order to produce a coherent meaning. Three sentential contexts were presented, in addition to a neutral sentence, where each sentence individually provided minimal contextual information, but when processed as a coherent whole produced a large amount of context. It was hypothesized that the presentation of three complete sentences would produce more facilitation for targets presented to the LVF/RH than to the RVF/LH. The results did not, however, support this hypothesis; in fact, there were no significant hemispheric differences in facilitation at any of the levels of context. It was also hypothesized that both hemispheres would show greater facilitation from normal sentences than from scrambled sentences, evidencing message-level processing. Although this finding was observed in the analysis of the facilitation data, it was not reflected in the analysis of the absolute RT data. It is therefore somewhat unclear as to whether the facilitation derived from the increasing context occurred due to word-level or to message-level processing.

This finding suggests, at first glance, that structural aspects of the sentences contributed little to the generation of meaningful context. This is surprising given that if no more than word-level processes were being predominantly utilized by both hemispheres, then results reflecting Beeman's (1998) coarse coding model should have been observed. The fact that the sentences were short and simple, however, meant that it was essentially impossible to properly scramble them in such a way as to remove all structural meaning. As a result, both hemispheres may well have been able to infer much of the message-level meaning of the sentences, even though scrambled. Interestingly, this finding is consistent with observations made in an earlier study (Gouldthorp & Coney, 2009) in which we speculated that it was possible that the LH was partially re-constructing message-level information in scrambled sentences. This explanation is, of course, only relevant to stimulus sets in which the sentences are short and simple. It is noteworthy that we did not observe such effects in a previous study in which sentences were considerably longer and therefore syntactically more complex (Gouldthorp & Coney, in press).

The small difference between the facilitation produced by scrambled and normal sentences is thus problematic for any attempt to attribute the facilitation effects resulting from context to either word or to message-level processing. On the one hand, it may be that both hemispheres were sensitive to the message-level information in the sentences, but that minimal differences between the normal and scrambled sentences were observed due to insufficient syntactic disruption of the scrambled sentences. On the other hand, it may be that the sentences, being short and simple, only required word-level processing for comprehension. Given the need to differentiate between these two possibilities in order to properly assess the hypotheses set out in Experiment 1, an additional experiment was conducted. Experiment 2 aimed to replicate Experiment 1 with a minor change to the scrambled conditions wherein the words were scrambled across all of the sentences presented in a trial rather than within each sentence, thus ensuring a more complete disruption of the syntactic structure. This disruption would occur to the greatest extent in the high context condition, whereas the low context condition would remain unchanged from Experiment 1. As such, it was hypothesized that, in the high context condition, facilitation would be significantly higher for targets preceded by normal sentences than by scrambled sentences. If this effect was observed for both hemispheres (i.e., for targets presented to the LVF/RH and for targets presented to the RVF/LH), then we could be confident that facilitation produced by increases to context in normal sentences was a reflection of message-level processes rather than simply word-level processes.

Experiment 2

Method

Participants

The 32 participants were undergraduate university students who had not already participated in Experiment 1 and were comprised of 5 males and 27 females (mean age=24.0 years, *SD*=7.3 years). All participants were right-handed, as assessed by a rating of .40 or above (*M*=0.97, *SD*=0.07) on the Bryden's Simplified Hand Preference

Questionnaire (Bryden, 1982). All participants possessed English as a first language and normal or corrected-to-normal vision.

Design and Stimulus Materials

The design and stimuli used in this experiment replicated all conditions of Experiment 1 with the exception of the two- and three-sentence scrambled conditions. As noted above, the scrambled conditions were altered such that the words were scrambled across all of the sentences presented in a trial rather than within each sentence. By doing this, the words that were presented in the scrambled conditions were identical to those presented in the corresponding normal condition, but the larger pool of words within which they were scrambled resulted in a more complete disruption of the syntactic structure of each sentence. That is, rather than the normal sentence set (e.g., "*I am held in the hand. I can be broken. I am used to drink wine.*") being scrambled only within each sentence, as in Experiment 1 (e.g., "*Held in am I hand the. Be can I broken. To wine used I drink to.*"), the words were scrambled across all three sentences (e.g., *"Broken drink I the be. Wine to can hand I to. In am used held I.").*

Apparatus & Procedure

The apparatus and procedure were identical to those used in Experiment 1.

Results

Reaction Time

RT data were initially screened using an outlier deletion criterion of +/- 2.5 standard deviations from each individual's mean response times for each condition. This resulted in 2.2% of the total observations being excluded. A further screening procedure was then applied to the sample as a whole, involving a winsorization process in which sample outliers for each condition were replaced with a value corresponding to 2.5 standard deviations above or below the sample mean for that condition. A total of 0.01% of means were replaced in this screening process. Data from the two sessions were collapsed prior to analysis, as each session only contained half of the total number of observations required for statistical reliability.

Table 4. Mean RT (ms) as a function of target visual field, sentence context, and sentence type. Standard deviations (ms) appear in parentheses.

	LH/RVF		RH/LVF	
	Normal Sentences	Scrambled Sentences	Normal Sentences	Scrambled Sentences
High Context	425 (70)	466 (75)	447 (77)	485 (73)
Medium Context	472 (76)	482 (68)	498 (77)	518 (89)
Low Context	516 (79)	514 (74)	552 (87)	566 (94)
Neutral / No Context	539 (85)	537 (80)	563 (84)	567 (72)

An overall 4x2x2 repeated-measures analysis of variance was initially performed on the RT data (summarized in Table 2). A significant main effect of context was revealed ($F(3, 93)=82.96$, MSe=2926.9, $p<.001$), with the highest RT occurring for targets following a neutral sentence (M=552ms) and decreasing as context increased from low (M=537ms), to medium (M=492ms), to high (M=456ms). The main effect of sentence type was significant ($F(1,31)=39.8$, MSe=739.7, $p<.001$), indicating that targets following normal sentences (M=502ms) were responded to faster than those following scrambled sentences (M=517ms). Additionally, a significant main effect of visual field was observed ($F(1,31)=39.6$, MSe=3009.6, $p<.001$), where targets presented to the RVF/LH (M=494ms) were responded to faster than targets presented to the LVF/RH (M=524ms). The interaction between context and sentence type was also significant ($F(3,93)=12.653$, MSe=755.1, $p<.001$) but none of the remaining interactions were significant (highest F=1.628, for the interaction between context and visual field). Follow-up t-tests on the interaction between context and sentence type revealed that targets following normal sentences were responded to significantly faster than scrambled sentences in the high ($t(31)=8.076$, $p<.001$) and medium ($t(31)=2.846$, $p=.008$) context conditions, but did not differ significantly in the low or neutral conditions.

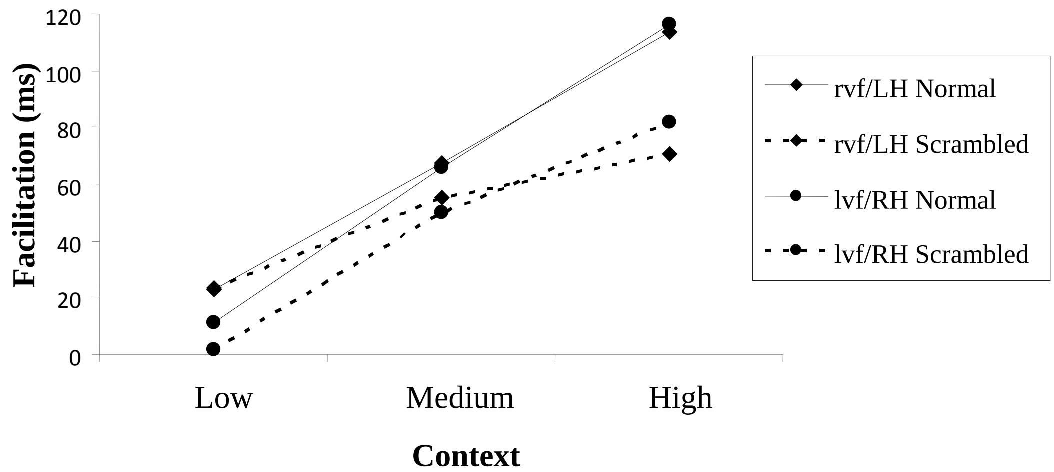

Figure 2. The relative facilitation (ms) of each visual field/hemisphere presentation as a function of context for normal compared to scrambled sentences.

A further repeated-measures ANOVA was conducted on the facilitation effects computed by subtracting RT of the low, medium, and high context conditions from the neutral condition (see Fig.2). The assumption of sphericity was violated for the main effect of context, and the Huynh-Feldt correction was applied in this instance. The main effect of context was significant ($F(1.8, 54.8)=81.3$, MSe=2930.1, $p<.001$), reflecting an essential linear increase in facilitation from low context (M=15ms) to medium (M=59ms) to high context (M=96ms). The main effect of sentence type was also significant in this analysis ($F(1,31)=11.453$, MSe=3096.1, $p=.002$), where normal sentences (M=66ms) generated more facilitation than scrambled sentences (M=47ms). The main effect of visual field was not significant ($F(1,31)=.252$, MSe=7646.5, $p=.619$). The interaction between sentence type and context was also significant ($F(2, 62)=13.275$, MSe=745.6, $p<.001$). The remaining interactions were not significant (highest F=.908 for the interaction between sentence type and visual field). Post-hoc paired-samples t-tests examining the interaction between sentence type and context indicated that responses to target words preceded by normal sentences were only significantly faster than those preceded by scrambled sentences in the high context condition (t(31)=5.820, p<.001), although this difference approached significance in the medium context condition (t(31)=1.997, p=.055).

Additionally, a split-plot analysis of variance was conducted on the facilitation data obtained in both Experiment 1 and Experiment 2. The only significant interaction of experiment type observed was with context and sentence type (F(2, 124)=4.33, MSe=726.5, p=.015). Follow-up between-samples t-tests were conducted to further examine this interaction. It was determined that facilitation differed between Experiment 1 and 2 only in the high-context, scrambled sentences condition (t(62)=2.941, p=.005). This confirms that all other main effects and interactions of facilitation observed in Experiment 1 were replicated in Experiment 2.

Errors

A repeated-measures analysis of variance was conducted on error rates for word-target trials. The relevant error rate data are summarized in Table 5.

Table 5. Mean error responses (%) to target words as a function of target visual field, sentence context, and sentence type. Standard deviations appear in parentheses.

	LH/RVF		RH/LVF	
	Normal Sentences	Scrambled Sentences	Normal Sentences	Scrambled Sentences
High Context	1.5 (2.7)	1.7 (3.9)	2.2 (3.3)	4.7 (4.9)
Medium Context	1.6 (2.4)	2.7 (3.1)	5.9 (7.6)	5.8 (7.9)
Low Context	5.6 (4.9)	4.9 (5.5)	9.7 (12.1)	10.6 (10.9)
Neutral / No Context	9.7 (7.5)	8.8 (8.4)	15.5 (12.8)	13.7 (13.7)

Sphericity was violated for the main effect of context as well as the interactions, resulting in the Huynh-Feldt Epsilon correction being applied in these instances. A significant main effect of context ($F(2.32, 72.0)=30.8$, MSe=94.70, $p<.001$) indicated that the most errors occurred when the contextual sentence was neutral (M=11.9%), with progressively fewer errors for low context (M=7.7%), medium context (M=4.0%), and high context (M=2.5%). As this suggests that there was an inverse relationship between accuracy and RT (i.e., accuracy increased and reaction time decreased with more contextual support) it is unlikely that a speed-accuracy trade-off occurred. In contrast to the RT data, the main effect of sentence type ($F(1,31)=.133$, MSe=17.96, $p=.718$) was not significant. A significant main effect of visual field ($F(1, 31)=13.5$, MSe=150.5, $p=.001$) was consistent with the RT data, with a greater error rate exhibited in the LVF/RH (M=8.5%) than in the RVF/LH (M=4.5%). There were no significant interactions (highest F=1.612 for the interaction between context and sentence type).

Discussion

The results of this experiment replicated the finding of interest in Experiment 1; that is, that in contrast to the coarse coding hypothesis, presentation of three complete sentences did not produce significant hemispheric differences in facilitation at any of the levels of context. Furthermore, this experiment demonstrated that the facilitation obtained by both hemispheres, at least in the high context condition, was not derived purely from word-level processing. This confirms that the relatively small difference in facilitation between normal and scrambled conditions in Experiment 1 was most likely due to both hemispheres extracting some message-level information from the scrambled sentences. In Experiment 2, the change in the method of scrambling meant that the syntactic structure was disrupted more completely. In fact, a close inspection of the two experiments shows that mean facilitation obtained in the normal conditions remained relatively constant across the two experiments; the only change occurred in the scrambled condition. As such, we can be confident that the results reflect message-level, rather than merely word-level, processing.

General Discussion

The finding that the LH gained as much facilitation from increases to context as the RH is initially surprising. It was assumed that if the RH uses coarse processing (Beeman, 1998), it would more effectively activate distantly-related associations evoked by each of the sentences, and thereby produce a stronger priming effect by the summation of these individually weak associations. Much of the literature, however, suggests that the LH is limited in its ability to activate distantly-related information (Beeman et al., 1994: Beeman, 1998) (although some evidence has more recently suggested that this limitation is due to a difficulty in the LH maintaining activation; Coney & Evans, 2000; Tompkins et al., 2008). Most of the evidence for the coarse-coding hypothesis comes from studies in which the semantic overlap of individual words has been used to explain RH processing; few studies have directly investigated its applicability to concepts at the sentence level. If the coarse-coding model can be validly applied at the sentence level, then the LH should not have been facilitated by increasing context to the same extent as the RH. The results of the present study, however, suggest that the hemispheres were equivalent in their capacity to derive distantly-related associations from individual sentences, and to combine those separate associations to produce a strong priming effect. Furthermore, this equivalence in facilitation was shown to occur as a result of message-level, as well as word-level, mechanisms for both hemispheres.

The finding that both hemispheres appeared to combine the distantly-related message-level information across the three sentences can thus be interpreted in either of two ways. Firstly, the results could be explained by *both* hemispheres (rather than just the RH) activating distantly-related information in each of the three sentences, with facilitation then resulting from the overlap of these concepts. Given the considerable quantity of evidence suggesting that the LH does not maintain activation of distantly-related concepts (as reviewed earlier), this explanation finds little support in the literature. An alternative, and perhaps more likely, explanation is that each hemisphere, although facilitated to roughly the same degree, used the sentential information in different ways. That is, although the outcome, as reflected in facilitation effects, was similar, different processes may have been used in order to achieve that outcome.

Federmeier (2007) outlined an alternative model of hemispheric processing that may account for the present results. She proposes that the RH uses *integrative* processing, whereas the LH uses *predictive* processing. Predictive processing involves using contextual information to preactivate, or predict, likely upcoming stimuli. Facilitation occurs if the target word overlaps with any features of the predicted word. This sort of processing is advantageous in terms of affording a quick and efficient processing ability in instances when the incoming stimulus is consistent with the expected stimulus. It is, however, presumably limited by an implied inability to revise an interpretation or "backtrack" if the incoming stimulus was not as expected. Indeed, this is where integrative processing might account for the RH's special role in instances where a reinterpretation of an initial meaning is required. Federmeier argues that the integrative processing of the RH is derived in a bottom-up manner directly from the ongoing context. Facilitation is then a function of the fit between the features of an incoming target and the broad context of the sentence itself (as opposed to a comparison with a word that was not actually presented but was predicted by the context).

This framework could explain how, in the present study, both hemispheres appeared to make similar use of the contextual information in the sentences. In the present study, when three sentences were presented (e.g., "*I taste sweet. I can be put on toast. I am made by an insect.*") the RH could integrate the target (*HONEY*) with the contextual framework created by the sentences. The fit between target and framework would be greatest in the high-context condition (i.e., when all three sentences were presented) and facilitation would therefore be maximal in this condition. As context decreases (i.e., fewer sentences and therefore less context) the fit would be reduced, resulting in less facilitation. The LH, on the other hand, might utilize contextual information in each sentence to predict the upcoming word, with the strength of the prediction, and therefore overlap with the target, becoming greater as more sentences were presented (thus facilitation increasing as a function of context). Notably, the association task used during pre-experimental stimulus construction aimed to confirm that the combination of the three sentences resulted in a high probability of the target being produced. That is, targets were highly predictable when preceded by three sentences, thus resulting in the facilitation of RVF/LH targets in this condition.

In summary, the present study provides evidence in support of previous research (e.g., Federmeier & Kutas, 1999) that has suggested that the coarse-coding model (Beeman, 1998) is not sufficient to explain hemispheric differences in sentential processing. In contrast, the finding that both hemispheres gained facilitation from the build up of distantly related concepts in the present study could be explained by Federmeier's (2007) integrative vs. predictive processing model, although this is tentative and requires further investigation. This study provides an important step forward, not only in uncovering the underlying processing mechanisms of each hemisphere, but also in reconciling some of the disparity between the observations made in behavioral studies of normal individuals and those made in neuropsychological, electrophysiological and neuroimaging studies.

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5. EXPERIMENT 4

The results of Experiment 3a, although demonstrating that both hemispheres were able to integrate the contextual information across three sentences in order to facilitate the target, did not provide a clear indication as to whether the facilitation was occurring predominantly from word-level or from message-level processes. That is, a significant difference in facilitation between the normal and the scrambled sentences was not observed. Rather than indicating that the message-level information in the sentences was not needed or able to increase facilitation of responses to the targets, it was argued that due to the simplicity of the sentences (e.g., they were very short) the message-level information was not entirely disrupted through the scrambling process. Experiment 3b was thus conducted in order to resolve this difficulty. Following a modification to the scrambled sentences (which ensured a more complete disruption of the syntactic information), significantly greater facilitation for targets preceded by normal sentences than by scrambled sentences was observed. Additionally, the main finding from Experiment 3a was replicated. Thus, the combined findings of Experiment 3a and 3b provided a clear demonstration that the coarse/fine coding distinction between hemispheric language processing cannot be applied to the message-level.

Although it was proposed that Federmeier's (2007) integrative/predictive model of hemispheric processing might provide a more satisfactory explanation, this model was not specifically tested in Experiment 3a or 3b. The fourth and final experiment in the present program of research therefore aimed to directly compare integrative versus predictive processing mechanisms in order to assess the applicability of Federmeier's

(2007) model as a means of explaining hemispheric differences in language processing at the message-level.

Participants were centrally presented with three sentences, of which coherence between the first and second sentence required the production of an inference. The third sentence, a fragment, was consistent with the scenario set out in the first two sentences, but did not directly contribute to the inference generation. Laterally presented target words either reflected the meaning derived from the integration of the first two sentences ("integrated" targets), or were the sentence-final completion of the third sentence and therefore could be predicted without integration of previous context ("predicted" targets). It was argued that should greater facilitation for the integrated targets be observed for the RH than for the LH, and greater facilitation for the predicted targets be observed for the LH than for the RH, then strong support for Federmeier's (2007) would be obtained.

The manuscript describing Experiment 4 has been submitted for publication and has undergone a peer review process. Although the reviewers agreed that, in general, the study provided a worthwhile contribution to the literature, the unforeseeable methodological problem relating to the integrated targets meant that the results were not considered to be suitable for publication. Directions for future research that may circumvent this difficulty are therefore proposed in Subsection 6.2.1, and suitable revisions were made to the manuscript on the basis of the reviewers' additional comments. The manuscript is presented in the following subsection in this revised form.

5.1 Right hemisphere use of contextual information in predicting targets.

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Running head: Context use and the right hemisphere

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Abstract

A number of models accounting for hemispheric differences in language comprehension have recently been proposed, with various levels of success in accounting for the diverse range of evidence in relation to RH comprehension abilities. The present study investigated the proposition that the RH processes in a bottom-up, integrative fashion that enables the maintenance of contextual information, whereas the LH processes in a top-down, predictive fashion and only keeps active the most recent concept (Federmeier, 2007; Federmeier & Kutas, 1999). Thirty-two right-handed undergraduate psychology students participated in a computer-based lexical decision task where reaction time and error rates were recorded. Three sentences were presented, where an inference was required in order to produce coherence between the first and second sentences. The third sentence was not directly related to the inference generation, but was consistent with the scenario set out in the prior contextual information. Targets were either "integrated", where the target reflected the meaning of the inference that needed to be generated in order for coherence to have been created, or "predicted", where the target was the sentence-final completion of the third sentence and therefore could be predicted without integration of previous context. Although it was hypothesized that facilitation for integrated targets would be significantly greater when presented to the LVF/RH than to the RVF/LH, the results indicated that both hemispheres produced significant inhibition for the integrated targets. Furthermore, contrary to expectations derived from Federmeier's (2007) model, predicted targets were facilitated to a significantly greater extent when presented to the LVF/RH than to the RVF/LH. The results suggest that the RH-integrative and LH-predictive distinction may not be entirely sufficient. It is

proposed that a situation-model processing method would support integrative processing whereas a purely linguistic mechanism would allow prediction to occur predominantly from the text-base.

KEYWORDS: sentence comprehension; hemisphere; visual field; context; prediction; integration.

Introduction

Rather than the view of right hemisphere (RH) processing as being purely at the word-level and left hemisphere (LH) processing being an integration of word and message-level processing, the mounting evidence from neuropsychological, electrophysiological, and neuroimaging research is that both hemispheres do in fact utilize message-level processing. It appears that the majority of behavioral measures in samples of normal individuals ("normal-behavioral"), until recently, have not reflected this view. A small number of recent normal-behavioral studies, however, have produced results that are consistent with the conclusions derived from the neuropsychological, electrophysiological and neuroimaging approaches in relation to RH use of message-level processing (e.g., Gouldthorp & Coney, 2009a, 2009b). In fact, a review of ERP studies by Federmeier (2007) strongly argues that the question that should be asked is not whether each hemisphere uses message and/or word-level processing, but rather *how* they each use these mechanisms.

Federmeier (2007) proposed an interesting framework in order to explain the hemispheric processing differences. This model suggests that the LH utilizes an essentially top-down processing strategy in order to *predict* upcoming words, whereas the RH utilizes bottom-up processing in order to *integrate* the new stimuli. For example, Federmeier and Kutas (1999) conducted an ERP study in which pairs of sentences providing contextual information were presented, followed by sentence-final targets that were unexpected given the sentence context. Targets were either "within-category violations", meaning that they were from the same semantic category as the expected target (e.g., palms and pines), or “between-category violations”, meaning that they were from a different semantic category to the expected target (e.g., palms and tulips). They found that the RH appeared sensitive to both violations, whereas the LH only appeared sensitive to the between-category violations; that is, the LH demonstrated priming for the within-category violation targets. This suggests that while the RH was influenced by congruency of the target with the contextual information, the LH was influenced not only by the contextual congruency but also by the semantic relatedness of the target to the expected sentence completion. As a result, Federmeier (2007; Federmeier & Kutas, 1999) argued that predictive processing involves incoming stimuli being integrated with current information to produce a message-level meaning that is then used to activate semantic features of the item most consistent with the context. The extracted meaning is therefore utilized to generate specific predictions without the contextual information itself being maintained. In integrative processing, however, the previous context must not only be kept active but must be flexible to account for changes of interpretation based on the new incoming information. In neurologically intact individuals, these two approaches work in conjunction to allow fast and efficient processing through prediction, which is nonetheless flexible for re-analysis should it be necessary for integration.

A large amount of evidence in the literature (see Tompkins, Fassbinder, Scharp & Meigh, 2008, for a review) supports the suggestion that the processing mechanisms used by the RH maintain activation of the contextual information, particularly peripheral features or subordinate meanings, whereas the LH does not. For example, Faust, Barak, and Chiarello (2006) investigated whether the two hemispheres maintain activation of script meaning (i.e., context) across neutral and unrelated information. Their findings suggested that although the RH kept several words simultaneously activated, LH activation of word meanings related to earlier scripts quickly declined once additional sentences were added. Similarly, Tompkins, Scharp, Meigh and Fassbinder (2008) found that sustained activation of peripheral semantic features of nouns was less in individuals with RHD that were poor comprehenders than those that were good comprehenders. These findings provide some support for the notion that differences in hemispheric processing mechanisms might be reflected in their respective abilities to maintain activation of contextual information and are thus consistent with Federmeier's (2007) framework; the ongoing activation of contextual information would be necessary for the RH's integrative processing mechanisms, whereas initial information would be deactivated in the LH as soon as sufficient meaning could be extracted from which to predict an upcoming word.

Furthermore, the ability to maintain activation of contextual information is argued to be essential for the various processes needed in order to produce coherence across extended discourse, such as reinterpreting information, integrating various world knowledge domains, and making inferences (Faust et al., 2006; Perfetti, 1999). For example, Mason and Just (2004) argued that inferential processing is necessary for comprehending extended discourse and, furthermore, that this is a task in which the RH appears to play an essential role. Additionally, Brownell, Potter, Bihrle and Gardner (1986) found evidence that the RH is important for reinterpreting, and thus correctly comprehending, contextual information. They presented two-sentence vignettes to groups of either RHD patients or normal controls, followed by test sentences which reflected either correct or incorrect inferences that could be derived from the vignettes. For example, “Barbara became too bored to finish the history book. She had already spent five years writing it.” (Brownell et al., p.313). In this example, a correct inference would indicate that Barbara became bored writing the history book, whereas an incorrect inference would indicate that, as misleadingly suggested by the first sentence, reading the history book bored Barbara. Brownell et al. found that, compared to the normal control group, patients with RHD demonstrated an impairment in reinterpreting their initial processing of the contextual information in the first sentence in order to integrate the new information in the second sentence. That is, the RHD patients appeared to have difficulty in cohering the contextual information across the sentences in order to make an appropriate inference. Similarly, St. George, Kutas, Martinez, and Sereno (1999) provided strong evidence of a special involvement of the RH in developing and maintaining “global coherence” during extended discourse. They presented participants with untitled paragraphs of semantically vague propositions, wherein coherence could only be derived through the integration of meaning across the sentences. Using fMRI, they found a considerable RH involvement in the comprehension of the untitled paragraphs, whereas no hemispheric differences were observed when paragraphs were preceded by a title (i.e., when a cohering topic was provided).

Some researchers have argued that the RH’s special role in cohering discourse comes from its activation and maintenance of distantly related words. For example, Beeman, Bowden, and Gernsbacher (2000) argued that the RH generates the information necessary to produce inferences through the semantic overlap of distantly related features of words within the sentences. This is explained in terms of the coarse-coding hypothesis, wherein the RH is presumed to weakly activate large semantic fields from which the converging activation of distantly related concepts results in priming. Conversely, the LH is argued to utilize relatively fine-tuned coding, highly activating only a small field of closely related concepts. Evidence for this model comes from studies investigating summation priming (Beeman et al., 1994), where three prime words provided stronger facilitation for weakly related targets presented to the LVF/RH than to the RVF/LH. Furthermore, LVF/RH targets were facilitated as much by these summation primes as by single word primes strongly related to the target. Single word primes, however, produced much stronger facilitation for highly related targets in the RVF/LH than did the summation primes. Although the coarse-coding model has been invoked as an explanation for the special role that the RH plays in a number of linguistic tasks (see Beeman, 1998, for review), and there is certainly strong evidence in favor of this model's applicability at the word-level (but see Joss & Virtue, 2008), support for the extension of this model to message-level processing is limited. For example, in a recent study we investigated the assumption that the proposed special role of the RH for producing coherence in extended discourse is derived from a coarser, more global, processing mechanism (Gouldthorp & Coney, 2009c). Three sentential contexts were presented, where each sentence individually provided minimal contextual information, but when processed as a coherent whole produced a large amount of context. This was designed to parallel the "summation priming" effects observed at the word level, by applying them to a task requiring message-level processing. In contrast to predictions derived from the coarse-coding model, the results did not demonstrate significant hemispheric differences in facilitation at any of the levels of context. As such, these results suggest that the coarse coding hypothesis (Beeman, 1998) is insufficient in explaining RH processing beyond the word-level.

Given the apparent limitations of the coarse-coding model (Beeman, 1998) when applied to sentences as opposed to single words (Gouldthorp & Coney 2009c), Federmeier's (2007) model provides an alternative way of accounting for many of the observed findings relating to a special role of the RH. Indeed, the aforementioned summation priming findings of Beeman et al. (1994) appear to be largely accounted for by Federmeier's model. Federmeier and Kutas (1999) argued that summation primes involving individual words would not produce a sufficient basis from which consistent predictions could occur, particularly when compared with a single strong associate, whereas integrative processing would support facilitation in both conditions. Nonetheless, the ability to maintain activation of contextual information, whether at the word-level (Beeman) or at the message-level (Federmeier), is an important component of both models. The assumption of a RH superiority in contextual maintenance in Federmeier's model is necessary in order to account for many of the findings relating to RH sentence-level comprehension that have previously been explained by the coarse-coding model (e.g., inference generation (Beeman et al., 2000; Mason & Just, 2000), discourse coherence (St. George et al., 1999), revising interpretations (Brownell et al., 1986; Tompkins, Bloise, Timko, & Baumgaertner, 1994; Tompkins, Lehman-Blake, Baumgaertner, & Fassbinder, 2001), and metaphor comprehension (Pobric, Mashal, Faust & Lavidor, 2008; but see Coulson & van Petten, 2007)). Similarly, a predictive mechanism allows the LH to process linguistic material quickly and efficiently, in a manner that one could conceptualize as "fine-tuned". That is, Federmeier proposes that the LH utilizes the meaning extracted from the contextual information to predict upcoming information, which, in turn, distorts the bottom-up signal of incoming stimuli resulting in the original information not being maintained. Conversely, because the RH maintains the original information, it benefits in tasks that require revision and integration of earlier material, but in doing so the processing is slower, less efficient and, inevitably, “coarser”.

The present study therefore investigated the notions proposed in Federmeier’s (2007) model that the RH is able to keep several concepts active (and thus integrate relevant components) and processes in a bottom-up, integrative fashion, whereas the LH is only able to keep active the most recent concept and processes in a top-down, predictive fashion. Three sentences were presented, where an inference was required in order to produce coherence between the first and second sentences. The third sentence was not directly related to the inference generation, but was consistent with the scenario set out in the prior contextual information. Furthermore, the third sentence was a fragment; that is, the sentence final word was removed. Targets were either “integrated”, where the target reflected the meaning of the inference that needed to be generated in order for coherence to have been created; or “predicted”, where the target was the sentence-final completion of the third sentence and therefore could be predicted without integration of previous context. The predictions made in this study were derived from several propositions evidenced in the literature. Firstly, the RH is better than the LH at generating inferences to produce coherence across sentences (Beeman, 1993; St. George et al., 1999). Secondly, the RH is able to maintain contextual information even if it has not been explicitly presented (as in the case of inferences) better than the LH (Lehman-

Blake & Tompkins, 2001). Thirdly, the RH is able to integrate inferred targets into the contextual information whereas the LH is more adept at predicting upcoming targets in a feed-forward manner (Federmeier & Kutas, 1999). Based on these findings, it was hypothesized that facilitation for integrated targets should be significantly greater when presented to the LVF/RH than to the RVF/LH and, secondly, that facilitation of predicted targets should be significantly greater when presented to the RVF/LH than to the LVF/RH.

Method

Participants

Thirty-two undergraduate university students participated in this study, with the majority of participants receiving course credits. Twenty-six of the participants were female and 6 were male, with a mean age of 24.6 years, (*SD*=7.1 years). All of the participants possessed English as a first language, had normal hearing, and normal or corrected-to-normal vision. Participants were all right-handed, as assessed by a rating of .40 or above (*M*=0.96, *SD*=0.07) on the Bryden's Simplified Hand Preference Questionnaire (Bryden, 1982), on which the scale ranges from +1.00 (extreme right-handedness) to -1.00 (extreme left-handedness).

Design & Stimulus Materials

Three variables were manipulated as repeated measures in the design: (i) visual field of target presentation, (ii) sentence type (contextual or neutral), and (iii) target type (predicted or integrated). The target set was divided equally between words and non-words in order to support a lexical decision task. Thus, each trial in the experiment consisted of the sequential presentation of 3 sentences, followed by the lateral exposure of a letter-string representing a word or nonword target. A total of 320 such trials (with 20 observations per condition) were presented to each participant in the course of the experiment. The dependent variables were RT and error rate, with RT being the primary experimental measure.

Stimulus Construction

Stimuli consisted of groups of three sentences. The first two sentences were constructed so as to provide contextual information that would allow the target word to be integrated. The contextual information provided in the third sentence, although not inconsistent, was designed to be essentially irrelevant to comprehending the preceding sentences. The third sentence was a fragment, with the sentence-final word providing an alternative, “predicted” target. That is, each sentence group was paired with both an “integrated” target and a “predicted” target. Target words were all short (3-5 letters, *M*=4.4, *SD*=0.7) nouns and restricted to those of high imagability (*M*=582) and concreteness (*M*=581) as derived from the MRC Database (1987) collated ratings (Coltheart, 1981).

Initially, 160 sentence groups were generated, and these were then subjected to two variations of the cloze procedure to remove unsuitable stimuli. Firstly, lists of the sentence groups were given to a panel of 10 participants (recruited from the same population as the experimental sample) who were required to write down the first one or two words that they felt best completed the sentences. By determining the probability of the predicted target word being produced as an answer, the predictability of a target was quantified. If the probability produced for a predicted target was less than 0.6 then that sentence group was eliminated. Secondly, lists of the sentence groups were given to a different panel of 10 participants (again recruited from the same population as the experimental sample), along with the corresponding integrated target. Participants were asked to read each group of three sentences and decide how well they thought the target word fitted into the general "idea" of the sentences; participants were instructed that it did not matter whether the target completed the last sentence or not. Participants gave the corresponding target word a rating between 1 and 5, where 1 meant it did not fit into the sentence context and 5 meant it fit very well. If the mean rating produced for the integrated target was less than 3 then that sentence group was eliminated. Targets and their corresponding sentences were also eliminated if a noun in any of the three sentences was determined by the University of South Florida association norms database (Nelson, McEvoy & Schreiber, 2004) to be a primary associate of either of the targets. The final stimulus set comprised 80 "predicted" target words with a mean cloze probability of 0.8 (*SD*=0.2) and 80 "integrated" targets words with a mean "integration rating" of 3.9 (*SD*=0.7). In addition, a neutral condition was included that always took the form of "This is a neutral sentence. This is a neutral sentence. The next word is".

The stimulus set for each target word therefore consisted of either a contextual sentence group or a neutral sentence group, and each sentence group was followed by either the predicted or integrated target. Table 1 shows three example stimulus groups.

Table 1. Example sentence groups and corresponding targets.

Sentence group	Integrated Target	Predicted Target
Sarah was pleased when her visitors arrived with pink balloons. Later, as she lay on her hospital bed, she tried to think of a name. The nurse came in mid-morning and asked what she would like to eat for	BABY	LUNCH
Karen was not feeling well and lay down in bed with a bucket. Later, after cleaning up the mess, she went to brush her teeth. She untangled her hair using a small plastic	VOMIT	COMB
Chris had been driving for hours when the light started to flash. Later, he cursed himself when his car slowed to a halt. He was already tired and wanted to get home to	FUEL	BED

An additional 160 sentence groups were created in order to be paired with two non-word targets. Eighty of these sentence groups took the neutral form and the remaining 80 sentence groups were designed to mimic the style of the contextual sentence groups. Non-word targets were generated by taking the 160 real-word targets and non-systematically changing a single letter so that the resulting letter string was a pronounceable, orthographically-legal pseudo-word. Any resulting pseudo-homophones were identified and replaced with alternate non-words.

With the addition of these sentences, the final stimulus ensemble comprised 320 items counterbalanced over four different stimulus sets so that each participant would only be presented once with each contextual sentence group (i.e., each participant was only presented with *either* the predicted or the integrated target for each sentence group). The remaining target was then presented following a neutral sentence group (e.g., if the predicted target was presented following the contextual sentence group, then the corresponding integrated target was presented following the neutral sentence group, or vice versa). Thus, each participant received equal numbers of predicted and integrated targets, preceded by equal numbers of contextual and neutral sentences, to each visual field (i.e., 20 trials per condition). The stimulus sets were also balanced to ensure that equal numbers of target words and non-words for each condition were presented to each visual field. Finally, an additional 12 sentence groups (of a similar style to the test stimuli) were produced for use in the practice task.

Apparatus

All programs associated with running both sessions were run on an Intel Pentium 4 processor with a Windows 98 SE operating system and 256 MB Ram. The experimental control program was a custom-written FORTRAN application compiled by a Salford Software compiler and real-time library system. The monitor on which stimuli were displayed was a Samsung SyncMaster 931c with a screen resolution of 1280 x 1024 pixels, 32-bit color and a refresh rate of 75 hertz. A 2-button micro-switch response box was used to record the participants' responses. Participants rested their head on a chin-rest that was positioned 60cm from the monitor and could be individually adjusted for height. Ear defenders were used to ensure exclusion of any possible extraneous noise. Finally, a CCTV system was used to permit the experimenter to monitor participants' eye movements in an adjoining room. A zoom lens was used to project an enlarged image of one of the participant's eyes on a CCTV monitor, and the position of the pupil during central fixation was marked on the screen. This permitted even minor deviations from central fixation to be readily detected during the experiment.

Procedure

Prior to the session commencing, the order of presentation of trials for the allocated stimulus set was randomized on-line within each discrete set of 16 experimental conditions. Participants attended one, two-hour session and were tested individually. Testing was conducted in a laboratory illuminated by both fluorescent and natural lighting. Prior to commencing the session, participants completed the Bryden's Simplified Hand Preference Questionnaire (Bryden, 1982). Participants were then read instructions and any questions answered.

Participants first participated in a supervised practice task. This task involved 12 trials and was included to ensure the participant understood the task prior to the commencement of data collection. Each sentence was presented centrally on the computer screen in black letters with a grey background and in Courier font approximately 1cm high (0.95 degrees of visual angle). The exposure duration of each sentence was computed on the basis of allowing 60ms per letter, which provided sufficient time for participants to read at a natural pace while still comprehending each word in the sentence. Each sentence was presented individually on the screen. The display screen was cleared after each sentence and remained blank for a period of 1000ms. Following presentation of the final sentence, a central fixation cross appeared on which participants were instructed to focus their gaze. Nine hundred milliseconds after the presentation of the fixation cross, the target was flashed to either the left or right side of the screen, with the innermost boundary located at 2.1 degrees of visual angle from the central fixation point. Targets were presented in black uppercase letters, using the Verdana font, for 150ms. Participants then decided whether the target was a word or a non-word, and were instructed to depress both micro-switches simultaneously with the index finger of each hand if the target was a word. Participants were instructed to withhold any response if the target was a non-word. If participants actively responded to a non-word or failed to respond within 1500ms to a word, an error message (consisting of the word "ERROR") appeared briefly on the screen. The completion of each trial was separated by two seconds from the commencement of the next trial.

Following completion of the practice task, it was reiterated that participants must maintain central fixation during target presentation. Participants were also advised that their eye movements would be monitored on a CCTV camera positioned above the computer screen, in order to ensure they were correctly fixating prior to target presentation. It was also emphasized that they must read each sentence carefully (i.e., not "skim read").

Participants were then presented with one of the four balanced stimulus sets of 320 sentence groups (i.e., 20 sets of each of the 16 conditions per session), divided into 10 blocks. Participants were allowed an untimed rest break between each block, during which feedback relating to their RT and errors for the preceding block of trials was provided. During the middle rest break (i.e., after half of the trials had been completed), participants were encouraged to take a longer break (approximately 10 minutes) to ensure that they were fully refreshed prior to completing the remaining trials.

Results

Reaction Time

RT data were initially screened using an outlier deletion criterion of +/- 2.5 standard deviations from each individual's mean response times for each condition. This resulted in 0.35% of the total observations being excluded. A further screening procedure was then applied to the sample as a whole, involving a winsorization process (Barnett & Lewis, 1994), in which sample outliers for each condition were replaced with a value corresponding to 2.0 standard deviations above or below the sample mean for that condition. A total of 2.1% of means were replaced in this screening process.

Table 2. Mean RT (ms) as a function of target visual field, sentence type, and target type. Standard deviations (ms) appear in parentheses.

	LH/RVF		RH/LVF	
	Predicted Targets	Integrated Targets	Predicted Targets	Integrated Targets
Contextual Sentence Group	469 (60)	532 (56)	481 (58)	573 (74)
Neutral Sentence Group	502 (53)	512 (54)	537 (61)	561 (65)

An overall 2x2x2 repeated-measures analysis of variance was initially performed on the RT data (summarized in Table 2). The ANOVA revealed a significant main effect of visual field ($F(1,31)=78.91$, MSe=941.47, $p<.001$), where targets presented to the RVF/LH were responded to 34 ms faster on average than those presented to the LVF/RH. There was also a significant main effect of sentence type ($F(1,31)=11.83$, MSe=1121.9, $p=.002$), where targets were preceded by a contextual sentence group (M=514 ms) were responded to faster than targets preceded by a neutral sentence group (M=528 ms). The main effect of target type was also significant ($F(1,31)=169.2$, MSe=836.16, $p<.001$), where predicted targets (M=497 ms) were responded to faster than integrated targets (M=544 ms). The interaction between sentence type and target type was significant (F(1,31)=71.59, MSe=802.01, $p<.001$). This was further investigated with post-hoc paired-samples t-tests (incorporating a Bonferroni adjustment to alpha=.008) which demonstrated significantly faster responses to predicted than integrated targets for both contextual (t(31)=13.494, $p<.001$) and neutral sentences (t(31)=3.950, *p*=.001), and also significantly faster responses to contextual than neutral sentences for predicted (t(31)=8.564, *p*<.001) but not for integrated targets. There was also a significant interaction between target type and visual field (*F*(1,31)=12.01, MSe=605.3, *p*=.002), but none of the remaining interactions were significant (highest *F*=2.91, for the interaction between sentence type and visual field). Additional paired-samples t-tests indicated that responses were significantly faster to targets presented to the RVF/LH than to the LVF/RH, regardless of whether they were predicted (t(31)=4.642, *p*<.001) or integrated (t(31)=9.434, *p*<.001).

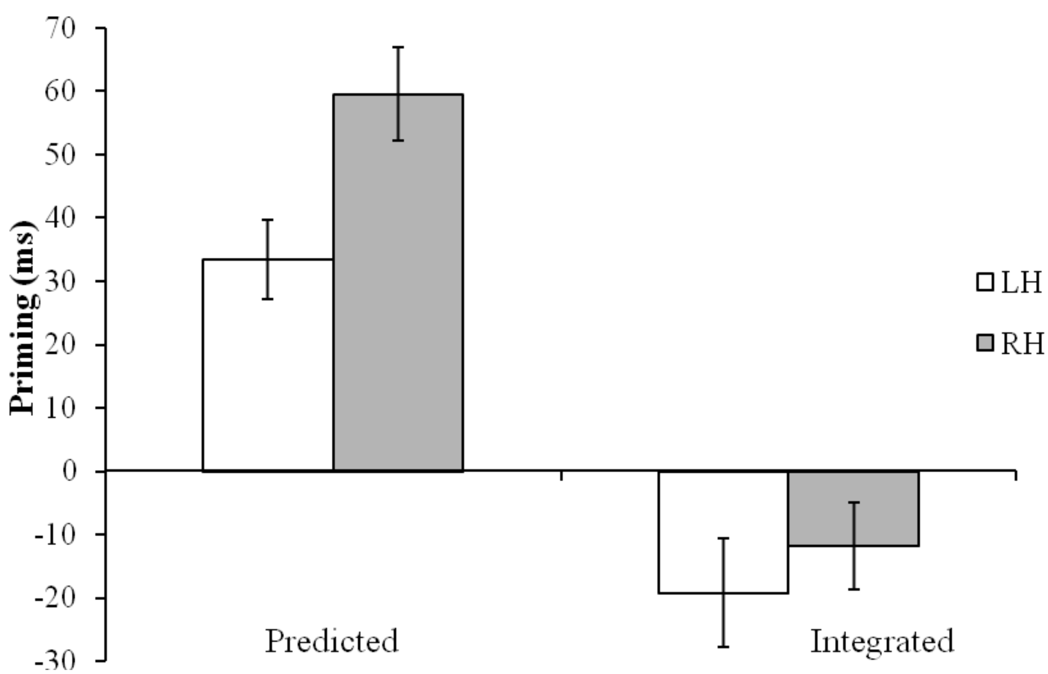

Figure 1. The relative priming (ms) of each visual field/hemisphere presentation as a function of target type. Error bars represent +/- 1 standard error from the mean.

An additional repeated-measures ANOVA was conducted on the facilitation and inhibition effects computed by subtracting the contextual sentences conditions from the respective neutral condition (see Fig.1). The main effect of visual field was significant ($F(1,31)=5.43$, MSe=1652.1, $p=.026$), reflecting greater facilitation on average for targets presented to the LVF/RH than to the RVF/LH. A significant main effect of target type ($F(1,31)=85.230$, MSe=1445.1, $p<.001$) reflected greater facilitation of predicted ($M=47$ ms) than integrated ($M=-16$ ms) targets. The interaction between visual field and target type approached significance ($F(1,31)=3.596$, MSe=783.3, $p=.067$) and further analyses were conducted on this interaction due to its relevance in evaluating the hypotheses. Paired samples t-tests revealed that although facilitation of predicted targets was significantly greater for those presented to the LVF/RH than to the RVF/LH ($t(31)=3.860$, $p=.001$), inhibition of integrated targets did not differ significantly as a result of visual field presentation.

Errors

A repeated-measures analysis of variance was conducted on error rates for word-target trials. The relevant error rate data are summarized in Table 3.

Table 3. Mean error responses (%) to target words as a function of target visual field, sentence type, and target type. Standard deviations (ms) appear in parentheses.

	LH/RVF		RH/LVF	
	Predicted Targets	Integrated Targets	Predicted Targets	Integrated Targets
Contextual Sentence Group	1.3 (3.0)	4.2 (6.1)	3.0 (4.7)	11.1 (9.5)
Neutral Sentence Group	7.2 (6.5)	7.4 (6.6)	8.3 (6.5)	11.6 (7.7)

A significant main effect of visual field (F(1, 31)=22.37, MSe=34.58, p<.001) was consistent with the RT data, with a greater error rate exhibited in the LVF/RH (M=8.5%) than in the RVF/LH (M=5.0%). A significant main effect of sentence type (F(1, 31)= 30.30, MSe=29.2, p<.001) paralleled the RT data, indicating that more errors occurred in correctly identifying word targets in the neutral conditions (M=8.6%) than in the contextual conditions (M=4.9%). As in the RT data, the main effect of target type was also significant (F(1, 31)=33.98, MSe=25.07, p<.001), where more errors occurred in identifying integrated (M=8.6%) than predicted (M=4.9%) targets. The interaction between sentence type and target type was significant (F(1,31)=8.57, MSe=27.15, p=.006), as was the interaction between target type and visual field (F(1,31)=10.06, MSe=27.26, p=.003). Paired-samples t-tests (incorporating a Bonferroni adjustment to alpha=.008) were used to investigate these interactions and it was found that a significantly greater percentage of errors was made for integrated than for predicted targets, but only when preceded by contextual sentences (t(31)=5.705, p<.001).

Additionally, the percentage of errors was significantly lower for contextual sentence conditions than neutral sentence conditions, but only for predicted targets ($t(31)=6.172$, $p<.001$). The percentage of errors was significantly higher for integrated targets presented to the LVF/RH (M=11.4%) than to the RVF/LH (M=5.8%), but unlike the RT data, did not differ significantly for predicted targets. As in the RT data, none of the remaining interactions were significant (highest F=0.871, for the interaction between sentence type and visual field). Given the consistency of the error rate data with the RT data, it is unlikely that any speed/accuracy trade off effects were impacting the results.

Discussion

The present study set out to investigate the proposition that the RH processes in a bottom-up, integrative fashion that enables the maintenance of contextual information, whereas the LH processes in a top-down, predictive fashion and only keeps active the most recent concept (Federmeier, 2007; Federmeier & Kutas, 1999). Three sentences were presented, of which coherence between the first and second sentence could be derived by the production of an inference. The third sentence, a fragment, was consistent with the scenario set out in the first two sentences, but did not directly contribute to the inference generation. "Integrated" targets thus reflected the meaning derived from the integration of the first two sentences, while "predicted" targets were the sentence-final completion of the third sentence and therefore could be predicted without integration of previous context. It was hypothesized that facilitation for integrated targets would be significantly greater when presented to the LVF/RH than to the RVF/LH. This hypothesis was not, however, supported by the results. Not only did inhibition of the integrated targets occur regardless of which visual field it was presented to, the amount of inhibition did not differ significantly between them. The hypothesis that facilitation of predicted targets would be significantly greater when presented to the RVF/LH than to the LVF/RH was also not supported; interestingly, predicted targets were facilitated to a significantly greater extent when presented to the LVF/RH than to the RVF/LH.

These findings, although inconsistent with our initial hypotheses, are nonetheless extremely beneficial in contributing to our understanding of the underlying language processing mechanisms of each cerebral hemisphere. Perhaps the most interesting finding of the present study is that the RH appeared better able to process the predicted target than the LH. This demonstrates a situation in which RH language processing mechanisms have produced a distinct advantage over the LH. Although this sort of finding has been observed in a number of studies investigating particular capacities such as inference generation (Beeman et al., 2000; Mason & Just, 2000) and information maintenance (Tompkins, Scharp, Meigh & Fassbinder, 2008), few behavioral studies have, until recently, demonstrated this advantage for extracting meaning from short contextual sentences. This finding therefore adds to the growing body of evidence that the special role of the RH in language tasks is its ability to extract, build and maintain a contextual base.

Based on this role, the finding that the predicted target was facilitated more in the RH than in the LH is not entirely inconsistent with Federmeier's (2007; Fedemeier & Kutas, 1999) proposed model. In the present study, the "predictive" processing mechanism theoretically should have resulted in the LH focusing entirely on the final, third sentence. Given that, based on pre-testing using cloze probabilities, the predicted target was considered to be a "highly predictable" sentence completion, the LH should therefore have been able to pre-activate features of the expected target and thus facilitate a fast and accurate response on presentation of this target. Indeed, the results reflect a significant facilitation effect for predicted targets presented to the RVF/LH. Intriguingly, however, when the predicted target was presented to the LVF/RH, significantly more facilitation was observed. This, initially, does not support the expectations derived from Federmeier's model. If the advantage of predictive processing is that it is fast, accurate, and thus efficient, then this should have been reflected in the present study, where the predicted target was deliberately tested to be particularly suitable to LH-"predictive" type processing. Given equal contextual information (i.e., the final sentence fragment), the LH-predictive processing mechanisms should have produced comparatively faster responses due to a forward priming effect (i.e., preactivation) than the backward-priming method effect (i.e., integration) of the RH. These results can instead be explained by the proposition that the RH may have somehow been utilizing the previous contextual information present in the first and second sentences, even though it was not directly relevant to facilitation of the predicted target. That is, the RH's integrative mechanisms may have had more contextual support than the LH's predictive strategy, leading to the greater facilitation effect. If this is the case, then these results provide some support for the LH not maintaining activation of prior contextual information, particularly after presentation of new, irrelevant information (as was intended to be demonstrated in the present study through comparison with the integrated targets).

The finding that integrated targets were inhibited in both hemispheres also appears, at first glance, to be inconsistent with Federmeier's (2007) model of hemispheric language processing. Federmeier proposed that the RH, through its ability to maintain activation of contextual information, is able to integrate target words into the prior meaning. Given that the integrated target reflected an inference that needed to be generated in order to cohere the first two sentences and thus derive meaning from the contextual information, and that the RH has been shown to maintain activation of non-presented words across neutral and irrelevant information (Faust et al., 2006), the integrated target should have been facilitated following presentation to the LVF/RH. Conversely, Federmeier proposes that the LH quickly deactivates contextual information and therefore in the present study the inclusion of the third sentence in which prediction of the sentence-final target was required should have resulted in the loss of activation of the prior contextual information. Although unsurprising that inhibition was observed for integrated targets presented to the RVF/LH, the same level of inhibition for integrated targets present to the LVF/RH is difficult to explain. Firstly, there is the possibility that the RH either did not derive the inferential meaning of the first two sentences at all or, alternatively, did not maintain activation of this contextual information until the presentation of the target. Either of these possibilities would suggest that the RH was processing the information in a manner similar to the proposed LH-predictive mechanism. These explanations would, however, appear unsatisfactory given that, firstly, this would not explain why *more* facilitation was observed for the predicted targets presented to the LVF/RH than to the RVF/LH and, secondly, given this is inconsistent with the large amount of empirical evidence in the literature that has demonstrated that the RH does contribute to inference generation in order to cohere meaning across sentences (e.g., Beeman et al., 2000) and, furthermore, maintains activation of contextual words and meanings (e.g., Tompkins, Scharp, Meigh & Fassbinder, 2008).

An alternative possibility is that the sentence-fragment nature of the final sentence produced a situation in which the integrated target was a semantic violation if it were used as the sentence-final word. It is possible that the RH may have inhibited the integrated target given it violated the sentence completion on a local level, despite being consistent with the context in a broader sense. This explanation would, however, be somewhat inconsistent with the proposition that the RH's role in language processing is to process in a global manner, whereas the role of LH is to process at a local level (Federmeier, 2007; Long, Baynes & Prat, 2005). Nonetheless, Federmeier and Kutas (1999) found that the RH was able to distinguish between expected sentence final words and unexpected, but semantically related, targets. The integrated-target condition would therefore have produced an integration conflict for the RH. According to Federmeier (2007; Federmeier & Kutas, 1999), the integration process occurs post-lexically, where facilitation is derived from the "fit" of the target with the preceding contextual information. Arguably, the integrated target presented to the LVF/RH could therefore be integrated with either the contextual meaning of the sentence (i.e., it "fits", resulting in facilitation), or with the sentence-level congruency (i.e., it violates the sentence completion, resulting in inhibition). When this conflict occurs, the RH may revert to inhibition given the target does not satisfy all of the integration requirements. If this supposition is correct, then it would seem logical that less inhibition should be observed for the integrated targets that are initially presented to the LVF/RH compared to those presented to the RVF/LH, given there should have been initial activation of these targets in the RH. Although the difference in inhibition was not statistically significant, the direction of the results is consistent with this expectation. Alternatively, it is also possible that the extremely fast and powerful processing mechanism of the LH in this circumstance overrode the slower, weaker processing mechanism of the RH and resulted in the inhibition of the integrated target in both hemispheres.

A clear resolution to the difficulty in measuring integrative processing caused by including the third, incomplete sentence is not readily apparent. For example, although including the third sentence as a complete sentence would eliminate the problem of integrated targets violating the sentence completion, a complete sentence would remove the ability to simultaneously measure (and thus compare with) the LH predictive processing capability. That is, predictive processing as explained by Federmeier and Kutas (2007) is "narrow, short-term [and] local" (p.388) which implies a restriction to predicting upcoming individual items as opposed to predicting general concepts and meanings that might be expressed in upcoming sentences. Thus if, following a series of complete sentences, a target was presented that reflected the overall concept or meaning derived from the context then it should not be facilitated (i.e., pre-activated) by predictive processing. According to the descriptions of integrative vs. predictive processing outlined by Federmeier (2007; Federmeier & Kutas, 1999), facilitation of a target that reflects the general meaning of the sentences as opposed to a specific upcoming item should only be possible as a result of a post-lexical, integrative processing mechanism. This contention is further supported by findings from studies on inference generation that the LH appears to have an extremely limited ability in the production of predictive (or elaborative) inferences. Beeman et al. (2000) found evidence that predictive inferences are produced only by the RH, through the activation of a wide range of possible concepts that are related to the initial statement or information. Although there is some evidence of individuals with RHD producing predictive inferences (e.g., Lehman-Blake & Tompkins, 2001) this occurred only given strong contextual support and also appeared to be moderated by the patients' comprehension ability in general.

These findings could be explained by Federmeier's (2007) model, as the majority of the studies finding that the RH has produced predictive inferences have used targets that could be readily integrated with the sentence-level meaning and with world knowledge. That is, when a target is presented (e.g., "LAUNCH"), the RH integrates that target into the context (or situation model) produced by the prior information (e.g., "*The shuttle sat on the ground, waiting for the signal*"; Beeman et al., 2000, p.311). Indeed, Fincher-Kiefer (1995, 1996) argued that elaborative inferences are part of the process of producing a situation model, which is the mental representation of the situation depicted in the context, and draws on world-knowledge to elaborate on the propositional information explicitly presented in the text (Hald, Steenbeek-Planting & Hagoot, 2007; Kintsch, 1988). As such, the RH may not be truly "predicting" the elaborative information, but instead is able to readily extend beyond the text-based information (e.g., drawing on world-knowledge relating to the situation model derived from the context) when required to integrate a target. In this case, the elaboration only occurs following the target presentation (as in the integration mechanism proposed by Federmeier). Conversely, since the predictive processing of the LH is not supported beyond completed sentences and since it is also unable to integrate the elaboration-related target into its narrow focus of the context, it therefore cannot generate elaborative inferences nor produce integrative facilitation in the manner that the RH processing mechanisms would allow. Nonetheless, although this explanation may allow Federmeier's model to account for findings of studies that have used target words to identify RH elaborative or predictive inferencing abilities, it is unclear how an integrative, "backward-priming" mechanism would be capable of explaining these results in studies that have not presented targets but, for example, have instead measured brain damaged participants' abilities to elaborate (e.g., Wapner, Hamby & Gardner, 1981).

Given the findings of the present study and the evidence in the literature (e.g., in producing elaborative or predictive inferences) it would appear that Federmeier's (2007; Federmeier & Kutas, 1999) model requires some expansion. Just as Beeman's (1998) coarse-coding model appears suited at the word-level but is limited in its applicability beyond this level (Gouldthorp & Coney, 2009c), Federmeier's model appears suited at the sentence-level but may be limited in its ability to explain processing beyond this level (i.e., in accounting for evidence relating to situation or discourse level processing). It is possible that the distinction between integrative and predictive processing (Federmeier, 2007) and also between coarse and fine coding (Beeman, 1998) are simply artifacts of broader hemispheric processing differences. For example, the LH may be utilizing a linguistic, predominantly text-based processing method (Kintsch, 1988; Long & Baynes, 2002, 2005) that is therefore narrow, yet fast and efficient in many tasks. Conversely, the RH may process in a para-linguistic manner (e.g., Fincher-Kiefer &

D'Agostino (2004) suggests that text-based information can be transferred into perceptual symbols) to produce a "situation model" (Kintsch, 1988), which results in a perceptual simulation of the meaning of the text (Barsalou, 1999). This would inevitably result in a broader and slower means of processing language, yet allow greater comprehension and maintenance of contextual information and, furthermore, integration of incoming information. If the RH does produce a situation model, where the incoming stimuli are transferred into a para-linguistic "blend-space" (Fauconnier & Turner, 1998), then this would explain the finding in the present study that the RH demonstrated greater facilitation of the predicted targets given the "build up" of the context. In the present study, one can imagine cursing oneself after running out of fuel and, having already been driving for hours, just wanting to get home to bed (see Table 1); that is, simulating, and thus expanding upon, the context through a situation model. Conversely, in the present study the LH was perhaps processing the information in a propositional, text-based format and so benefited less by the situational information presented in the prior sentences leading to less facilitation of the predicted targets. Several studies have presented evidence in support of this hemispheric processing distinction (e.g., Long & Baynes, 2002; Long et al., 2005) but it nonetheless remains equivocal; further research is required to determine the nature of hemispheric differences in language comprehension.

In conclusion, the results of the present study provide some support for Federmeier's (2007; Federmeier & Kutas, 1999) model of hemispheric language processing mechanisms but it does not appear entirely sufficient for explaining how the RH gained so much more facilitation for predicted targets compared to the LH from integrative processing alone. This, in combination with evidence from predictive inferencing (Beeman et al., 2000), suggests the RH-integrative and LH-predictive distinction may be too narrow. Rather, a broader difference in processing mechanisms might account for Federmeier and Kutas' (1999) results from which the predictive-integrative distinction was initially derived; indeed, a situation-model processing method would support integrative processing (as well as the prediction of broader concepts as opposed to particular items) whereas a purely linguistic mechanism would allow prediction predominantly from the text-base. This conceptualization of language processing would also serve to account for hemispheric differences in a number of other language comprehension areas (e.g., metaphor comprehension, ambiguous words, congruency studies, etc.) and, in particular, would account for the recurrent finding that the RH utilizes contextual information to a greater extent than the LH.

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6. DISCUSSION

6.1 Summary of Findings

The sensitivity of the RH to message-level contextual information has been the subject of much discussion in the recent literature. Although the combined evidence from studies utilizing electrophysiology, neuroimaging and the investigation of neuropsychological patients suggests that not only is the RH capable of processing language at a higher-level, it is particularly sensitive to contextual information and, furthermore, this may form part of a special role that the RH has in language comprehension. Surprisingly, results from behavioral studies on neurologically normal individuals tend to produce results that indicate a restriction of the RH to lower-level processing mechanisms, which are comparatively less sensitive to context than the LH. The overall purpose of the present program of research was thus to further investigate the role of the RH in sentence comprehension, particularly in regard to the use of contextual information, and reconcile the discrepant evidence produced by the normal-behavioral studies with the evidence produced by the alternative methodologies. The four studies undertaken were centered around the RH's use of contextual information embedded in sentences with the specific aims of, firstly, clarifying to just what extent the RH utilizes message-level rather than simply word-level information present in sentences and, secondly, investigating the relative applicability of the "coarse vs. fine coding" and "integration vs. prediction" models of hemispheric processing differences to higher levels of language processing (i.e., beyond single sentences).

The first study in this program of research was designed to specifically test the sensitivity of the RH to contextual information present in sentences at the message-level compared to the word-level. An earlier study by Faust and Kravetz (1998) presented participants with sentences of varying levels of context and argued that although both hemispheres benefited more from high compared to low levels of context, the RH derived facilitation of targets preceded by sentences due to word-level processes whereas the LH also utilized message-level processes. As argued in the Chapter 1, however, the facilitatory effects of word-level compared to message-level processing can only be disentangled by controlling for the presence of word-level associations. Experiment 1 thus aimed to determine whether Faust and Kravetz's (1998) findings were indicative of RH message-level processing, or simply a result of the presence of associated words, by including a baseline measure of priming derived from word-level processing (i.e., by disrupting message-level content by scrambling the sentences, thus reducing them to randomly-ordered strings of words). Experiment 1 found that both hemispheres responded more quickly to target words following highly constraining sentences as compared to low constraint or neutral sentences. Additionally, both hemispheres responded more quickly to normal compared to scrambled sentences. These results provided a clear demonstration that not only does the RH benefit from increased context, it does so by utilizing both word and message-level information derived from the sentences at a level comparable to the LH. Although this finding is quite unusual in a behavioral study on normal individuals, it reinforces mounting evidence from other methodologies that suggests that, under at least some circumstances, both hemispheres utilize message-level information.

Although the major findings of Experiment 1 were consistent with expectations, there were some additional results relating to the scrambled conditions that were somewhat surprising. It was found that the low constraint, scrambled sentences produced higher levels of facilitation for targets presented to the LH than to the RH. The pattern of results was such that facilitation for the low constraint, scrambled sentences was quite minimal for the RH, but comparatively higher for the high-constraint, scrambled sentences; conversely, the LH had moderate levels of facilitation in both low and high constraint, scrambled sentences. In order to explain how the LH gained more facilitation than the RH from low constraint scrambled sentences it was argued that the LH must be using some form of controlled processing; the RH, on the other hand, was presumably using summation priming as this would explain the increase in facilitation from low to high constraint scrambled conditions. There are, however, inconsistent findings in the literature of hemispheric differences in the use of summation priming and, particularly, whether these differences can be explained in terms of a coarse/fine coding distinction. The conclusions made in Experiment 1 relating to the scrambled sentences were therefore equivocal and required further investigation.

The second study in the present program of research thus aimed to examine whether these scrambled sentence results were reflective of the RH's use of coarse coding leading to a summation priming effect while the LH utilized controlled processing to extract information beyond the word-level. Experiment 2 used the content words (i.e., nouns, verbs, and adjectives) from the scrambled sentences in Experiment 1 in a summation priming paradigm. It was argued that in order to support the conclusions made in Experiment 1, it would be necessary to show that the LH advantage in the low context scrambled condition was eliminated when only word-level information was available. The results supported this expectation and, furthermore, implied that the presence of message-level information may override or alter the way in which concurrently available semantic information is processed. Additionally, the results provided confirmation of Beeman's (1998; Beeman et al., 1994) coarse/fine semantic coding model. Consistent with the mechanisms proposed by Beeman, when constraint was high the LH was able to select and amplify the likely meaning of the upcoming target, whereas in the low constraint condition there was no more facilitation than that available to the RH. This suggests that the LH utilizes a finer coding than the RH when processing highly constraining information at the word-level, although additional investigation would be required to confirm that the RH's coarse coding mechanism yields greater facilitation in instances of very low constraint.

Although the results of Experiment 1 provided strong evidence that the RH is sensitive to message-level information and is therefore not restricted to word-level processing, the results of Experiment 2 suggest that there is some applicability of the coarse/fine-coding distinction between right and left hemisphere processing. Thus, based on these conclusions, the third study in the present program of research aimed to investigate the "coarse" processing of the RH at the message-level. Experiment 3a incorporated what could be considered as a summation priming paradigm at the sentential level. One, two, or three sentences were presented where each sentence individually provided only minimal cues to the nature of the target, but when processed as a coherent whole created a much more powerful context. It was argued that, if coarse-coding could be used to explain the processing mechanisms of the RH at the message-level, significantly greater facilitation should have been observed for the RH than for the LH in the high-context condition (i.e., where the low-context message-level information present in each of the three sentences needed to be integrated, or "summated", in order to produce high context). There was not, however, a significant difference in facilitation between the hemispheres at any of the levels of context. It was not, however, clear whether this effect arose as a result of word-level or message-level processes; significant differences in facilitation between the normal and scrambled sentence variants were not observed in the absolute RT data for either hemisphere. As observed in Experiment 2, the presence of any syntactic structure can lead to the partial re-construction of the message-level interpretation, which in turn can confound the baseline measure of word-level processes occurring in the scrambled sentences. Experiment 3b was therefore conducted, in which a minor change to the scrambled conditions was applied. The words were scrambled across all of the sentences presented in a trial rather than within each sentence, thus ensuring a more complete disruption of the syntactic structure in order to remove the possibility that both hemispheres were extracting message-level information from the scrambled sentences. Through the observation that normal sentences lead to significantly greater facilitation than scrambled sentences, the results of the Experiment 3b provided a clear demonstration that the equality of facilitation observed in both studies occurred as a result of message-level, rather than merely word-level, processing. Given that the results suggested that the coarse-coding model is insufficient in explaining hemispheric differences in sentential processing, it was proposed that Federmeier's (2007) integrative/predictive model of hemispheric processing might provide a more satisfactory explanation. Nonetheless, given that Experiment 3 did not set out specifically to test the applicability of the integrative/predictive distinction and thus did not produce evidence specifically supporting it, this proposition remained tentative.

The fourth and final experiment in the present program of research therefore aimed to directly compare integrative versus predictive processing mechanisms in order to assess the applicability of Federmeier's (2007) model as a means of explaining hemispheric differences in language processing at the message-level. Specifically, the aim of Experiment 4 was to investigate the proposition that the RH processes in a bottom-up, integrative fashion that enables the maintenance of contextual information, whereas the LH processes in a top-down, predictive fashion and only keeps active the most recent concept. Three sentences were presented, of which coherence between the first and second sentence required the production of an inference. The third sentence, a fragment, was consistent with the scenario set out in the first two sentences, but did not directly contribute to the inference generation. "Integrated" targets thus reflected the meaning derived from the integration of the first two sentences, while "predicted" targets were the sentence-final completion of the third sentence and therefore could be predicted without integration of previous context. Federmeier's model would therefore have been supported if the results reflected greater facilitation of integrated targets for the RH than for the LH, and greater facilitation of predicted targets for the LH than for the RH. The results, however, showed significantly greater facilitation of predicted targets for the RH than for the LH, and approximately equal inhibition of integrated targets for both hemispheres. On reflection, it appears that the effect of targets being processed as sentence-final completions due to the requirement for the third sentence to be incomplete (in order to accommodate the predicted target) resulted in the inhibition of the integrated targets. Although the finding that the predicted targets were facilitated significantly more for the RH than for the LH casts some doubt on Federmeier's model, the RH facilitation may have resulted from an integrative processing mechanism that utilized the context from the preceding sentences. Future research could investigate this conclusion; specific suggestions for further research directions are outlined in Subsection 6.2.1. The results of Experiment 4 therefore do not rule out Federmeier's predictive-integrative model of hemispheric language processing mechanisms, but do provide a basis from which it can be theorized that this distinction may be too narrow.

6.2 Implications: Updating the Current Understanding

There has been a tendency for researchers (as reviewed in Chapter 1) utilizing a normal-behavioral methodology to assume that, even if the RH is not restricted solely to word-level processing, it is less sensitive to message-level information and relies predominantly on intra-lexical mechanisms. The results of the present program of research do not support this assumption and instead provide confirmation of the recurrent finding observed in neuropsychological, neuroimaging, and electrophysiological studies that the RH does not solely rely on, or even predominantly use, word-level processing. The tendency to assume that the RH predominantly uses word-level processes appears to be, at least in part, derived from the proposition that evidence of a special role of the RH can be explained by a coarse-coding mechanism (Beeman, 1998). As reviewed in Chapter 1, a number of researchers (e.g., Beeman, 1998; Beeman et al., 2000) have argued that evidence of a RH role in tasks such as metaphor comprehension, predictive inference generation, discourse coherence, and humor appreciation can be explained by there being a greater chance of semantic overlap in the RH as a result of a broad activation of weakly related words. Given that there are a number of studies (including Experiment 2 of the present program of research) that have provided evidence in support of the proposition that the LH activates a narrower range of word meanings than the RH, it is quite likely that the fine/coarse coding distinction of hemispheric processing is applicable at some, albeit relatively basic, level.

The assumption that this distinction can be applied to higher levels of processing is, however, problematic. Based on the evidence for a coarse coding of the RH that was produced by studies specifically investigating hemispheric differences in summation priming (e.g., Beeman et al., 1994), some researchers have extrapolated the coarse coding model to higher level processing. For example, evidence of a considerable RH involvement in discourse coherence (demonstrated through the comprehension of untitled paragraphs) observed in St. George et al.'s (1999) study has been attributed to the semantic overlap of distantly related words within the semantically vague propositions presented. Similarly, Faust and Mashal (2007) argued that the apparent RH involvement in the processing of metaphors may reflect coarse coding of the RH, based on the likelihood that the metaphorical meaning of a word will be more semantically distant than its literal meaning. Nonetheless, these attributions of evidence of RH processing to a coarse coding mechanism have been made despite there being no clear evidence of its applicability to instances of higher language processing except in a theoretical sense. Indeed, the present program of research provided strong evidence that the coarse coding model of RH language processing is too simplistic to account for the role of the RH in language comprehension when the need to incorporate the extraction of message-level information into any complete model of RH processing is considered. Furthermore, the presumption of the fine/coarse coding model that priming is derived only from an automatic spreading activation precludes priming from additional controlled processes in which, for example, hemispheric differences may arise as a result of post-lexical matching strategies. This model is thus quite limited in that it does not appear able to incorporate the variety of mechanisms used during language comprehension. Rather than RH language comprehension resulting from a single processing mechanism (i.e., coarse semantic coding), the present program of research concludes that comprehension is derived from the combination of a number of mechanisms (specifically, at the word- and the message-level) that, depending on the particular circumstance, contribute more or less to the comprehension process.

An implication of this conclusion is that previous research findings accounted for in the context of coarse coding may need to be reinterpreted. For example, Beeman et al. (2000) interpreted their observation that targets reflecting a predictive inference were facilitated when presented to the LVF/RH, but not to the RVF/LH, as being a demonstration of coarse coding. They argued that predictive inferences are likely to be produced by the RH due to the summation of a large number of weakly related words. Similarly, Faust et al. (2006) suggested that the RH's ability to maintain activation of multiple meanings (e.g., across unrelated information) may be explained by coarse semantic coding. They argued that the activation of a number of word meanings (and thus greater change of overlap of semantic fields with previously presented information) leads to the maintenance of priming effects. They further argued that this coarse coding ability is likely to be involved in drawing inferences, maintaining coherence, and understanding the overall meaning of a story. Additionally, it is not uncommon in the literature for deficits in language processing in individuals with RHD to be explained as occurring due to a presumed deficit in coarse coding (although the small number of studies that have attempted to directly investigate this explanation have produced inconsistent results (see Tompkins et al., 2008, for review)). Given that the present program of research has demonstrated that the coarse coding model is insufficient in accounting for RH discourse comprehension in an intact brain, the assumption that the deficits in language processing in RHD patients are due to the impairment in coarse coding is therefore inherently flawed. That is, if coarse coding is not solely sufficient for explaining RH language processing capacities, it cannot then be assumed to fully account for language comprehension deficits following RHD. Thus, the tendency for the coarse coding model to be applied in a post hoc manner in order to explain evidence of RH contributions to language processing appears to have allowed the model to take greater precedence in the literature than the present program of research suggests is substantiated and, accordingly, researchers should consider alternative processing mechanisms when attempting to provide a coherent explanation of their results.

One of the few alternatives to the coarse/fine coding distinction of hemispheric processing is the RH-integrative/LH-predictive processing model (Federmeier, 2007), which was examined in Experiment 4 of the present program of research. This model provides an alternative account of many of the same observations that the coarse coding model claims to explain. For example, Federmeier and Kutas (1999) argue that the same summation priming findings of Beeman et al. (1994) that underpin the coarse coding hypothesis can be readily accounted for by a predictive mechanism of the LH, which operates optimally in instances of high constraint. Thus, in a summation priming paradigm where weakly related words do not produce constraint and thus do not facilitate the prediction of the upcoming word, minimal priming is observed for the LH. Federmeier and Kutas argue that, conversely, an integrative processing mechanism involves the comparison of the target with each of the prime words and thus enables facilitation of the target following LVF/RH presentation. Federmeier and Kutas based this conceptualization of the processing differences between the hemispheres on their finding that sentence-final target words were only primed in the RH when they corresponded directly with the preceding sentential context, whereas words that shared similar features to the expected target were also primed in the LH. They explained their results by proposing that the RH uses a bottom-up method of processing that thus maintains the representation of the individual words and is less sensitive to higher-level information, whereas the LH uses a top-down processing mechanism in which the higher-level information alters the incoming bottom-up signal.

This model, however, is limited in its application to comprehension of extended discourse rather than just to the priming of individual words. For example, as argued in Experiment 4, the conceptualization of RH-Integrative processing in which facilitation occurs due to a backward-priming effect does not appear able to fully account for the RH's role in the production of predictive (or elaborative) inferences. Furthermore, this model suggests that the LH is driven by higher-level contextual information and the RH relies on the lower-level, local contextual information. This is not, however, consistent with evidence in the literature that suggests the low-level, text-base representation is held only in the LH and that the RH appears to have a role in the higher-level, discourse representation (Long & Baynes, 2002; Long, Baynes, & Prat, 2005). The observations made throughout the present program of research also lend support to the suggestion that the RH appears to be particularly sensitive to higher-level contextual information. The underlying mechanisms used to explain a RH-integrative and LH-predictive processing distinction therefore requires some expansion in order to account for evidence relating to situation, or discourse, level processing.

6.3 Theoretical Speculation: The Special Role of the RH in Language Comprehension

The present program of research provides evidence that the RH utilizes higher-level processing mechanisms and suggests that the RH has an important role in language comprehension. Given that the coarse/fine coding model and the integrative/predictive processing model were not found to be adequate for explaining the complexity of differences in hemispheric language processing, further speculation as to what *would* fully account for these differences is warranted. The discussion contained within the following subsections therefore goes beyond the results of the present program of research in order to consider what the specific contribution of the RH to language comprehension is likely to be, with a view to directions for future theoretical and empirical inquiry.

6.3.1 Conceptual Integration in Situation Modeling

As outlined in Chapter 1, text comprehension is often conceptualized in the psycholinguistic literature in terms of a distinction between the textbase (or propositional representation) and the situation (or discourse) model (Johnson-Laird, 1983; Van Dijk & Kintsch, 1983); although, some theorists propose that rather than the propositional representation and the discourse model being two separate components of comprehension, they instead represent the extremities of a single continuum of comprehension (e.g., van den Broek, Risden, Fletcher, & Thurlow, 1996). A special role of the RH in the construction of the situation model is quite plausible when one considers the sorts of tasks that the RH appears particularly involved in (e.g., discourse cohesion, inference generation, metaphor comprehension). The suggestion that the RH may have a special role in the construction of the situation model, while the LH is especially involved in the propositional representation, is by no means new to the language processing literature. For example, Long and Baynes (2002; Long et al., 2005) attempted to investigate whether the propositional representation and discourse model are differentially constructed by, or represented in, each of the hemispheres. Although they provided strong evidence that the propositional representation resides only in the LH, the RH's involvement was less clear as aspects of the discourse model appeared to be represented in both hemispheres. Additionally, this view is not necessarily inconsistent with Federmeier's (2007) account wherein the RH utilizes an integrative processing mechanism; indeed, integration of information at the message-level is essential for the construction of a situation model. Zwaan and Radvansky (1998) argue that an integrated situation model incorporates both the currently active information derived from the textbase and the implicit, background knowledge. For example, Albrecht and O'Brien (1995) observed increased reading times as a result of explicit, text-based information that was inconsistent with the situation model produced by previous information (e.g., that the protagonist ordered a hamburger given previous information they were a vegetarian). Thus, in addition to the linguistic cues, readers utilize their world knowledge to identify, for example, causal relationships and to attribute spatial and temporal characteristics in order to construct the integrated situation model (Zwaan & Radvansky, 1998).

It is this necessity of *integration* of contextual information for the construction of a situation model, which in turn is necessary for discourse coherence (Zwaan & Radvansky, 1998), that may explain the special role that the RH appears to have for certain tasks. For example, Fauconnier and Turner (1998) argued that the comprehension of metaphors requires the integration of a number of events and described this process as occurring in a nonlinguistic "blend" space. For example, "*He digested the book*" contains individual linguistic sources of information, from which two separate events are derived (e.g., "*digestion of food"* and "*reading the book"*). The events associated with these separate meanings ("inputs") must be integrated, or "blended". The event of "digesting food", for example, entails an array of events such as chewing, swallowing, finishing and processing the food within the body systems. The event of "reading the book" constitutes taking up the book, parsing its individual sentences, finishing it, and mentally processing the information. Fauconnier and Turner (see also Coulson, 2001; Coulson & Oakley, 2000) argue that these individual events are projected to a "blend" space, in which they are elaborated on and integrated into a single unit. This integration not only allows for the comprehension of the metaphor itself, but allows the revision of the initial interpretations of the inputs. This is particularly noteworthy given the deficit in the ability to modify initial interpretations of contextual information that has been observed in individuals with RHD (e.g., Brownell et al., 1986). As such, if conceptual blending/integration is necessary for the higher-level comprehension of the meaning of at least certain types of sentences and discourse and is essential for the types of comprehension for which the LH appears to show deficits in (e.g., in the comprehension of metaphors (Anaki et al., 1998; Birhle et al., 1990; Brownell et al., 1990), integrating elements of an account into a coherent narrative (Delis et al., 1983; Wapner et al., 1981) and understanding humorous content (Brownell et al., 1983; McDonald, 1996; Coulson & Williams, 2005; Coulson & Wu, 2005)), then it would appear logical that the RH may be specially involved in the conceptual integration process that forms part of the construction of the situation model.

6.3.2 Para-Linguistic Processing in Situation Modeling

Furthermore, as noted by Fauconnier and Turner (1998), the "blending" process of conceptual integration is not reliant on plausibility; pragmatic incongruity is disregarded during the blending process in order to integrate the various features. That is, the conceptual blend can contain structure that is implausible, or even impossible, for the inputs (e.g., a peanut may fall in love, or a girl may comfort a clock, despite the obvious pragmatic incongruity of these statements with what we know about the characteristics of inanimate objects (Niewland & Van Berkum, 2006)). Thus, if (or when) conceptual blending is used to extract meaning from non-literal language (e.g., metaphors), some level of non-linguistic processing must be incorporated. Hemispheric differences in the ability to construct and update a situation model may therefore occur as a result of the mechanisms used in its construction. For example, dual-coding theory (Paivio, 1986) proposes that, in addition to linguistic mechanisms, non-linguistic mechanisms contribute to a coherent comprehension of discourse. Paivio (2007) argues that words are used to evoke episodic, autobiographical, semantic and procedural memory; this view is supported by Zwaan and Radvansky (1998) who state that "*language can be regarded as a set of processing instructions on how to construct a mental representation of the described situation*" (p.177). Thus, as noted by Faust et al. (2006), the textbase is essentially linguistic, whereas the situation model may also be non-linguistic. For example, a non-linguistic mechanism may utilize imagery (not necessarily restricted to a visual dimension; imagery may also incorporate auditory, haptic, gustatory and olfactory information (Paivio, 2007)) whereas a purely linguistic mechanism, through the extraction of text-based propositions that are then integrated with related propositions held in long term memory, could build a new situation or discourse model wherein the experience of imagery is an epiphenomenon (Paivio, 2007). Thus, the question may not be whether the situation model resides only in the RH, but whether the hemispheres construct different situation models wherein the underlying components are predominantly linguistic (LH) or non-linguistic (RH). (This is not to say, however, that the RH is restricted to purely non-linguistic processing overall; The term "para-linguistic" was used in Experiment 4 in order to avoid the unintended implication that the RH is unable to use any linguistic mechanisms. Given that dual-coding theory argues that there is a direct associative relationship between the verbal and the nonverbal system, wherein images can evoke other images within the nonverbal systems as well as language referents (Sadoski & Paivio, 2001), the more flexible term, "para-linguistic", would appear better suited to incorporate this relationship than the more restrictive term, "non-linguistic".) Logically, a situation model constructed from a purely linguistic representation would be limited in its representation of information that is not either explicitly stated in the text (i.e., part of the initial text-base) or readily accessible from long-term memory (i.e., stored propositions that are closely related to the text-base). Thus, a situation model constructed from para-linguistic information would inevitably be richer, leading to an increased ability to produce coherence of extended discourse (particularly when meaning is implicit) and would also be more readily able to utilize the conceptual blending process in order to comprehend non-literal language. Nonetheless, this theoretical proposition clearly requires further empirical investigation.

6.4 Future Research Directions

6.4.1 Future Research Directions: Derived from the present program of research

The conclusion made in the present program of research that the RH is at least as sensitive to message-level information as the LH suggests that some evidence derived from behavioral studies on normal participants has underestimated the capacity of the RH for the comprehension of sentences. As suggested in a study conducted prior to the present Doctoral program of research (Gouldthorp & Coney, 2009), this underestimation of RH processing capacities might be the result of the use of stimuli that are not easily processed by the RH. As reviewed in Chapter 1, RH sentence processing capacities may potentially have been masked in some previous normal-behavioral studies (e.g., Chiarello et al., 1999; Faust et al., 1995) due to the critical role of verbs in deriving meaning from the sentence primes. For example, determination of the message-level content of the sentences used by Faust et al. (1995) and Chiarello et al. (1999) was contingent on appreciating the linguistic function of the verb or verb phrase (e.g., congruent: “The patient *swallowed* the MEDICINE” vs. incongruent: “The patient *parked* the MEDICINE”), despite a strong indication in the literature that the RH has difficulty in processing verbs (as reviewed in Chapter 1). In addition to the potential confound of grammatical category, studies that have not controlled for imagability, concreteness, or length of word targets may also have underestimated RH capacities in extracting meaning (see Chapter 1 for review). Thus, it is possible that the demonstration of RH message-level sentence processing mechanisms produced in the present series of studies occurred due to the use of a normal-behavioral methodology that reduced the likelihood of an inherent underestimation of RH processing capacities (e.g., through the use of targets that were short, concrete, highly-imageable nouns).

This assumption that prior inconsistencies in the results of normal-behavioral studies have occurred due to the presence of confounding variables that have generally served to disadvantage, and therefore underestimate, the processing capacities of the RH requires further examination. That is, a future research direction of some necessity would be to determine whether there is evidence to support the claim that some normal-behavioral studies have been compromised by the use of target words and sentence constructions that are inappropriate for probing RH processing mechanisms and, furthermore, to determine under what stimulus circumstances the RH contributes to language comprehension. For example, a potential series of studies could aim to examine the likely confounds (e.g., abstract vs. concrete targets; verbs vs. nouns; short vs. long targets, etc.), in order to determine at what point evidence of RH higher-level processing is concealed. Although there is substantial evidence already in the literature on the effect of these factors individually on RH processing (see Chapter 1 for review), there is less research available on the impact of these factors given the presence of additional sentential information. For example, the impact of grammatical class on RH processing may be altered given sufficient contextual support within the sentence; higher-level processing abilities have been demonstrated to counteract processing difficulties of lower-level information (Schneider & Korkel, 1989). Thus, an additional stimulus factor that should be considered is the possibility that the sentences themselves may vary in terms of support for RH processing. For example, the sentences used in the present series of studies were consistently highly-imageable and this may have contributed to the construction of a conceptual environment suited to RH processing. The finding in Experiment 4 that the predicted targets were facilitated significantly more for the RH than for the LH suggests that the RH used the context from the preceding sentences to construct the situation depicted in the sentences and was therefore able to integrate the target more readily than the LH. It is possible that the sorts of sentences used in some previous normal-behavioral studies may not have developed this conceptual environment to the same extent (e.g., they may have supported a more propositional, text-based processing method). Further research could therefore test this assumption through the presentation of sentence primes that are concrete and easily-imagined compared to those that are abstract and less readily imagined. It might be predicted that where sentence primes represent easily imagined scenarios, higher-level sentence processing would be observed for the RH, whereas this processing capacity would be eliminated (or substantially limited) for the RH given sentence primes that do not allow the construction of an image of the situation. The proposal that the RH may have a special role in the formation of an image-based situation model was expanded upon in Subsection 6.3.2.

Additionally, further investigation could be pursued in order to disentangle the message-level effects of predictive and integrative processing observed in Experiment 4. Specifically, the methodological problem of the integrated target being inhibited due to it being a syntactic violation of the final sentence could be addressed. Future research could thus aim to determine whether greater facilitation of predictive targets for the RH compared to the LH is due to additional contextual information provided by the preceding sentences, and whether the LH has any advantage over the RH for predictive targets when there is less supportive context. This could be accomplished by two studies in which integrative and predictive processing are measured separately, through the application of minor changes to the methods used in Experiment 4. For example, one study could investigate whether there are any hemispheric differences in the integration of contextual information by presenting only the integrated target word preceded by: (i) the first two sentences used in Experiment 4, and (ii) all three sentences (including the sentence final word). This method would essentially test bridging inference generation at two time points to see if there are hemispheric differences in the initial activation of implicit information and, additionally, if it is maintained across a third sentence of related but unnecessary information. It would be expected that although both hemispheres may activate the integrated target immediately at the coherence break (i.e., after the first two sentences), facilitation would only be observed for the RH following presentation of the third sentence. A second study could be conducted in order to determine whether the RH utilizes context to a greater extent than the LH in order to produce greater facilitation of the predictive targets. The facilitation of the sentence-final target could be compared for each hemisphere when preceded by: (i) all three sentences, wherein the third sentence is a sentence fragment (i.e., no difference from the original "predictive" condition used in Experiment 4), and (ii) only the third sentence fragment (i.e., so that the preceding contextual information is removed). It would be expected that greater facilitation of targets presented to the LVF/RH than to the RVF/LH would be observed in the first condition (i.e., where all three sentences are presented), and greater facilitation for RVF/LH than LVF/RH in the second condition (i.e., where only the final sentence is presented).

6.4.2 Future Research Directions: Derived from theoretical speculation

Based on the theoretical speculation presented in subsection 6.3, a research direction of potential importance is the investigation of whether there are hemispheric differences in the construction of situation models. It would also be worthwhile for future research to investigate whether the LH processing of higher-level language uses a purely linguistic mechanism, whereas the RH uses a para-linguistic mechanism and, if so, the nature of this mechanism. Further, if the non-linguistic component is considered to be an imaginal representation, it would also be necessary to investigate the nature of the image (e.g., whether it is predominantly visual, or whether it also incorporates other sensory experiences).

For example, based on Zwaan and Radvansky's (1998) statement that language can be conceptualized as instructions for the construction of a mental representation of a described situation, a potential experiment investigating the use of mental imagery could incorporate a task where the text directs the production of the mental image but where meaning cannot be derived from the text itself (i.e., without the production of a mental image). This task could, for example, involve the central presentation of a series of sentences that instruct the participant to add various shapes to their mental representation, in different locations (e.g., "Draw a thick green vertical line. Draw a purple circle directly above the green line, so that it is just touching but not overlapping. Color the circle so that it is a solid purple. Draw five red semi-circle lines around the purple circle, where the open edge of each semicircular line just touches."). The lateralized target would represent the picture (e.g., the word "*Flower*" or, alternatively, a picture of a flower with a green stem, purple centre, and red petals). Faster RTs and higher accuracy to a lexical decision task, or to a match/mismatch decision for a picture target, would indicate that the corresponding hemisphere had converted the linguistic instructions into an imaginal mental representation.

Further exploration into the role of situation modeling in language comprehension has potential importance for applications of a non-hemispheric nature. For example, there is considerable evidence in the literature to suggest that the construction of situation models plays an important part in language acquisition. Kintsch (1998) argued that people develop situation models through perceptual experience, which in turn is represented by a verbal label (e.g., the verbal label of *red rose* represents the perceptual experience of particular flowers within a particular color range). Thus, before one can apply an appropriate verbal label (i.e., a word) to the perceptual experience, one needs to differentiate between various concepts. It is therefore possible that language acquisition difficulties may arise either as a result of the development of a situation model, or in its translation into words. At later stages of language processing (e.g., reading), there may also be difficulties in the "backward" translation (i.e., words serving as cues to activate the mental model of the concept). As reading becomes developed, the reader may no longer need to use each and every word to access the mental model; rather, they extract propositions or text-based meaning which by itself may convey sufficient information (i.e., a purely linguistic representation). Alternatively, the propositions may be used to access the mental model, after which the information can be entered into the conceptual blend space to construct the evolving situation model of the text. For example, Schneider and Korkel (1989) found that a reader's difficulty with low-level text processing could be offset by a strong knowledge of the topic (i.e., a strong capacity for a higher-level representation in the text). They argued that the readers with high-knowledge were able to utilize relevant knowledge structures in long-term memory in order to construct the situation model of the text, whereas readers with low-knowledge had to rely heavily on the text-based information in order to assemble the model. Similarly, Baggett (1979) presented participants with either a visual film or a spoken version of the same film and found that, regardless of the version they were presented with, participants demonstrated a similar understanding, or mental representation, of the overall theme. This suggests that the situation model itself is not necessarily linguistic but, rather, language is used as a means by which to access non-linguistic representations of experience. Thus, good readers are likely to have strong situation models since this allows them to sacrifice surface-level attention due to the counteracting effect of their stronger higher-level representation. Similarly, individuals with strong situation modeling capacities may enjoy reading to a greater extent than those with weaker situation modeling capacities (i.e., since those with weaker situation modeling capacities would presumably access fewer sensory experiences, whereas those with stronger capacities would be able to produce and update a multi-dimensional image derived from the text cues). Although these suggestions have been addressed to some extent previously in the literature (e.g., see Oakhill, 1996 for review), further research could investigate the specific role of situation modeling in language acquisition and reading development, and also individual differences in reading ability and enjoyment.

6.4 Conclusions

The combined findings of the present program of research provide three major conclusions. Firstly, the RH is able to utilize message-level processing in a manner that is, in many instances, at least comparable to the LH. There is no evidence in the present series of experiments that the RH is restricted to, or uses preferentially, word-level processing. Secondly, the coarse-fine coding distinction does not account for hemispheric processing differences beyond the single word level. Thirdly, the integrative-predictive distinction does not fully account for differences in hemispheric processing at the message-level and, instead, is likely to reflect a broader processing distinction (e.g., where the LH utilizes a linguistic, predominantly text-based processing method whereas the RH processes in a para-linguistic manner in which a situation model results in a perceptual simulation of the message-level meaning); future research directions should specifically investigate this possibility. The combined findings of the present program of research provide an important contribution to the literature given that they not only go some way in resolving previous discrepancies in relation to the RH’s use of contextual information at the message-level, but also in providing a step forward in the on-going investigation of how the hemispheres differ in their processing of message-level information.

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