# CONTRIBUTIONS OF THE LEFT AND RIGHT HEMISPHERE IN LANGUAGE: INVESTIGATING THE EFFECTS OF UNILATERAL BRAIN DAMAGE (STROKE) ON METAPHOR PROCESSING

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# INTELLECTUAL PROPERTY

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# ABSTRACT

It is widely accepted that the left hemisphere of the brain is specialised and dominant for language comprehension and production and that those with left hemisphere damage often display profound language disruption (Geschwind, 1965). The importance of the left hemisphere is shown by communication problems or extreme difficulty in producing speech following damage to this brain region. In contrast, following right hemisphere damage, disruption to language is less perceptible to the casual observer. The evidence base currently available acknowledges a critical role for the right hemisphere in processing inferred or implied information by maintaining relevant facts and/or suppressing irrelevant ones but the exact role of the right hemisphere and its coordination with the left is open for debate (Johns, Tooley and Traxler, 2008).

Two theories have been proposed to explain communication/language difficulties in individuals with right hemisphere damage: (i) the “coarse semantic coding” hypothesis and (ii) the “suppression deficit” hypothesis. The “coarse semantic coding” hypothesis proposes that damage to the right hemisphere causes an over reliance on fine coding assumed to be undertaken by the left hemisphere in the comprehension of language, implying the recall of most literal interpretations. The “suppression deficit” hypothesis proposes that damage in the right hemisphere means multiple activations of meanings of words are not attenuated leading to ineffective suppression of inappropriate interpretations. This project investigated competing evidence for each of these hypotheses by studying the processing abilities of individuals with depressed unilateral brain function caused by stroke or innovatively produced by transcranial DC stimulation (tDCS), on semantic judgement tasks using metaphorical language

The results demonstrated the strongest of evidence for the coarse semantic coding hypothesis when the data from participants with damage to the right hemisphere, both caused by stroke and simulated by tDCS was considered. Overall, the study has furthered the understanding of the role of the right hemisphere in language comprehension and demonstrated the contribution of the tDCS methodology in the field.

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# ABBREVIATIONS

ACC: Accuracy

BD: Brain damaged

BDAE: Boston Diagnostic Aphasia Examination

CSC: Coarse semantic coding hypothesis

CVA: Cerebrovascular accident

DVF: Divided visual field

EEG: Electroencephalography

EVPs: Event related potentials

fMRI:  Functional magnetic resonance imaging

ISI: Inter-stimulus interval

LH: Left hemisphere

LHD: Left hemisphere damage

MoCA: Montreal Cognitive Assessment

NBD: Non-brain damaged

NHS: National Health Service

NRES: National Research Ethics Service

PET: Positron emission tomography

RH: Right hemisphere

RHD: Right hemisphere damage

RT: Reaction time

SDH: Suppression deficit hypothesis

tDCS: Transcranial direct current stimulation

TMS: Transcranial magnetic stimulation

WM: Working memory

# INTRODUCTION

It is generally accepted that the left hemisphere (LH) is specialised/dominant for language comprehension and production (Geschwind, 1965). Individuals with left hemisphere damage (LHD) often display profound language disruption (i.e., aphasia) and this disruption is evidenced by failures in communication or extreme difficulty in producing speech. In contrast, for individuals with right hemisphere damage (RHD), the disruption is much less perceptible to the casual observer. According to Love and Webb (2001), neglect, inattention and denial are three major characteristics of damage to the right hemisphere (RH). Shields (1991) describes deficits characterised by emotional and interpersonal difficulties, visuospatial difficulties and poor paralinguistic communication abilities. Eisenson (1962) carried out a study after observing individuals with RHD displaying linguistic impairment in his clinic. He compared the performance of individuals with RHD with matched healthy control participants on a variety of standardised vocabulary and sentence completion tasks and found that RHD was associated with linguistic and intellectual adaptation and also that the impairment would become more obvious once abstract concepts were introduced. Based on these observations, Eisenson (1962) suggested a role for the RH in higher-level language functioning. Johns, Tooley and Traxler (2008) in their review of discourse impairments after RH damage acknowledge a critical role for the RH in processing inferred or implied information by maintaining relevant facts and/or suppressing irrelevant ones. They also conclude that the exact role of the RH in language and its coordination with the LH is still open for debate.

Research into RHD and its implications for language understanding is sparse; as a result, the clinical implications for this population are not easily defined. Benton and Bryan (1996) carried out a study of 11 patients identifying that 50% of the sample with RHD showed language impairment that did not spontaneously resolve after a 3-month period. Lehman-Blake (2007) reviewed the current status of treatments available for adults with RHD and found that treatments mainly centred on aprosodia with many clinicians relying on their clinical expertise when formulating treatment plans. The difficulty with this is that although 94% of patients in one study were diagnosed with cognitive or communication deficit following RHD on admission, only 45% were then referred for treatment (Blake, Duffy, Myers, and Tompkins, 2002). In conducting her review, Lehman-Blake (2007) found reference to only one treatment programme developed specifically for individuals with RHD. This programme has not been extensively tested although results based on providing individuals with RHD with a method of generating semantic maps using a computer programme have been shown to be beneficial (Lundgren, Brownell, Roy and Cayer-Meade, 2006). It is clear that further exploration into the language deficits caused by RHD will help inform clinicians in both testing for and treating such deficits.

## Right hemisphere contributions to language comprehension

Early clinical observations of adults with RHD demonstrated a focus on literal meanings and a difficulty with identifying connotative meanings. Brownell, Potter, Michelow and Gardner (1984) note that sensitivity to denotation (dictionary definition of a word) and connotation (implied meaning of word in a semantic context) may be assigned to different cognitive structures or networks. In testing participants with unilateral LHD or RHD, they found that patients with RHD had relatively preserved strengths for assigning denotation but not connotation, whilst individuals with LHD demonstrated similar performance for both assignations. A study using the Montreal Communication Battery sought to explore communication differences between individuals with RHD and healthy participants (Fonseca, Chaves, Liedtke, and Parente, 2007). They found significant differences in the areas of discursive, lexical-semantic and prosodic processes between the groups with those with RHD being impaired and showing greater heterogeneity. After noting that studies focus mainly on individuals who are right-handed, Mackenzie and Brady (2004) carried out a study designed to compare both left handed and right handed individuals with RHD. They found both groups to be similarly impaired on communication measures, notably those measures testing for inferred meaning and non-verbal conversation, and significantly so when compared to healthy control participants. The UK population is aging; Laidlaw and Pachana (2009) quote statistics from the United Nations population prospects of 2006 whereby the population of older people is expected to triple over the next 50 years (673 million in 2005 to 2 billion by 2050). In addition, stroke incidence rate increases with age, from 14.34 per 1000 population for 75-84 year olds to 19.87 per 1000 population at 85 and over, making it imperative to develop better measures of language communication and rehabilitation to cater to the needs of an aging population (Bamford, Sandercock, Dennis, and Warlow et al., 1988).

In a review of the literature supporting the RH contribution to language comprehension, Beeman (1993) discusses the variety of neuropsychological methodology used to investigate this area, such as divided visual field studies, neuroimaging and electrophysiological techniques, studying split-brain and other brain-injured populations as well as healthy older adults, in order to understand language processes and the brain systems that subserve them (see also Kacinik and Chiarello, 2007).

Further support for the role of the RH in semantic activation comes from studies with healthy adults using the divided visual field methodology. When healthy adults were presented with category matching tasks, for example deciding if animal-animal, bird-bird, animal-bird, bird-animal word pairs are categorically matched, differences were found in the depth of activation across the hemispheres, with the LH showing rapid and focal activation and the RH slow and diffuse activation of semantic networks (Taylor, Brugger, Weniger, and Regard, 1999). In another study with healthy adults, Chiarello and colleagues (Chiarello, Lui, Shears, Quan and Kacinik, 2003) further demonstrated that the RH maintains the activation of alternative interpretations longer than the LH. Similarly, when presented with lateralised stimuli, event-related potentials (ERPs) show large responses over the RH especially after delay or when more complex decisions or inferences are required (Coulson and Van Petten, 2007). An experiment using ERPs to investigate the assumption that the LH is sensitive to sentential context whilst the RH is more sensitive to lexical context demonstrated that the LH and RH both use lexical and sentential context and that when both contexts are available sentential information is weighted more heavily. However, for the LH, lexical content is accessed only when sentential information is unobtainable (e.g. in incongruous sentences), while the RH always shows a preference for the use of sentential context, even when the sentence is nonsensical (Coulson, Federmeier, Van Petten and Kutas, 2005).

Van Lanker and Kempler (1987), using a picture-matching auditory comprehension task, compared comprehension of single words, familiar phrases (e.g. “she had him eating out of her hand”) and novel sentences in individuals with LHD, RHD and healthy control participants. For the single words, they did not find any significant differences between the groups. For the sentence stimuli, however, they found opposite response patterns; in particular, individuals with LHD performed better for familiar than novel phrases whilst for subjects with RHD the reverse was true. Based on these findings, the authors suggested that the RH has a special role in the comprehension of familiar speech. Wapner, Hamby and Gardner (1981) assessed sensitivity to narration and humorous material administered to participants with LHD, RHD and healthy controls. They found that elementary linguistic functioning was comparable across the three groups. However, individuals with RHD consistently demonstrated difficulties once the stimuli contained emotional content or non-canonical facts and when asked to judge plausibility of stories.

These findings, thus, demonstrate a special difficulty for individuals with RHD in processing complex linguistic structure and utilizing context in comprehension.

Beeman (1993) further suggested that adults with RHD are not only just limited to understanding literal interpretations but also draw incorrect inferences. Early research indicated that it is possible that inference disruption is due to poor recall and also that working memory could play a part. In a study investigating narrative comprehension, Hough (1990) demonstrated impaired theme identification in individuals with RHD when the central theme presentation was delayed to the end of paragraphs compared to when it was presented at the beginning. Individuals with damage to the anterior RH produced significantly more errors, such as embellishments and confabulations, possibly suggesting that individuals with RHD expand on information in a way that does not relate to the original narrative. Similarly, Brownell, Potter, Birhle and Gardner (1986), in a study testing the inferencing/reasoning ability of individuals with RHD, demonstrated difficulties in answering questions related to inferences, especially when the information was contained in the first of two presented sentences, pointing to difficulties in revising knowledge when new information counteracted it.

Research designed to investigate the relation between attention and word retrieval in individuals with aphasia, as well as individuals with RHD and healthy participants, suggested an alternative explanation for the communication difficulties in individuals who have suffered RHD (Murray, 2000). Participants were asked to complete phrases with one (appropriate) word in increasingly demanding attention conditions. In both brain-damaged groups, errors increased with increased attentional demands, suggesting that attentional impairment affects semantic and phonological word retrieval. Seeking to explore further whether impaired language understanding after brain damage could be explained by a deficit in cognitive resource allocation, Monetta, Hamel and Joanette (2001) replicated this study with healthy adults. They presented verbal decision stimuli with three levels of difficulty; phonological (presence of vocal sound, e.g. ‘O’), lexical (words vs. non-words) and semantic (category matching task). Stimuli were presented with one of three levels of interference to increase attentional demand: level 1 (isolation) had no interference; level 2 (focused) was the simultaneous presentation of auditory tones; and at level 3 (dual task) participants were to determine if tones were higher or lower than the previous one at the same time as completing the verbal task. Increased response times were observed for the dual-task, however these results were not uniform across participants and each participant developed a strategy for answering at this increased attentional demand. So, although the authors concluded that attentional demand did affect success at verbal task, they also noted considerable challenges for use of this method of exploration.

In another study, Gagnon, Goulet, Giroux and Joanette (2003) investigated the specific impairments of individuals with RHD when processing metaphoric meanings of single words. In the first task, word triads were presented to participants to test their preference for literal vs. metaphoric words and for dominant/metaphoric vs. non-metaphoric semantic relationships. In the second task, word-dyads were presented to test for detection of semantic relationships. Based on past results, the authors predicted that individuals with RHD would be impaired in their performance in identifying metaphoric meanings compared to those with LHD and healthy control groups. The findings showed that whilst both the LHD and RHD groups performed significantly poorly compared to healthy controls, there was no support for the hypothesis that the RH contributed to the processing of the metaphoric meaning of words as there was a lack of double dissociation between the two groups with brain damage. Monetta, Ouellet-Plamondon and Joanette (2006) extended further the study by Gagnon et al. (2003), testing only healthy adult participants, in order to explore the role of the RH in terms of cognitive resource allocation. Using a dual-task paradigm designed to limit cognitive resources, the authors hypothesised that healthy participants will exhibit patterns of performance similar to those of the individuals with RHD in Gagnon et al.’s (2003) study when asked to process metaphorical vs. non-metaphorical words. The findings supported their hypothesis as healthy participants chose significantly less metaphorical relationships when subjected to the dual-task paradigm, suggesting that metaphorical processing requires more cognitive resources and that damage to the RH seems to reduce the number of cognitive resources available for language comprehension.

Thus, in exploring the RH’s contributions to language, researchers have looked at a number of different areas including the role of discourse structure, inference and non-literal language, such as humour, sarcasm and metaphor. Neuroimaging studies with healthy individuals show increased activations in the RH as subjects attempt to establish a macrostructure or monitor thematic information when attempting to comprehend passages or conversation (e.g. see St. George et al., 1999 and Nichelli et al., 1995).  Research, therefore, suggests that when the RH is impaired, its ability to manipulate inferences is affected with suppression deficit or impaired maintenance of multiple inferences currently being posited as possible explanations (e.g. see Lehman-Blake and Lesniewicz, 2005; and Jung-Beeman, Bowden and Gernsbacher, 2000).

Evidence gathered thus far in this area of RH contribution to language understanding has given rise to two major and competing theories, outlined below, that propose to explain the difficulties identified.

### *“Suppression Deficit” hypothesis*

Tompkins and Lehman (1998) proposed that one part of the puzzle in understanding how RHD affects an individual’s discourse comprehension can be explained by the “suppression deficit” hypothesis. In considering findings from both their own studies with individuals with brain damage (BD) and building on Gernsbacher’s proposed suppression mechanism from cognitive psychology they made a number of observations about adults with RHD (Gernsbacher and Faust, 1991). Firstly, adults with RHD can use contextual cues in their interpretation of meaning as long as processing demands are limited. Secondly, and contrary to earlier studies, adults with RHD are in fact able to process and understand non-literal, emotional, prosodic and inferential cues in conditions where other demands are not placed on their cognitive resources; and finally, inferencing performance in situations of greater processing load covaries with patients’ with RHD working memory (WM) capacity (Tompkins, Bloise, Timko and Baumgaertner, 1994). These observations led Tompkins and Lehman (1998) to propose that observed discourse comprehension difficulties are in fact not due to adults with RHD losing the knowledge of semantic ambiguities. Instead, due to prolonged activation of inappropriate meanings and difficulties with memory and processing, adults with RHD struggle to find the appropriate interpretation or to adjust when inference revision is required. The premise of this hypothesis, thus, is that because of damage to the right hemisphere, multiple activations are not attenuated.

### *“Coarse Semantic Coding” hypothesis*

The second major hypothesis has its roots in Beeman’s work (1993 and 1998) with healthy individuals. It is based on the assumption that coarse coding (weak activation of large semantic fields) occurs in the RH whilst fine coding (strong activation of small semantic fields) occurs in the LH. Therefore, damage to the RH causes an over reliance on the LH in language comprehension and thus there will be difficulties in inference and deriving non-literal interpretations. This difference was directly observed in an experiment using the divided visual field methodology to explore what happens when participants are asked to make semantic relatedness judgements (Taylor, Brugger, Weniger and Regard, 1999). Results showed the LH rapidly and focally activating the semantic network whilst the RH activated more slowly and diffusely. Similarly, it was demonstrated that subjects show stronger semantic priming in the RH than the LH for target words that are distantly related to a preceding prime and stronger priming in the LH for target words closely related to a preceding prime (Chiarello, Liu, Shears, Quan and Kacinik, 2003). Jung-Beeman (2005) further extended his work on coarse semantic coding by considering the differences in the neural bases that support the differences in activations in either hemisphere. Jung-Beeman gathered evidence from a variety of different fields, including neuroanatomy, neuroimaging and neuropsychology, which demonstrated bilateral components of semantic processing. However, research using event-related potentials to measure summation-priming, designed to tap more directly into the semantic activation process, found no difference between visual fields and thus no hemispheric differences (Kandhadai and Federmeier, 2008).

Thus, an increasingly large volume of research carried out in the area of the RH's contributions to language processing is demonstrating difficulties in language comprehension generally and non-literal interpretations specifically. The next section will consider the processing of metaphors in more detail as they are the focus of this current research study.

## Metaphors

Words can be interpreted by their literal (denotative) meaning and also their non-literal (connotative) meaning (Brownell et al, 1984). These interpretations are thought to be not mutually exclusive and instead lie on a continuum that requires the listener to make inferences from the usage of the word within a sentential context. Certain adjectives seem to have both denotative and connotative meanings, for example 'deep' can be used to describe a distance from the surface and also, metaphorically, to refer to intellectual traits. When words are used connotatively as part of a sentence they form metaphors. A useful definition of metaphor can be taken from the Oxford Dictionary Online (2011):

- "A noun with 2 complimentary meanings,
- A figure of speech in which a word or phrase is applied to an object or action to which it is not literally applicable: when we speak of gene maps and gene mapping, we use a cartographic metaphor[mass noun], and also
- A thing regarded as representative or symbolic of something else: the amounts of money being lost by the company were enough to make it a **metaphor for** an industry that was teetering"

Glucksberg and Kaysar (1993) describe metaphors as an efficient way of providing information by using a vehicle as a prototype of an ad-hoc category that can then be applied to a topic. Ortony (1979) makes a useful distinction between metaphor and simile; metaphors are indirect comparisons, for example, “cigarettes are time bombs”, and similes are direct comparisons (also metaphorical), for example, “cigarettes are like time bombs”. Johns et al. (2008) provide the following example to explain this in more detail “Kenny is a pop-up ad whenever he’s around”. Here, Kenny is the topic while the vehicle is pop-up ad, a prototype of the category relating to surprising, unwanted and annoying things. Taken more literally this example means “Kenny is surprising, unwanted and annoying whenever he’s around”; the metaphor simply conveys this more efficiently.

There are two theoretical approaches that can be used to understand how metaphors are processed and understood (Blasko and Connine, 1993). Firstly the direct processing model that suggests that metaphors are processed directly from the information contained within the metaphor, without the need to first compute, understand and reject a literal meaning. Both Ortony (1979) and Glucksberg and Kaysar (1990) subscribe to this model. Using the example, ‘Simon is an elephant’, Ortony would say that the salient features of ‘large and lumbering’ from the vehicle “elephant” are applied to the topic “Simon”. Similarly, Glucksberg and Kaysar, using a categorisation model, would say that the topic “Simon” is temporarily assigned to the ad hoc category exemplified by the vehicle “elephant”, ‘things that are large and lumbering’. In contrast to these is the indirect processing approach to metaphor comprehension as typified by Searle’s 3-stage model (1979). Searle proposes that in order to process and understand a metaphor the listener must first attempt to interpret the metaphor literally and that the non-literal interpretation is only begun once this literal one is found to be nonsensical, either logically or contextually.

There are several factors that seem to influence the processing of metaphors. The first one is novelty/conventionality. Conventional metaphors are those which are commonly used in language and can be said to exist as discourse units in their own right (Glucksberg, 2001). A metaphor commonly used experimentally is that of ‘he had a heavy heart’ which has an accepted non-literal meaning to describe that someone feels sad. It is thought that because these metaphors are stored as discrete units, their processing is relatively automatic and relies heavily on accessing stored knowledge. In contrast to conventional ones, novel metaphors require the listener to consider and hold in mind alternative interpretations until an appropriate non-literal meaning is computed and selected. Novel metaphors are best described as being identical in form to conventional ones but using analogies that are new to the listener as in ‘Kenny is a pop-up ad’ described above (Johns et al., 2008).

Another factor shown to influence the processing of metaphors is plausibility (Miller, 1979). Some metaphors refer to images that are possible in the real world; for example, ‘kicking the bucket’ whilst metaphorically refers to dying is also a plausible action. In contrast, a metaphor such as ‘being on cloud nine’ (metaphorically referring to happiness) is not a possible action, outside of a cartoon world, and would be considered implausible.

It is also important to make the distinction between non-literal or figurative language used in ordinary, everyday communication such as conversation or newspapers and that which is used in poetry or other forms of creative writing as the later is much more specialist. Literary metaphors have been found to receive lower ratings on dimensions such as ease of interpretation and mental imagery; thus it may be that reduced performance in their interpretation is due to the qualities of the literary metaphor itself rather than due to non-literal language in general (Katz, Paivio, Marschark and Clark, 1988). This is an important consideration in this study which intends to explore how difficulties with non-literal language affect individuals in their everyday lives rather than in a philosophical sense.

Research on unilateral hemisphere damage has shown that non-literal interpretation can be a weakness in individuals with RHD. The assumption that the RH is specialised in interpreting metaphors dates back to the seminal study by Winner and Gardner in 1977, though it is acknowledged that this research is often misinterpreted (Giora, 2007). In their study, Winner and Gardner (1977) aimed to clarify the existing categorisation of the two hemispheres as ‘linguistic’ (left) and ‘aesthetic’ (right), and to determine the overall competence of healthy adults and patients with brain damage on a task in which a metaphoric sentence must be matched to its appropriate interpretation in a set of four pictures. The experimental stimuli consisted of 18 syntactically equivalent sentences containing simple metaphoric expressions, nine were psychological-physical metaphors (e.g., heavy heart) and the others were cross-sensory metaphors (e.g., colourful music). For each sentence, four coloured pictures were randomly ordered on a display board. The pictures represented one appropriate (metaphoric) meaning (e.g., crying person), one literal (e.g., person carrying heavy heart), one with an object whose salient quality was depicted by the adjective (e.g., 500lb weight), and one with a noun (e.g., a red heart). The findings revealed that individuals with LHD chose significantly more metaphoric pictures than the RHD group and that individuals with RHD chose significantly more literal pictures than the LHD group. Thus, Winner and Gardner (1977) concluded that the LH is dominant for literal language interpretation, but also stated that such dominance did not extend to more figurative uses of language. They held the view that metaphoric interpretation requires more cognitive operations than other language forms and examined metaphor interpretation within brain damaged individuals to explore the roles of the two hemispheres. Of note in Winner and Gardner's (1977) findings is that individuals with RHD were not as good as ones with LHD at choosing the correct pictorial representation of a metaphor. Nevertheless, they were able to give verbal explanations of metaphors whilst for individuals with LHD the reverse was true.

Brownell, Simpson, Bihrle, Potter and Gardner (1990) further investigated the hypothesis that individuals with RHD would not only show a deficit in identifying alternative word meanings but that this would also be more pronounced when metaphoric words compared to non-metaphoric words were used experimentally. In an un-timed sorting task involving the presentation of word-triads, participants with LHD and RHD were asked to choose the two words that were most similar in meaning. Target words were either polysemous adjectives with alternative metaphoric meanings (e.g., “warm” as “hot” and “loving”) or ambiguous nouns with alternative non-metaphoric meanings (e.g., “pen” as “a writing device” or “a cage”). Brownell et al. (1990) found that individuals with RHD demonstrated insensitivity to metaphoric alternative words suggesting a role for the RH in lexical-semantic processes related to metaphor comprehension.

Tompkins (1990) described a continuum of effort in information processing that could be applied to language understanding. This continuum ranges from rapid spreading activation, like a reflex and similar to associative network theories of learning and memory, to a slower mechanism that allocates limited attentional resources for input processing, such as imaging, organisation and rehearsal, in the processing of lexical metaphor. Tompkins suggested that this would allow for automatic activations to be built on, allowing flexibility in novel or inconsistent situations; for example memory relied on prior to damage vs. an ability to learn new processes after damage. This distinction between ‘on-line’ or automatic processing and ‘off-line’ or delayed processing is important in understanding the RH's role in the interpretation of language. In Tompkins' research (designed to assess the effects of RHD on the automatic activation and effortful processing of metaphoric and literal word meanings) brain damaged participants perform similarly, albeit more slowly, to healthy participants on auditory lexical relatedness decisions based on metaphoric or literal primes. Nevertheless, subjects with RHD tended to use denotative as opposed to connotative categories to group words while subjects with LHD showed the reverse pattern. Similarly, minimal correlations were found between participants with BD estimated WM capacity and discourse comprehension for non-demanding tasks (Tompkins, Bloise, Timko and Baumgaertner, 1994). Furthermore, subjects with RHD did not display a difference between the automatic and effortful processing conditions. Klepousniotou and Baum (2005a) also demonstrated no significant differences between participants with RHD, LHD and age matched controls for the processing of ambiguous words in the single-word level, especially homonymous and metonymous words. In their experiment, the metaphoric words generally only facilitated a dominant meaning suggesting that experiments at a single word level do not provide enough information to distinguish hemispheric differences in figurative language processing.

Experiments using metaphors in a sentential context help to explore the role for the RH in more detail. Blasko and Connine (1993) examined the comprehension of metaphors in healthy adults using metaphorical sentences with varying degrees of aptness and familiarity. They found that aptness of a metaphor, or how well the metaphor expresses its non-literal meaning, affected the availability of figurative meaning for low familiar or novel metaphors. They also explored priming effects induced by the topic and vehicle of the metaphor to the target word. For example, they used the metaphor "The old man was a history book", whereby the topic 'old man' is given the salient feature of 'containing lots of information' by the vehicle 'history book'. This priming metaphor would then be followed by a number of target words, e.g. 'wise' (metaphorical related); 'facts' (literal related); or 'imitated' (control word). Blasko and Connine (1993) found no such priming effects, suggesting that words within the metaphors did not cause lexical activation; instead the properties of the metaphor itself primed the target words.

The current research base does not allow us to fully understand the contribution of each hemisphere to metaphor appreciation. Studies using single lexical units (words) have not been able to fully capture differences in contribution between the hemispheres when it comes to metaphor processing. On the other hand, early studies that used pictures to represent metaphors, such as Winner and Gardner's (1977) work, appear to have complicated understanding possibly due to the different way images are processed and the deficits in neglect that individuals with RHD can typically show. It would appear therefore, that using sentences to explore metaphor processing would help to unravel the complex relation between automatic and effortful encoding, attention capacity and attentional allocation which appear to all interact and provide flexibility in novel situations.

### *Exploring metaphor processing using sentences*

A review of the evidence exploring the processing of metaphors within a sentential context reveals that researchers have conducted studies with young healthy adults as well as older healthy adults and individuals with BD. Some neuroimaging studies with young healthy participants found no support for a RH specificity for the interpretation of metaphors. For example, Rapp, Leube, Erb and Grodd et al. (2007) used event-related functional magnetic resonance imaging (fMRI) to investigate the processing of metaphoric sentences. Healthy young participants were required to judge metaphoric content and positive or negative connotation of metaphoric and literal sentences. The results found clear left laterality and only small group differences between the two tasks which the authors suggested indicated other factors than metaphoricity as triggering RH involvement. Similarly, Stringaris, Medford, Giampietro and Brammer et al. (2007), using fMRI methodology, designed an experiment in which healthy young participants were required to decide whether sentences made sense or not when presented with three types of sentences; metaphorical, literal and non-meaningful. Again they did not find support for a specific involvement for the RH in metaphor comprehension.

On the other hand, there are also neuroimaging studies with healthy young participants that have supported the RH involvement. For example, Marshal, Faust, Hendler and Jung-Beeman (2007) showed significant involvement of the RH when novel metaphor word pairs (e.g., pearl tears) were processed compared to conventional ones (e.g., bright student). Similarly, Bottini, Corcoran, Sterzi, and Paulesu et al., (1994) investigated the role of the RH in figurative language interpretation using positron emission tomography (PET). Six healthy young participants carried out three linguistic tasks; metaphor and literal comprehension of sentences and a lexical decision task.  The authors found extensive activation across areas of the LH during the lexical decision task and also in the comprehension of metaphors. However, during the metaphor task, a number of areas on the RH were similarly activated. Bottini et al. (1994) concluded that there were bilateral roles for the comprehension of language with the RH having a special role in the interpretation of figurative language. Schmidt, Debuse, and Seger (2007) carried out experiments using the divided visual field methodology to investigate hemispheric contributions to metaphor processing. The authors varied metaphorical and literal sentence familiarity and found a RH advantage (measured by reaction times) for unfamiliar sentences containing distant semantic relationships and a LH advantage for familiar sentences containing close semantic relationships regardless of whether the sentences were metaphorical or literal.

The studies reviewed above have used a mixture of methods (i.e., fMRI, PET and divided visual fields) making it difficult to compare results across them. Other studies have highlighted the increased effort and processing required for metaphoric compared to literal stimuli across both hemispheres using event-related brain potentials (ERP) (e.g., Lai, Curran and Menn, 2009; Coulson and Van Petten, 2002 and 2007; Coulson, Federmeier, Van Petten, and Kutas, 2005).

Few studies have been carried out with individuals who have suffered unilateral brain damage (BD) but one did demonstrate a selective problem for the subjects with RHD with figurative meanings (Klepousniotou and Baum, 2005b). In this study, participants with LHD, RHD and older healthy controls were compared in their ability to access the meaning of ambiguous words in a sentential context. The results for the subjects with LHD and control participants were largely similar with multiple meanings activated in the short inter-stimulus interval (ISI) condition and contextually appropriate ones at the long ISI condition. However, for the participants with RHD there were limited effects of context which did not change over time, demonstrating a selective impairment in the interpretation of figurative meanings.

Although functional imaging techniques, such as fMRI and PET, can highlight the neural networks involved in language processing in healthy adults, it is also possible that areas showing activation do so simply because of neural connections to regions required for a task (Rorden and Karnath, 2004). In contrast, studies carried out with individuals with BD allow determination of specific areas that are essential for specific tasks. Thus, complementary evidence from all these methods provides the richest of data to help us understand how the brain processes language.

## Research question and Experimental Hypotheses for Experiment 1

The current research study aims to explore further the impact of unilateral (left and right) brain damage on non-literal language understanding, specifically the processing of metaphors, by testing the predictions of two major hypotheses, the “suppression deficit” and “coarse semantic coding” hypotheses, posited to best explain the contribution of each hemisphere by comparing the performance of individuals with LHD, RHD and healthy aged matched controls.

The research uses literal, conventional and novel metaphoric sentences in auditory sentence priming semantic judgment tasks. The priming sentence is followed by a target word that is related, literally or metaphorically, or unrelated to the sentence prime. The two hypotheses lead to specific predictions described next and summarised in Table 1.

The key distinction underpinning the “coarse semantic coding” hypothesis is its suggested division of fine and coarse coding across the hemispheres such that if there is damage to the LH then fine coding (strong activation of small semantic fields) is compromised and conversely if there is damage to the RH then coarse coding (strong activation of large semantic fields) is compromised. This hypothesis is primarily based on data from healthy adults and divided visual field studies; so a number of assumptions are extrapolated for the impact of unilateral damage through stroke to the processing of sentences with metaphorical or literal meanings. Therefore, if an individual has damage to the right hemisphere this hypothesis suggests that there will be an over reliance on fine semantic coding in the LH so that their performance with novel metaphors will be impaired in comparison to non-brain damaged (NBD) individuals as it will be harder for them to identify the non-obvious, non-literal meaning. Their performance with conventional metaphors and literal sentences should be similar, if slower, to their non-brain damaged counterparts as long as memory for meanings is intact. If an individual has damage to the left hemisphere, this hypothesis suggests that there would be an over-reliance on the coarse semantic coding posited to be carried out in the intact RH. These individuals then should take longer to understand literal sentences and novel metaphors due to activation of large semantic fields and make more errors compared to NBD individuals. If they are relying on memory of word pairs/phrases then their performance on conventional metaphors should be similar, though slower, to NBD individuals as it is likely that the semantic meanings of conventional metaphors will be stored as discrete units. In the case of healthy individuals with no brain damage who have access to both fine and coarse coding it is suggested that literal sentences will be the easiest (fastest) to understand and that the metaphorical meaning of conventional metaphors will be faster than that of novel metaphors.

On the other hand, the key distinction underpinning the “suppression deficit” hypothesis is that, due to RHD causing prolonged activation of inappropriate meanings, multiple activations are not attenuated or suppressed. This allows for the following assumption to be made about the impact of unilateral damage to the understanding of sentences. For individuals with RHD, the multiple activations and attenuation deficit will lead to increased processing times for both types of metaphors, compared to NBD individuals and there is likely to be a greater number of errors made for novel metaphors. When the sentence has only one meaning, i.e. a literal sentence, then their performance should be similar to NBD individuals as suppression of meaning need not play a part. In contrast to the coarse semantic coding hypothesis, the suppression deficit hypothesis does not allocate a role for the left-hemisphere in understanding non-literal language therefore it could be assumed that individuals with LHD would perform similarly to NBD individuals. As NBD individuals would not be assumed to have processing difficulties within this hypothesis then it would predict similar processing patterns to that of the previous hypothesis.

| **Literal Sentences** | **Conventional metaphorical sentences** | **Novel metaphorical sentences** |
|---|---|---|
| **“Coarse Semantic Coding” hypothesis** | | |
| LHD – fine coding compromised so may take longer and make more mistakes than NBD | LHD - reliance on memory of word pairs/phrases. Should recognise metaphors as quickly as NBD | LHD - if only using coarse coding in RH then performance will be similar if slower than NBD |
| RHD- fine coding intact and as such should perform similar to NBD | RHD – reliance on fine coding in LH, could still recognise metaphors (if memory is intact) | RHD- using fine coding in the LH will find it more difficult to process novel metaphors and will be much slower than other groups |
| NBD* – both coarse and fine coding intact. At least as fast, if not quicker identification than conventional metaphor | NBD - both coarse and fine coding intact and able to bring memory into it. Quick identification of metaphor | NBD - both coarse and fine coding intact. Can process novel metaphor though slower than for conventional metaphor and literal sentences |
| **“Suppression Deficit” Hypothesis** | | |
| LHD – the hypothesis doesn’t make any specific predictions for LH, it could be extended to suggest intact processing but slower and more errors than NBD | LHD – as per literal sentences | LHD – as per literal sentences |
| RHD – attenuation deficit should not play a part in sentences with only one meaning, similar response to NBD | RHD- multiple activations, hampered by attenuation deficit. Could identify conventional metaphor but take longer to do so | RHD- multiple activations and attenuation deficit, could interpret as metaphor but likely to take longer and make more errors than other groups. |
| NBD – no processing difficulties; at least as fast, if not quicker processing than for conventional metaphor | NBD - able to attenuate semantic activation. Quick processing of metaphor | NBD - Longer processing time than for conventional metaphor due to additional complexity of novel metaphors |

*NBD refers to control participants with no brain damage

**Table 1: Summary of experimental predictions**

## Experiments 2 and 3

In light of difficulties in recruiting participants to Experiment 1, an innovative methodology has been investigated and used to good effect to develop the evidence discussed as part of this doctoral project.

Currently, a variety of non-invasive methods of brain stimulation are available for use by both investigative and clinical studies. These include transcranial magnetic stimulation (TMS), caloric vestibular stimulation (CVS) and transcranial direct current stimulation (tDCS). The last of these, tDCS, has been widely demonstrated as a safe, inexpensive means of modulating brain functions for research and clinical treatment (Fregni, Boggio, Lima, Ferreira, Wagner et al., 2006; Poreisz, Boros, Antal and Paulus, 2007;  Nitsche and Paulus, 2001).

### *Transcranial direct current stimulation (tDCS) and language studies*

Transcranial direct current stimulation, tDCS, is the delivery of weak polarising direct currents (<2 mA), either excitatory (anodal) or inhibitory (cathodal), to the cortex via electrodes placed on the scalp. A growing body of literature supports the enhancement of cognitive function by the use of tDCS in healthy subjects including higher motor functions, working memory, auditory memory and learning (Been, Ngo, Miller and Fitzgerald, 2007).

One of the earliest reports on the use of tDCS was in therapy with psychiatric patients in the 1960's with early experiments demonstrating change in affect which varied according to polarity and position of stimulation (Lippold and Redfaern, 1964).  It has only been since the start of this century that interest in demonstrating the functional use of tDCS has again become popular.  Most notable, is the use of tDCS to improve corticomotor excitability with both healthy adults and stroke sufferers for which the evidence is both plentiful and effectual (for review see Bastini and Jaberzadeh, 2012).

There is also the beginnings of an evidence base supporting the enhancement of language processes through the use of tDCS methods though the relationship between stimulation, excitatory or inhibitory, and the exact neurophysiological effects are still under investigation (Sparing, Dafotakis, Meister, Thirugnanasambandam and Fink, 2008). In fact, a recent meta-analysis of tDCS effects in cognitive domains (Jacobson, Koslowsky and Lavidor, 2012) investigated a number of differing effects of tDCS including the dual polarity, i.e. anodal-excitation and cathodal-inhibition effects, and those studies which seek to either excite or inhibit areas of interest in the brain. In total, the authors identified 34 cognitive studies using tDCS methods, eight of which focused on language.

In particular, in an early study, Iyer, Mattu, Grafman, Lomarev, Sato and Wassermann (2005) were aiming to identify the safe and effective levels of tDCS applied current required to affect letter-cued word generation. Over  three experiments carried out with healthy participants, they applied anodal, cathodal and sham stimulation measuring processing and psychomotor speed, emotions and verbal fluency using established measures and EEG, pre and post application of tDCS at both 1mA and 2mA. The sham condition is an established blinding condition (Gandiga, Hummel and Cohen, 2006). Since tDCS is usually felt only as a slight tingling under the electrodes during the first 30-60 seconds, the sham condition can be generated by switching off the current after 30 seconds of active stimulation which is not enough to affect cortical activity.  Iyer et al. (2005) established that there were no significant effects at 1mA but at 2mA verbal fluency improved significantly with anodal and decreased mildly with cathodal tDCS.

Cerruti and Schlaug (2008) building on the previous study assessed whether modulating excitability at the left dorsolateral prefrontal cortex could affect complex verbal abilities in healthy participants. They placed the reference electrode over the opposing supraorbital region. Using the remote associates test with 18 healthy adults, and a within subjects design, they showed a significant overall effect of stimulation condition, with anodal stimulation at 1mA demonstrating an increase in performance compared to cathodal or sham conditions.

Sparing et al. (2008) compared different stimulation configurations with fifteen healthy adults performing a picture naming task. The area of interest in this study was the left posterior perisylvian region (PPR), including Wernicke’s area. The experimental conditions were (1) anodal and (2) cathodal stimulation of the left hemisphere region and, for control, (3) anodal stimulation of the homologous region of the right hemisphere and (4) a sham condition. Initially they placed the reference electrode over the opposing supraorbital region as per previous studies. However this did not provide significant results and they moved it to Cz (a point on top of the skull). They found significant increases in reactions times of naming following anodal tDCS but, in contrast to other studies (Nitsche and Paulus, 2000; Nitsche, Seeber, Frommann, Klein, Rochford, Nitsche, et al., 2005) no significant influence of cathodal tDCS.

Floel, Rosser, Michka, Knecht and Breitenstein (2008) also stimulated the left PPR in order to explore language learning of a miniature lexicon with 19 young healthy adults. Each participant took part in 3 experimental sessions; one anodal tDCS, one cathodal tDCS and one sham session. In each case the reference electrode was placed over the opposing supraorbital region. By measuring both reaction time and accuracy for a vocabulary learning task they demonstrated that anodal stimulation increased accuracy compared to both cathodal and sham conditions; no differences for reaction times were found. They note the importance of further exploring the effects of cathodal tDCS within language studies to determine if its application to non-language-dominant (i.e. the right hemisphere in this case) causes changes in performance.

Effects of cathodal tDCS have been demonstrated with non-fluent aphasic patients. Monti, Cogiamanian, Marceglia, Ferrucci, Mameli et al. (2008) investigated the use of tDCS as a technique to improve functional recovery after stoke. They used a computer controlled picture task, before and after anodal tDCS, cathodal tDCS and a sham condition applied over the damaged left fronto-temporal area with eight participants with chronic non-fluent aphasia. For these experiments the reference electrode was placed on the right shoulder. They found that whilst anodal and sham tDCS failed to induce any changes, cathodal tDCS significantly improved the accuracy of picture naming. They tentatively attributed this effect to the tDCS reducing disinhibition of the damaged language area of the cerebral cortex.

Although few studies report the use of cathodal tDCS in its inhibitory form with healthy young adults, one of key importance to this project has been identified. Berryhill, Wencil, Coslett and Olson (2010), seeking to generalise their results on working memory studies with older adults, applied tDCS to the right inferior parietal cortex of 11 young healthy adults. Participants took part in three experimental conditions; anodal, cathodal and sham tDCS with the reference electrode on the left cheek. The results demonstrated that cathodal stimulation selectively impaired working memory on recognition tasks providing support for the authors existing data from participants with parietal lobe lesions.

Overall, then, although research findings using tDCS remain mixed, they generally support the use of anodal (excitatory) tDCS as a potential treatment option with those suffering from persistent language deficits following stroke; strong effects have also been shown with healthy young adults. Additionally, studies have demonstrated significant effects through the use of the cathodal (inhibitory) condition, depending on the area of cortex being stimulated. It is important to note the proviso that whilst tDCS may provide a mechanism for mimicking stroke-like effects in young healthy adults, the transient inhibition of a discrete area of the brain under experimental conditions is a different neurological experience compared to the potentially catastrophic implications of a real stroke.

Given the difficulties that can be experienced in recruiting participants with brain damage to studies due to their additional health complications relating to age and/or their lesions, it seems efficacious to be able to identify a method which could temporarily simulate lesions in healthy young adults. In fact, a large proportion of the evidence base discussed earlier has already been generated from healthy young adults, especially that in support of the coarse semantic coding hypothesis. The ability to study the effects of simulated stroke would allow researchers not only to generalise their findings to the wider population but also to understand more clearly the impact of stroke in specific cortical areas on cognitive processing, in this case the role that the right hemisphere plays in language understanding.

## Research question and Experimental Hypotheses for Experiment 2 and 3

The primary aim of using tDCS with healthy young adults in this project is to complement and extend the findings of Experiment 1. As such the results of Experiment 2 will inform the best methods to be used for this purpose.  It is designed to apply the same materials and procedure as Experiment 1 with healthy young adult participants with a view to establishing baseline performance for this new participant group.  In addition, it is necessary to identify if

ISI will show processing differences in young healthy adults so that the tDCS participants are not subjected to unnecessary experimental procedures in Experiment 3.

Experiment 3 is designed to use the tDCS technique with cathodal (inhibitory) stimulation to simulate stroke effects in young healthy adult participants to further explore right hemisphere contributions to language understanding. It is predicted that the application of cathodal (inhibitory) stimulation to the left hemisphere, in particular over Broca's area, of healthy young adults is unlikely to affect their processing of non-literal language, in this case metaphorical sentences. On the other hand, it is predicted that inhibiting the homologous area in the right-hemisphere should lead to disrupted language processing in line with previous research in patients with RHD.

The next sections will explain, in detail, the methodology employed in this study to explore the right hemisphere contribution to language understanding and the role of the dominant hypotheses posited to explain.

# METHOD

## Ethical clearance

Ethical approval was granted by NRES Committee North East - Northern and Yorkshire (Reference Number 11/NE/0159). Research and Development committees within the Leeds Teaching Hospitals and Leeds Community Hospitals Trusts also supported the research (Reference Numbers PY11/9909 and NP0083 respectively). Ethical approval was sought and granted from the Institute of Psychological Sciences at the University of Leeds for participants from outside NHS services (Certificate Number 11-0257). Copies of the Ethical Approvals can be found in Appendix 1. Additional ethical approval was sought for companion projects carried out with both healthy younger and older adults by undergraduate students from the University of Leeds to provide control data.

## Experiment One

### *Design*

A 2(ISI: 100ms, 1000ms) x 3(Sentence type: conventional metaphor, novel metaphor and literal sentence) x 3(Target type: literal related, metaphorical related and unrelated word) repeated measures design was utilised. The dependent variables were the reaction times and accuracy data for each condition.

### *Participants*

Two individuals with unilateral damage to the left hemisphere, seven with right hemisphere focal lesions and 20 healthy age matched individuals were successfully recruited. Demographic information for all participants is reported in Table 2. All participants were native English speakers and right handed (pre-morbidly) as classified on a handedness inventory (Briggs and Nebes, 1975). Patients with LHD were classified as non-fluent aphasic based on completion of the BDAE Short Version (Goodglass, Kaplan and Barresi, 2001). Healthy control participants had no history of neurological or speech-language disorders and were matched demographically as closely as possible with participants with brain damage (BD). Participants with BD had all suffered a single unilateral cerebrovascular accident. For the participants with damage to the left hemisphere one had experienced an ischemic (clot) stroke and the other a hemorrhagic (bleed) stroke. For the participants with damage to the right hemisphere five had experienced ischemic strokes and the remaining two participants had hemorrhagic strokes. While hemorrhagic strokes are less common than the ischemic type, they also have a higher mortality as they can be more difficult to locate and treat. Once survived however, hemorrhagic strokes can have better long-term prognosis due to the plasticity of the brain. In the case of ischemic strokes brain tissue is often irreparably damaged leading to significant disability (Andersen, Olsen, Dehlendorff and Kammersgaard, 2009). To exclude dementia and mild cognitive impairment, all participants completed the Montreal Cognitive Assessment, MoCA (Nasreddine, Philips, Bedirian, Charbonneau, Whitehead, et al., 2005); scores are reported in Table 2.

| **Group** | **LHD** | **RHD** | **NBD** |
|---|---|---|---|
| N | 2 | 7 | 20 |
| Age | 62yrs 7mos<br>±8yrs 9mos | 65 yrs 2mos<br>±12yrs 9mos | 65yrs 7mos<br>±6yrs 11mos |
| Gender | 2 male | 4 male, 3 female | 10 male,10 female |
| Age at leaving school (yrs) | 16.5 ± 0.71 | 15.43 ± 1.40 | 16.1 ± 1.40 |
| Time since CVA (in months) | 92.5 ± 76.87 | 73.6 ± 61.1 | N/A |
| Handedness (range -24 - +24) | 21.4 ± 4.24 | 21.42 ± 4.76 | 23.1 ± 1.83 |
| MoCA (Max 30) | 13 ± 0* | 26.86 ± 1.22 | 28 ± 1.49 |

*MoCA scoring requires verbal responses not possible in non-fluent aphasia

**Table 2: Demographics of LHD, RHD and BD participants (means and standard deviations)**

*Screening Tests*

All participants were given time to read the information sheet (see Appendix 3) and then signed an informed consent form, (see Appendix 2). Criteria for initial exclusion included the presence of multiple infarcts, a history of drug or alcohol abuse, or a history of psychiatric and/or neurological disorders. Brain-damaged patients were given a series of screening and diagnostic tests which differed (in part) across the groups.

Healthy participants were administered the following screening tests:

- Montreal Cognitive Assessment (MoCA) (Nasreddine, Phillips, Bédirian, Charbonneau, Whitehead, Collin, Cummings J, and Chertkow, 2005), (Appendix 4).
- Handedness Inventory (Briggs and Nebes, 1975), (Appendix 5).
- Auditory computerised lexical decision task (Klepousniotou and Baum, 2007).

BD participants were administered the following screening tests in addition to those listed above:

- Auditory Digit Span test (screening working memory for auditory presented stimuli), taken from the Wechsler Adult Intelligence Scale (Wechsler, 1997)(Appendix 6),
- Spoken Word-Picture Matching and Auditory Sentence Comprehension subtest from the Psycholinguistic Assessment of Language (Caplan, 1992) (to screen their speech and language skills)

Furthermore, patients with BD were administered the following screening tests which differed depending on the side of the lesion. In particular, participants with LHD were administered the Boston Diagnostic Aphasia Examination - Short Form (BDAE) (Goodglass, Kaplan and Barresi, 2001), while participants with RHD were administered a test battery adapted from the Test of Language Competence-Expanded Edition (Wiig and Secord, 1987) to test for their inferencing and figurative language abilities.

| **Group** | **Digit Span (14)** | **Max No of digits (8)** | **Auditory word picture matching (32)** | **Auditory sentence Comprehension (40)** | **Boston Naming Test (Short Version) (15)** | **TLC-E Inferencing language test (10)** | **TLC-E Figurative Language Test**** | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | **[a]Correct (10)** | ***Literal (10)** |
| RHD | 8.57 ±1.62 | 5.57 ±0.79 | 31.86 ±0.38 | 37.86 ±2.41 | 14.14 ±1.21 | 7.86 ±1.21 | [a]5.86 ±1.68 | *3.57 ±1.27 |
| LHD | 2 ±2.83 | 1.5 ±2.12 | 31.5 ± 0.71 | 30 ± 7.07 | 11.5 ±2.12 | N/A | N/A | N/A |

Maximum scores in brackets ( ), ** this test allows for 3 types of responses to each of the 10 items; correct, literal and incorrect

**Table 3: LHD and RHD Performance on screening tests (means and standard deviations)**

It was important to ensure that participants understood and could perform these tasks in order to engage in the experiments. No participants referred performed below or at chance levels in the screening tests and so none were excluded from the study. The screening tests took approximately 45 minutes and were completed in the first testing session. The BDAE – Short Form took an additional screening session for the LHD participants. Summary of the participants' performance on the screening tests appears in Table 3.

### *Materials*

Once screening was completed, all participants were presented with two experiments testing the processing of conventional and novel metaphors as well as literal sentences. In order to investigate both automatic and controlled processing of metaphors, two inter-stimulus intervals (ISI), a short (100 ms) and a long (1000 ms), were used across the two experiments. Time-course studies with non brain-damaged individuals as well as individuals with brain-damage have indicated that short interstimulus intervals (less than 200ms) evaluate 'on-line' or automatic processing, whereas longer interstimulus intervals (more than 500ms) evaluate 'off-line' or delayed processing (Swaab, Brown, and Hagoort, 2003; Klepousniotou and Baum, 2005b). Thus the short (100ms) and long (1000ms) interstimulus intervals (ISI) used within these experiments should allow the assessment of the types of processing and further the comparison of the two hypotheses being evaluated. Each experiment contained 30 literal, 30 conventional plausible and 30 novel plausible metaphoric sentence primes followed by a target word that was literal, metaphoric or unrelated to the sentence. Priming sentences and target words were recorded using the 'Audacity' programme (Audacity Team, 2008). All sentence primes were matched for length and syntactic complexity. Likewise, target words were matched for frequency, letter length and familiarity according to data from the MRC psycholinguistic database (Coltheart, 1981). Information regarding matching of sentence primes and target words is contained in Tables 4 to 7 where means and standard deviations are displayed. All stimuli were presented auditorily using headphones to avoid difficulties with neglect (known to be a problem with some individuals with RHD). E-Prime was used for stimulus presentation and recording of the participants' responses (Schneider, Eschman, and Zuccolotto, 2002). Filler sentences were added to the test materials to counterbalance related/unrelated responses to target words in order to avoid response bias for target type. These sentences were similar to the experimental sentence primes in length and syntactic complexity. Data from the filler sentences were removed prior to analysis.

| Conventional metaphors : No. of words per sentence = 7.77 ± 1.52 | | | | |
|---|---|---|---|---|
| | No. of letters | Kucera and Francis Written Frequency | Kucera and Francis No. of categories | Kucera and Francis No. of samples |
| Literal Related Target | 5.43 ±1.33 | 17.83 ±15.12 | 6.43 ±3.33 | 14.17 ±14.65 |
| Metaphorical related target | 6.00 ±1.36 | 20.20 ±21.85 | 6.57 ±4.34 | 15.90 ±15.83 |
| Unrelated target | 6.10 ±0.84 | 18.97 ±18.07 | 6.10 ±3.23 | 12.73 ±12.73 |

**Table 4: Detail of conventional metaphor stimuli**

| Novel metaphors : No. of words per sentence = 7.87 ± 1.96 | | | | |
|---|---|---|---|---|
| | No. of letters | Kucera and Francis Written Frequency | Kucera and Francis No. of categories | Kucera and Francis No. of samples |
| Literal Related Target | 5.70 ±1.70 | 16.13 ±17.46 | 5.60 ±3.96 | 10.13 ±10.10 |
| Metaphorical related target | 5.53 ±1.25 | 16.53 ±18.28 | 6.40 ±4.05 | 12.73 ±13.62 |
| Unrelated target | 5.57 ±1.01 | 15.40 ±17.17 | 5.50 ±3.87 | 11.40 ±12.48 |

**Table 5: Detail of novel metaphor stimuli**

| Literal sentences : No. of words per sentence = 7.23 ± 1.38 | | | | |
|---|---|---|---|---|
| | No. of letters | Kucera and Francis Written Frequency | Kucera and Francis No. of categories | Kucera and Francis No. of samples |
| Literal Related Target | 5.30 ±1.18 | 20.07 ±17.41 | 6.50 ±3.14 | 14.40 ±11.83 |
| Unrelated target A | 5.15 ±0.07 | 19.83 ±15.73 | 6.70 ±3.08 | 13.03 ±8.85 |
| Unrelated target B | 5.50 ±1.14 | 19.83 ±15.73 | 6.87 ±3.28 | 14.03 ±10.06 |

**Table 6: Detail of literal sentence stimuli**

| Filler sentences : No. of words per sentence = 7.37 ± 1.00 | | | | |
|---|---|---|---|---|
| | No. of letters | Kucera and Francis Written Frequency | Kucera and Francis No. of categories | Kucera and Francis No. of samples |
| Unrelated target | 5.53 ±1.53 | 19.63 ±15.09 | 6.97 ±3.58 | 14.27 ±10.61 |

**Table 7: Detail of filler sentence stimuli**

Table 8 below contains a brief selection of examples of the sentence primes with their target word triads (see Appendix 7 for complete sets).

*Procedure*

Participants were required to judge whether the target word was related or unrelated to the priming sentence by pressing the designated yes/no button on a computer mouse. Stimuli were presented in pseudo-random order ensuring that no more than three of the same type, either sentence or target, occurred consecutively. Reaction times and accuracy rates were measured. Participants were given practice items prior to the experimental stimuli in order to ensure that the volume was suitable, that they understood the task and were able to complete the experiments. Most participants completed the whole procedure in three sessions which occurred one week apart. However, for some participants more sessions were required as time was adjusted according their level of fatigue. Order of experiment presentation was counterbalanced to avoid order effects.

| **Conventional Metaphors** | **Literal related target** | **Metaphorical related target** | **Unrelated target** |
|---|---|---|---|
| The man's face looked as white as a sheet | Linen | Ashen | Banana |
| Helen had green fingers in her garden | Stain | Adept | Symptom |
| The laser printer ate the paper | Food | Ripped | Coarse |
| **Novel metaphors** | | | |
| The newly wed's heart was a lovebird's egg | Shell | Fragile | Compose |
| The stubborn old man was a tram | Transport | Rigid | Cannon |
| The therapist helped the patient reach shore | Travel | Solution | Circle |
| **Literal Sentences** | **Literal related target** | **Unrelated target 1** | **Unrelated target 2** |
| The boy used a plastic bag as a rain hat | Protect | Arrive | Seized |
| The hairdresser styled Jane's hair | Clean | China | League |
| The athlete usually swims for two hours | Muscle | Spoken | Belong |

**Table 8: Examples of experimental stimuli**

## Experiment Two

### *Design*

A 2(ISI: 100ms, 1000ms) x 3(Sentence type: conventional metaphor, novel metaphor and literal sentence) x 3(Target type: literal related, metaphorical related and unrelated word) repeated measures design was utilised. The dependent variables were the reaction times and accuracy data for each condition.

### *Participants*

20 healthy young individuals were recruited for an undergraduate project in the Institute of Psychological Sciences (details in Table 9 below). All participants were native English speakers and right handed as classified on a handedness inventory, (Briggs and Nebes, 1975) and had no neurological, psychological or language disorders.

| **Group** | **Experiment 2 participants** |
|---|---|
| N | 20 |
| Age | 21 yrs ± 1yr 1 month |
| Gender | 10 male, 10 female |
| Handedness (range -24 - +24) | 20.35 ± 3.6 |

**Table 9: Demographics of healthy young adults in Experiment 2 (means and standard deviations)**

### *Materials*

All materials used were the same as in Experiment 1 above.

### *Procedure*

All healthy young participants participated in the same experimental procedure as in the previous study. As in Experiment 1, participants were required to judge whether the target word was related or un-related to the priming sentence by pressing the designated yes/no button on a computer mouse. Reaction times and accuracy rates were measured. Participants were given practice items prior to the experimental stimuli in order to ensure that the volume was suitable and that they understood the task. The whole procedure was completed in two sessions held one week apart.

## Experiment Three

### *Design*

A 2(Condition: Sham-tDCS, Stimulation-tDCS) x 3(Sentence type: conventional metaphor, novel metaphor and literal sentence) x 3(Target type: literal related, metaphorical related and unrelated word) repeated measures design was utilised. The dependent variables were the reaction times and accuracy data for each condition.

### *Participants*

12 healthy young individuals, age matched with Experiment Two participants (details in Table 10 below), were recruited to take part in an experiment in which stroke like effects were simulated using transcranial direct current stimulation (tDCS). All participants were native English speakers and right handed as classified on a handedness inventory (Briggs and Nebes, 1975) and had no neurological, psychological or language disorders.

| **Group** | **RH Simulated stroke** | **LH simulated stroke** |
|---|---|---|
| N | 6 | 6 |
| Age | 25 yrs 11mos<br>± 4yrs 2mos | 23yrs 5mos<br>± 3yrs 11mos |
| Gender | 2 male, 4 female | 1 male, 5 female |
| Handedness (range -24 - +24) | 21.67 ± 3.50 | 21.83 ± 2.40 |

**Table 10: Demographics of healthy young adults in Experiment 3 (means and standard deviations)**

### *Materials*

All materials used were the same as in Experiment 1 above.

### *Procedure*

All healthy young participants participated in the same experimental procedure as in Experiments 1 and 2. Participants received the 100ms ISI condition twice, one session with stimulation Cathodal-tDCS and one a sham condition, Sham-tDCS. These were delivered one week apart and the order of stimulation/sham was counterbalanced between groups.

Transcranial direct current stimulation (tDCS) was delivered by a battery driven, constant current stimulator (Magstim GmbH, Ilmenau, Germany) using a pair of surface saline-soaked sponge electrodes (5 cm × 5 cm). A constant current of 1500μA intensity was applied for the duration of the experiment with a maximum time per session of 30 minutes. During Sham-tDCS the stimulator 'ramped up' to the same current and switched off after 30 seconds thus ensuring the participant felt the same, if any, effect in the stimulation and sham experimental conditions. No participants were able to correctly judge which experimental condition they received when asked at the end of the experiments. Two different electrode montages were used: the cathode electrode was placed over F7 of the extended International 10–20 system for EEG electrode placement, in the left hemisphere (LH) simulated stroke condition. This site has been shown to correspond best with the location of Broca's area (Cattaneo, Pisoni and Pagagno, 2011; de Vries, Barth, Maiworm, Knecht, Zwisterlood and Floel, 2009) and was designed to simulate 'stroke-like' effects similar to the participants with LHD and non-fluent aphasia from Experiment 1. The homologous area of the right hemisphere was inhibited over F8 in the right-hemisphere (RH) simulated-stroke condition. The anode electrode was placed on the participants' forehead at the opposing side to the cathode. Participants were randomly allocated to LH or RH conditions and then randomly allocated Stimulation-tDCS or Sham-tDCS in the first session and received the corresponding condition in the second session which took place one week later.

As in Experiment 1 participants were required to judge whether the target word was related or un-related to the priming sentence by pressing the designated yes/no button on a computer mouse. Reaction times and accuracy rates were measured. Participants were given practice items prior to the experimental stimuli in order to ensure that the volume was suitable and that they understood the task. The whole procedure was completed in two sessions.

The next section details and summarises the results of Experiments 1, 2, and 3.

# RESULTS

## Experiment 1

Error rates were examined first. For each participant, error rates were calculated separately for each inter-stimulus interval (ISI) condition. A cutoff accuracy rate of 60% per list was used, so that the data of any participant who made more than 40% errors in a single list would be removed from further analysis. No participant reached the cutoff point for any of the lists. Thus, the data of all the lists were used in the statistical analyses. Prior to statistical analysis, errors and outliers (±2 SD from each participant's mean per condition) were removed. Data were then subjected to a 2(ISI: 100ms, 1000ms) x 3(Sentence type: conventional metaphor, novel metaphor and literal sentence) x 3(Target type: literal related, metaphorical related and unrelated word) repeated measures ANOVA for participants (F1) and items (F2) for each participant group separately. The process was repeated for both reaction time (RT) and accuracy (ACC) data. All significant main and interaction effects were explored further using the Newman-Keuls ($p<.05$) post-hoc tests.

### *Non-brain damaged older healthy control participants*

For the non-brain damaged older healthy control (NBD) participants, errors and outliers (±2 *SD*) comprised 17.1% and 3.6%, respectively, of the data for the short ISI (100 ms) and 15.8% and 3.7% for the long (1000ms) ISI.

### Reaction Time ANOVA

The ISI (100ms, 1000ms) x Sentence type (conventional metaphor, novel metaphor, literal sentence) x Target type (literal related, metaphorical related, unrelated word) ANOVA carried out with reaction time (RT) data revealed significant main effects of Sentence type [$F1(2,38)=6.67$, $p<.01$; $F2(2,522)=4.97$, $p<.01$] and Target type [$F1(2,38)=7.91$, $p<.01$; $F2(2,522)=15.41$, $p<.0001$], as well as a significant interaction of Sentence type x Target type [$F1(4,76)=6.6$, $p<.001$; $F2(4, 522)=7.68$, $p<.0001$]. In addition, the three-way interaction of ISI x Sentence type x Target type was also approaching significance (for participants) [$F1(4,76)=2.2$, $p=.077$; $F2(4,522)=0.95$, $p=.43$]. Figure 1 displays mean reaction times with standard error bars for each ISI, 100ms and 1000ms, for this participant group.

Post-hoc comparisons using the Newman-Keuls test ($p <.05$) to further explore all significant main and interaction effects revealed differences of interest as follows. For sentence type, conventional metaphors did not differ from literal sentences in RT. However, both types were significantly faster than novel metaphors (p<.05 and p<.01 respectively). When looking at target type, related targets were significantly faster than unrelated ones (p<.01). Interactions between Sentence type and Target type can be further quantified by looking at the ISI x Sentence type x Target type as reaction times for targets differ depending on sentence context and ISI. At the short ISI (100 ms), for conventional metaphors, metaphorical related targets were faster than literal ones and both were faster than unrelated ones (all p<.05). At the longer ISI (1000ms) these effects were strengthened with metaphorical related targets being faster than literal related (p<.01) and unrelated targets (p<.001), while literal related targets only showed a trend at being faster than unrelated targets (p=.06). For novel metaphors at the short (100ms) ISI, both literal and metaphorical related targets were significantly faster than unrelated ones (p<.001) with literal targets being numerically faster than metaphorical ones. At the long ISI (1000ms), although related targets remained faster than unrelated ones (p<.001), metaphorical targets were numerically faster than literal ones, reversing the order of the effects. In literal sentences, related target words were significantly faster than unrelated ones (p<.001) and this effect remained unchanged across both ISIs.

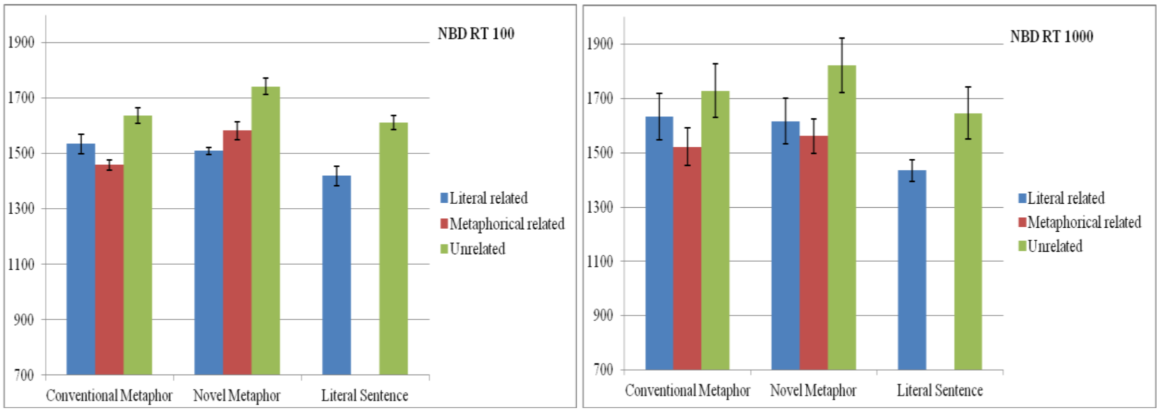


**Figure 1: Mean reaction time data (with standard error) for non-brain damaged older healthy control (NBD) participants at both ISIs**

Accuracy ANOVA

The ISI (100ms, 1000ms) x Sentence type (conventional metaphor, novel metaphor, literal sentence) x Target type (literal related, metaphorical related, unrelated word) ANOVA carried out with accuracy (ACC) data revealed significant main effects of Sentence type [*F*1(2,38)=11.92, *p*<.001; *F*2(2,522)=6.18, *p*<.01] and Target type [*F*1(2,38)=12.3, *p*<.001; *F*2(2,522)=21.7, *p*<.0001], as well as a significant interaction of Sentence type x Target type [*F*1(4,76)=10.67, *p*<.0001; *F*2(4, 522)=5.48, *p*<.001]. Similar to the RT ANOVA, the three way interaction of ISI x Sentence type x Target type was approaching significance (for participants) [*F*1(4,76)=2.32, *p*=.064; *F*2(4,522)=0.53, *p*=.71]. Figure 2 displays mean percentage distribution of errors with standard error bars for each ISI, 100ms and 1000ms, for this participant group.

Post-hoc comparisons using the Newman-Keuls test (p<.05) revealed that for sentence type, participants made significantly less errors on literal sentences (p<.001) than they did on both conventional and novel metaphors. For target type, participants made significantly more errors on literal targets than metaphorical ones (p<.01) and significantly more errors on metaphorical targets than unrelated ones (p<.05). Interactions between Sentence type and Target type can be further quantified by looking at the ISI x Sentence type x Target type as accuracy for targets again differed according to sentence context and ISI. Looking at the accuracy with conventional metaphorical sentences, there were no differences between metaphorical and unrelated targets while literal related targets generated significantly more errors (p<.001). This pattern of errors was observed at both ISIs. In considering novel metaphorical sentences at the short (100ms) ISI, there were significantly more errors on metaphorical targets compared to literal ones (p<.001). There were also numerically more errors on literal targets compared to unrelated ones and this difference approached significance (p=.07). This pattern was strengthened at the long (1000ms) ISI with the numerical difference between literal targets and unrelated ones becoming significant (p<.001). In literal sentences significantly more errors were made with literal related targets than with unrelated ones at both ISIs (p<.001).

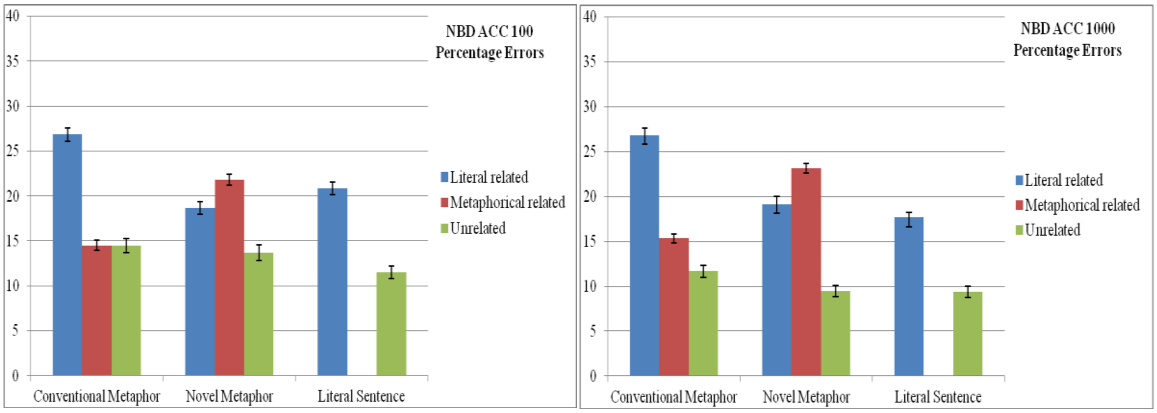


**Figure 2: Mean percentage distribution of errors (with standard error) for non-brain damaged older healthy control (NBD) participants at both ISIs**

### *Right Hemisphere Damaged participants*

For the participants with Right Hemisphere Damage (RHD), errors and outliers (±2 SD) comprised 17.3% and 3.8%, respectively, of the data for the short ISI (100 ms) and 17.1% and 3.5% for the long (1000ms) ISI.

#### Reaction Times ANOVA

The ISI (100ms, 1000ms) x Sentence type (conventional metaphor, novel metaphor, literal sentence) x Target type (literal related, metaphorical related, unrelated word) ANOVA carried out with reaction time (RT) data revealed only a significant main effect of Sentence type [$F1(2,12)=4$, $p<.05$; $F2(2,522)=16.73$, $p<.0001$], indicating that for RHD participants ISI did not play a role in processing. Figure 3 displays mean reaction times with standard error bars for each ISI, 100ms and 1000ms, for this participant group.

Post-hoc comparisons using the Newman-Keuls test ($p<.05$) to further explore the significant main effect of sentence type showed that literal sentences were processed significantly faster than novel metaphorical ($p<.05$) and conventional metaphorical sentences ($p=.057$) which did not differ from each other ($p=.57$). Thus, for RHD participants, metaphorical sentences in general (both conventional and novel) were harder to process than literal sentences, unlike NBD participants who showed similar processing for conventional metaphorical and literal sentences.

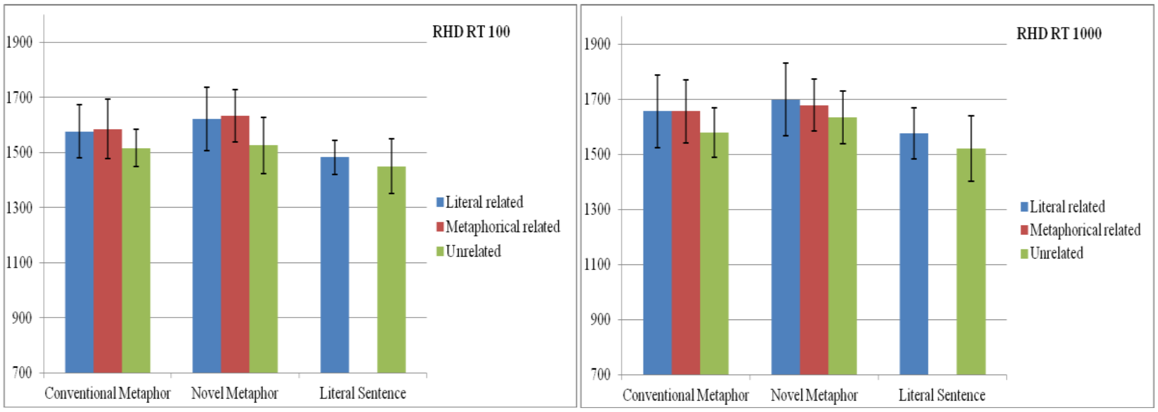


**Figure 3: Mean reaction time data (with standard error) for right-hemisphere damaged (RHD) participants at both ISIs**

Accuracy ANOVA

The ISI (100ms, 1000ms) x Sentence type (conventional metaphor, novel metaphor, literal sentence) x Target type (literal related, metaphorical related, unrelated word) ANOVA carried out with accuracy (ACC) data revealed significant main effects of Sentence type [$F1(2,12)=27.68$, $p<.0001$; $F2(2,522)=29.11$, $p<.0001$] and Target type [$F1(2,12)=10.83$, $p<.01$; $F2(2,522)=50.69$, $p<.0001$], as well as a significant two-way interaction of Sentence type x Target type [$F1(4,24)=16.41$, $p<.0001$; $F2(4, 522)=14.64$, $p<.0001$]. Again there were no effects of ISI, indicating that processing for RHD participants was similar across the two ISIs. Figure 4 displays mean percentage distribution of errors with standard error bars for each ISI, 100ms and 1000ms for this participant group.

Post-hoc comparisons using the Newman-Keuls test ($p<.05$) to further explore all significant effects revealed differences of interest as follows. For sentence type, the accuracy rate for conventional and novel metaphors was identical and for both was significantly less than literal sentences ($p<.001$). For target type, participants made significantly less errors for unrelated targets than both literal related and metaphorical related ones ($p<.01$). When the interaction between sentence type and target type was considered, it was observed that for conventional metaphors, significantly more errors were made on literal related targets than on metaphorical ones ($p<.01$); furthermore, unrelated target errors were significantly less than both related types ($p<.001$). For novel metaphorical sentences, this pattern was reversed with significantly more errors being made with metaphorical targets compared to literal ones ($p<.01$). Again, errors to unrelated targets were significantly fewer than both related types ($p<.001$). In literal sentences, significantly more errors were made with literal related targets than with unrelated ones ($p<.05$).

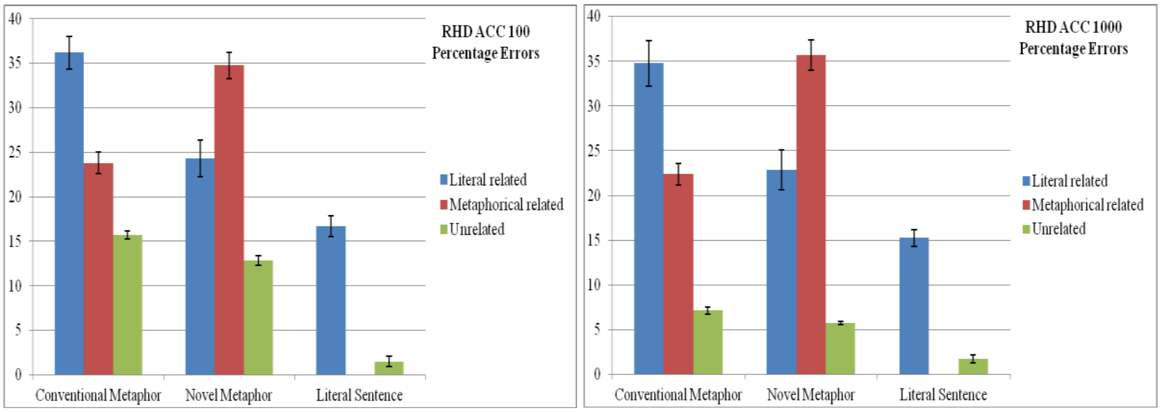


**Figure 4: Mean percentage distribution of errors (with standard error) for right-hemisphere damaged (RHD) participants at both ISIs**

### *Left Hemisphere Damaged participants*

For the participants with Left Hemisphere Damage (LHD) and non-fluent aphasia, errors and outliers (±2 SD) comprised 41.1% and 2.2%, respectively, of the data for the short ISI (100 ms) and 35.4% and 1.7% for the long (1000ms) ISI.

Single case study analysis

As identified in the Method Chapter the project had a paucity of referrals and this is apparent by the unfortunate low numbers within this section. However, single case study analysis was used to good effect to analyse, in part, the data from these participants. Initially, a matched control sample approach was used whereby the participants' data was converted to Z scores based on the mean and SD of the non-brain damaged control sample in order to check for qualitative differences between the left hemisphere damaged participants and the control sample (Crawford, Garthwaite, and Porter, 2010). In order to control for the possibility of increasing type 1 errors and overestimating the abnormality of the participants' scores an upgraded version of the Crawford and Garthwaite programme, using Bayesian methods, was used for this purpose (Crawford and Garthwaite, 2007). Following convention, *Z*-scores of over 2 were considered as significantly different from the control sample mean (Moulin, Conway, Thompson, James and Jones, 2005). A separate *Z*-score was calculated for each participant's scores on both sentence and target type reaction times and accuracy at each ISI presentation allowing comparison between that participant and the control sample mean. Full results are included in Appendix 8; as anticipated, overall, this analysis demonstrated that for metaphorical and literal sentences and targets the left hemisphere damaged participants largely took significantly longer and made significantly more errors than their matched control counterparts, while these differences were attenuated for unrelated targets.

Having established a qualitative difference between the left hemisphere damaged participants and the older non-brain damaged control sample, such that, as anticipated, LHD non-fluent aphasic participants take longer and make more errors, it is useful to carry out a tentative ANOVA looking at the interactions as these are of key importance for the present study. Visual inspection of the data confirms that non-fluent aphasic left hemisphere damaged individuals maintain the patterns of interactions of their non-brain damaged counterparts. Thus, with the caveat that the small sample size is clearly noted, a 2(ISI: 100ms, 1000ms) x 3(Sentence type: conventional metaphor, novel metaphor and literal sentence) x 3(Target type: literal related, metaphorical related and unrelated word) repeated measures ANOVA was conducted with both reaction time and accuracy data as per previous participant groups.

Reaction Times ANOVA

The ISI (100ms, 1000ms) x Sentence type (conventional metaphor, novel metaphor, literal sentence) x Target type (literal related, metaphorical related, unrelated word) ANOVA carried out with reaction time (RT) data revealed no significant main or interaction effects. Figure 5 displays mean reaction times with standard error bars for each ISI, 100ms and 1000ms, for this participant group*.

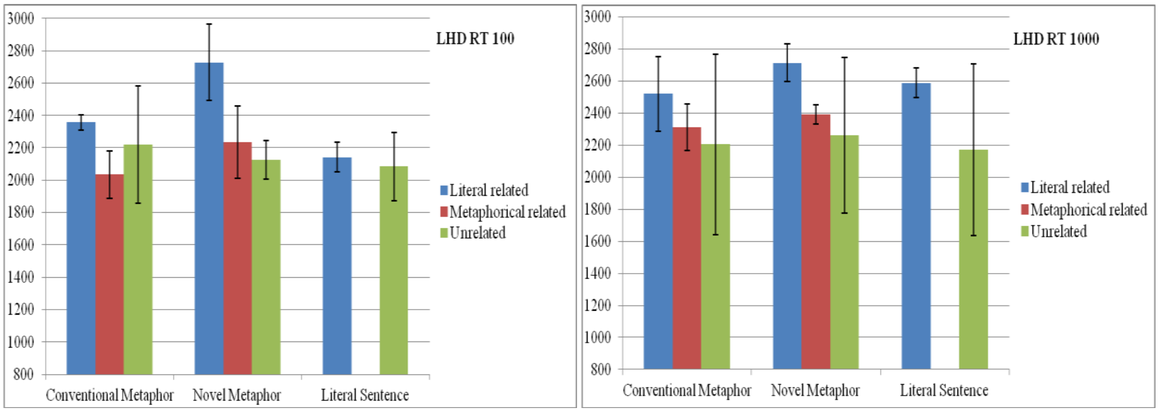


**Figure 5: Mean reaction time data (with standard error) for left-hemisphere damaged (LHD) participants at both ISIs**

*N.B. Scale is different from all other RT graphs due to significant increase in RT for this group.

Accuracy ANOVA

The ISI (100ms, 1000ms) x Sentence type (conventional metaphor, novel metaphor, literal sentence) x Target type (literal related, metaphorical related, unrelated word) ANOVA carried out with accuracy (ACC) data revealed marginally significant interactions effects of ISI x Target type [*F*1(2,2)=9.57, *p*<.095; *F*2(2,522)=1.26, *p*=.285] and ISI x Sentence type x Target type [*F*1(4,4)=5.64, *p*=.061; *F*2(4,522)=1.46, *p*=.214]. Figure 6 displays mean percentage distribution of errors with standard error bars for each ISI, 100ms and 1000ms, for this participant group.

Post-hoc comparisons using the Newman-Keuls test (p<.05) to further explore the significant ISI x Target interaction revealed that at the short (100ms) ISI, significantly more errors were made with literal related targets than metaphorical ones (p<.05) and both had more errors than unrelated targets (p<.05). At the long ISI (1000ms), literal related targets had significantly more errors than both metaphorical and unrelated ones (p<.05) which did not differ from each other (p=.58). These effects were further quantified by the significant ISI x Sentence type x Target type interaction. In particular, for conventional metaphors at the short ISI (100ms), there were more errors with literal related targets than metaphorical ones (p=.063) which in turn had significantly more errors than unrelated ones (p<.05); at the longer ISI (1000ms), both literal and unrelated targets had more errors than metaphorical ones (p<.01 and p<.05). For novel metaphors, at the short ISI (100ms) numerically more errors were made with metaphorical targets than literal ones which in turn had more errors than unrelated ones, though these differences were not significant. At the longer ISI (1000ms) participants made numerically more errors for literal related targets than metaphorical ones. Both types of related targets continued to have more errors than unrelated ones and this was significant for the relationship between literal related and unrelated targets (p<.05). For literal sentences, more errors were made with literal related targets than unrelated targets; this relationship though numerically different at both ISIs approached significance only at the short (100ms) ISI (p=.084).

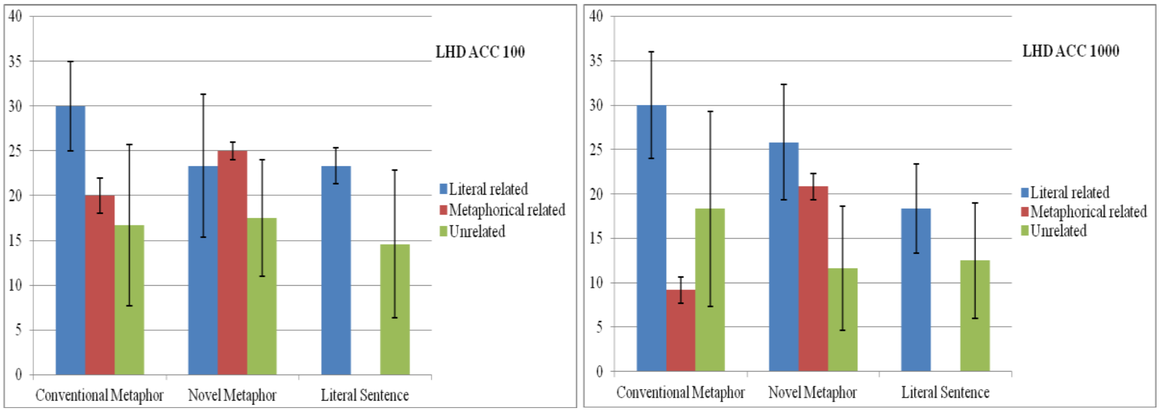


**Figure 6: Mean percentage distribution of errors (with standard error) for left-hemisphere damaged (LHD) participants at both ISIs**

*Experiment 1 Summary*

Overall, then, the findings of Experiment 1 indicated that for non-brain damaged older control participants, processing times for conventional metaphors and literal sentences did not differ. Novel metaphors were harder to process as evidenced by the longer reaction times; in addition, ISI played a role in processing such that at the short ISI metaphorical targets were slower than literal ones while at the long ISI they were faster, i.e. the pattern was reversed. In terms of accuracy, these participants showed a preference for the metaphorical target in conventional metaphors and the literal target in novel metaphors, while overall responses to unrelated targets were more accurate. On the other hand, RHD participants found both conventional and novel metaphorical sentences significantly harder to process than literal sentences. In terms of accuracy, nevertheless, RHD patients did show preference for metaphorical targets following conventional metaphors but literal targets following novel metaphor primes indicating that, at some level, differences in metaphoricity (i.e., conventional vs. novel) did play a role. However, no effects of ISI were observed for RHD participants indicating that for this population ISI did not play a role in processing. Finally, tentative analysis of the data from the non-fluent aphasic left-hemisphere damaged participants showed that they maintained processing patterns similar to those of the non-brain damaged control group (despite largely taking longer overall) and that their post-stroke language impairment did not appear to affect a single aspect of their performance.

## Experiment 2

Before administering the tDCS study in Experiment 3, baseline performance with young healthy adults needed to be established using the same materials and procedure as in Experiment 1. In addition, it was important to identify which ISI showed optimum processing in young healthy adults so that tDCS participants were not subjected to unnecessary experimental procedures. Experiment 2 was designed to address these issues.

Error rates were examined first. For each participant, error rates were calculated separately for each ISI condition. As in experiment 1, a cutoff accuracy rate of 60% per list was used, so that the data of any participant who made more than 40% errors in a single list would be removed from further analysis. No participant reached the cutoff point for any of the lists. Thus, the data of all the lists were used in the statistical analyses. Prior to statistical analysis, errors and outliers (±2 SD from each participant's mean per condition) were removed.

In order to capture the optimum paradigm for Experiment 3, data were analyzed separately for each ISI and were subjected to a 3(Sentence type: conventional metaphor, novel metaphor and literal sentence) x 3(Target type: literal related, metaphorical related and unrelated word) repeated measures ANOVA for participants (F1) and items (F2) for reaction time and accuracy rates separately. All significant main and interaction effects were explored further using the Newman-Keuls ($p<.05$) post-hoc tests.

For the healthy young participants errors and outliers (±2 SD) comprised 13.9% and 3.9%, respectively, of the data for the short ISI (100 ms) and 15.1% and 3.9% for the long (1000ms) ISI.

### *Short (100ms) ISI*

Figure 7 is a graphical display of means of reaction time and percentage distribution of errors data (with standard errors) for young healthy participants at the short ISI (100ms)

### Reaction Time ANOVA

For the short (100ms) ISI a Sentence type (conventional metaphor, novel metaphor, literal sentence) x Target type (literal related, metaphorical related, unrelated word) ANOVA carried out with reaction time (RT) data revealed significant main effects of Sentence type [$F1(2,38)=6.89$, $p<.01$; $F2(2,261)=2.58$, $p=.078$], Target type [$F1(2,38)=3.64$, $p<.05$; $F2(2,261)=1.60$, $p=.20$], as well as a significant interaction of Sentence type x Target type [$F1(4,76)=2.58$, $p<.05$; $F2(4, 261)=1.16$, $p=.33$].

Post hoc comparisons using the Newman-Keuls test ($p<.05$) to further explore all significant effects revealed that for sentence type, conventional metaphorical sentences and literal sentences were significantly faster than novel metaphorical ones (both $p<.01$). For target types, unrelated targets took significantly longer than both types of related ones (both $p<.05$) which did not differ from each other. When the interaction between sentence type and target type was considered for conventional metaphors, there were no significant differences between the different target words; literal and metaphorical related target words had similar RT and unrelated ones took numerically longer. In the case of literal sentences there were no significant differences between related and unrelated target words either though overall, unrelated words were numerically faster. For novel metaphorical sentences, literal related targets were processed significantly faster than unrelated ones ($p<.01$), while there was also a trend for metaphorical related targets to be faster than unrelated ones too ($p=.09$); literal related targets were also numerically faster than metaphorical ones though this difference was not significant.

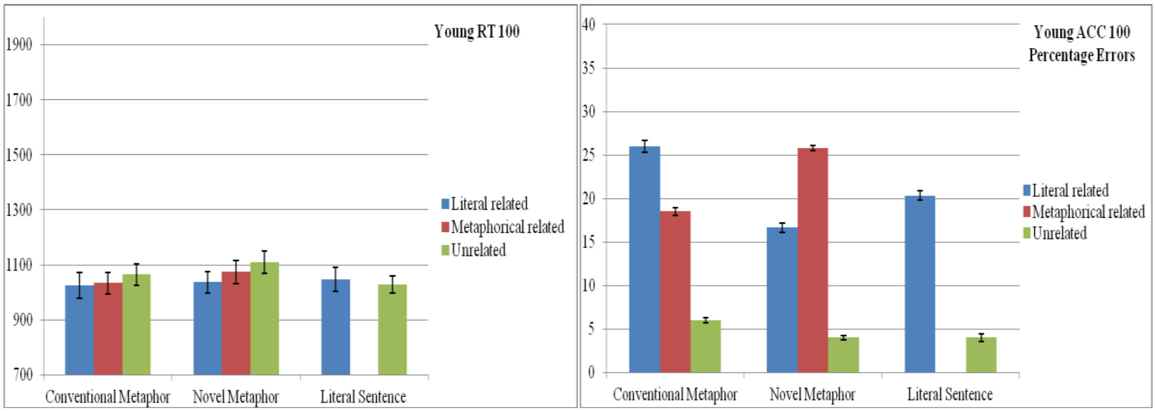


**Figure 7: Means of reaction time and percentage distribution of errors data (with standard errors) for young healthy participants - short ISI (100ms)**

Accuracy ANOVA

For the short (100ms) ISI, the Sentence type (conventional metaphor, novel metaphor, literal sentence) x Target type (literal related, metaphorical related, unrelated word) ANOVA revealed significant main effects of Sentence type [*F*1(2,38)=31.44, *p*<.0001; *F*2(2,261)=4.43, *p*<.05], Target type [*F*1(2,38)=82.93, *p*<.0001; *F*2(2,261)=20.26, *p*<.0001], and a significant Sentence type x Target type interaction [*F*1(4,76)=26.86, *p*<.0001; *F*2(4, 261)=4.69, *p*<.01].

Post hoc comparisons using the Newman-Keuls test (p<.05) revealed that for sentence type, both conventional metaphorical and novel metaphorical sentences generated significantly more errors than literal sentences (p<.001). For target type, literal related targets had significantly more errors than metaphorical ones, which in turn had significantly more errors than unrelated ones (p<.001). When interactions between sentence type and target type were considered, accuracy rates for targets differed according to sentence context. For conventional metaphors, significantly more errors were made on literal related targets than on metaphorical ones (p<.01) and unrelated target errors were significantly less than both related types (p<.001). For novel metaphorical sentences, this pattern was reversed with significantly more errors being made with metaphorical targets compared to literal ones (p<.001). Again, unrelated target errors were significantly less than both related types (p<.001). In literal sentences, significantly more errors were made with literal related targets than with unrelated ones (p<.001).

### *Long (1000ms) ISI*

Figure 8 is a graphical display of means of reaction time and percentage distribution of errors data (with standard errors) for young healthy participants at the long ISI (1000ms)

Reaction Time ANOVA

For the long (1000ms) ISI a Sentence type (conventional metaphor, novel metaphor, literal sentence) x Target type (literal related, metaphorical related, unrelated word) ANOVA carried out with reaction time (RT) data revealed marginal main effects of Sentence type [$F1(2,38)=2.95$, $p=.064$; $F2(2,261)=2.57$, $p=.079$] and Target type [$F1(2,38)=2.69$, $p=.081$; $F2(2,261)=0.67$, $p=.64$].

Post hoc comparisons using the Newman-Keuls test ($p<.05$) to further explore this data revealed few differences of interest as follows. For sentence type, novel metaphorical sentences were slower than literal sentences ($p=.052$); there were no other differences between the sentence types. For target type, literal related targets were identified numerically faster than unrelated ones ($p=.062$) while there were no other difference between target types.

Accuracy ANOVA

For the long (1000ms) ISI, the Sentence type (conventional metaphor, novel metaphor, literal sentence) x Target type (literal related, metaphorical related, unrelated word) ANOVA revealed significant main effects of Sentence type [$F1(2,38)=30.61$, $p<.0001$; $F2(2,261)=5.66$, $p<.01$], Target type [$F1(2,38)=63.66$, $p<.0001$; $F2(2,261)=22.86$, $p<.0001$], as well as a significant Sentence type x Target type interaction [$F1(4,76)=18.86$, $p<.0001$; $F2(4, 261)=4.78$, $p<.001$].

Post hoc comparisons using the Newman-Keuls test ($p<.05$) revealed that for sentence type, both conventional and novel metaphorical sentences generated significantly more errors that literal sentences ($p<.001$). For target type, literal related targets had significantly more errors than metaphorical ones, which in turn had significantly more errors than unrelated ones ($p<.001$). When interactions between sentence type and target type were considered, accuracy rates for targets again differ according to sentence context showing a familiar pattern. For conventional metaphors, significantly more errors were made on literal related targets than on metaphorical ones ($p<.01$) while unrelated target errors were significantly less than both related types ($p<.001$). For novel metaphorical sentences, this pattern was reversed with significantly more errors being made with metaphorical targets compared to literal ones (p<.05). Again, unrelated target errors were significantly less than both related types (p<.001). In literal sentences, significantly more errors were made with literal related targets than with unrelated ones (p<.001).

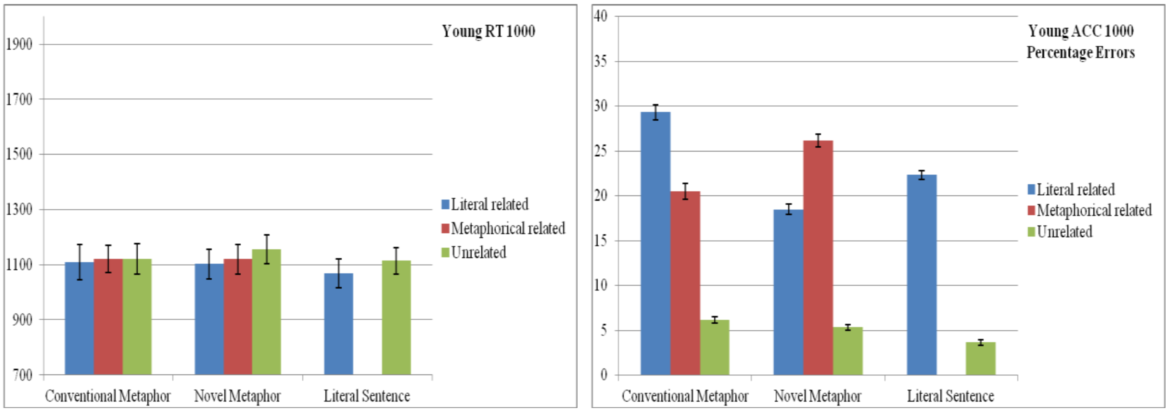


**Figure 8: Means of reaction time and percentage distribution of errors data (with standard errors) for young healthy participants - long ISI (1000ms)**

### *Experiment 2 Summary*

Overall, then, Experiment 2 was designed in order to identify which ISI shows optimum processing in young healthy adults; the results revealed that any interaction effects in reaction times had decayed at the longer ISI (1000ms) suggesting that the use of the short ISI (100ms), in which effects are more robust, would be most appropriate and ethical to use in Experiment 3. Briefly, the results of the young healthy adults in Experiment 2 indicated that novel metaphors took significantly longer to process than both conventional metaphors and literal sentences which did not differ from each other. The pattern of errors followed that demonstrated by the previous participant groups, namely that for conventional metaphors more errors were made with literal targets than metaphorical ones with the reverse being true for novel metaphors. In literal sentences more errors were made with literal targets than unrelated ones.

## Experiment 3

Experiment 3 employed the tDCS technique with cathodal stimulation to simulate stroke effects in young healthy adult participants using the short (100 ms) ISI. Error rates were examined first. A cutoff accuracy rate of 60% per list was used, so that the data of any participant who made more than 40% errors in a single list would be removed from further analysis. No participant reached the cutoff point for any of the lists. Thus, the data of all the lists were used in the statistical analyses. Prior to statistical analysis, errors and outliers (±2 SD from each participant's mean per condition) were removed. Data were then subjected to a 2(Condition: Sham-tDCS, Stimulation-tDCS) x 3(Sentence type: conventional metaphor, novel metaphor and literal sentence) x 3(Target type: literal related, metaphorical related and unrelated word) repeated measures ANOVA for participants (F1) and items (F2) for each participant group (LH 'simulated-stroke', RH 'simulated-stroke') separately. The process was repeated for both reaction time (RT) and accuracy (ACC). All significant main and interaction effects were explored further using the Newman-Keuls (p<.05) post-hoc tests.

For the LH 'simulated-stroke' participants errors and outliers (±2 SD) comprised 11.1% and 3.8%, respectively, of the data for the sham condition (Sham-tDCS) and 9.7% and 3.8% for the stimulation condition (Stimulation-tDCS). For the RH 'simulated-stroke' participants errors and outliers (±2 SD) comprised 15.1% and 3.8%, respectively, of the data for the sham condition (Sham-tDCS) and 14.4% and 4.2% for the stimulation condition (Stimulation-tDCS).

### *LH 'simulated-stroke' participants*

#### Reaction Time ANOVA

The Condition (Sham-tDCS, Stimulation-tDCS) x Sentence type (conventional metaphor, novel metaphor, literal sentence) x Target type (literal related, metaphorical related, unrelated word) ANOVA carried out with reaction time (RT) data for the LH 'simulated-stroke' participants revealed a significant main effect of Target type [$F1(2,10)=17.74$, $p<.001$; $F2(2,522)=23.57$, $p<.0001$] and marginal effects of Sentence type [$F1(2,10)=3.16$, $p=.087$; $F2(2,522)=2.29$, $p<.10$] and Sentence type x Target type [$F1(4,20)=2.49$, $p=.076$; $F2(4,522)=1.80$, $p<.128$]. Importantly, there were no effects of condition. Figure 9 displays mean reaction times with standard error bars for both the sham and stimulation conditions of this participant group.

Post-hoc comparisons using the Newman-Keuls test (p<.05) to further explore the significant effect of target type showed that both literal and metaphorical target words had significantly faster reaction times than unrelated ones (p<.001 and p<.01). Literal related targets were also faster than metaphorical ones (p<.052). For the effect of sentence type, novel metaphors were slower than conventional metaphors and literal sentences (p=.081). When the interaction between sentence type and target type was considered for conventional metaphors, unrelated targets were slower than both literal related (p<.05) and metaphorical related types (p=.057) and there was no difference between related target types. For novel metaphors, unrelated targets were slower than both related types (p<.01) and again there was no difference between literal and metaphorical related types. For literal sentences, unrelated words were slower than related ones (p<.05).

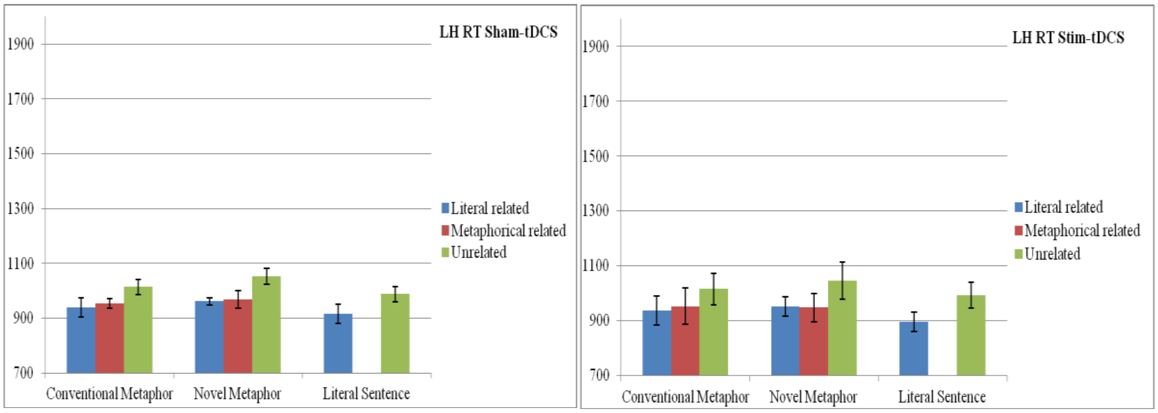


**Figure 9: Mean reaction time data (with standard error) for LH ‘simulated-stroke’ participants**

Accuracy ANOVA

The Condition (Sham-tDCS, Stimulation-tDCS) x Sentence type (conventional metaphor, novel metaphor, literal sentence) x Target type (literal related, metaphorical related, unrelated word) ANOVA carried out with accuracy (ACC) data for the LH ‘simulated-stroke’ participants revealed significant main effects of Sentence type [*F*1(2,10)=10.33, *p*<.001; *F*2(2,522)=6.08, *p*<.01], Target type [*F*1(2,10)=10.31, *p*<.001; *F*2(2,522)=20.85, *p*<.0001], and interaction effects of Sentence type x Target type [*F*1(4,20)=15.12, *p*<.0001; *F*2(4, 522)=5.44, *p*<.001]. As in the RT analysis, there were no effects of condition. Figure 10 displays mean percentage distribution of errors with standard error bars for both the sham and stimulation conditions of this participant group

Post-hoc comparisons using the Newman-Keuls test (p<.05) to further explore the significant effects revealed differences of interest as follows. For sentence type, there was no difference between accuracy for conventional and novel metaphors. Both, however, had significantly more errors than literal sentences (p<.01). Unrelated target words had significantly less errors than both literal and metaphorical ones (p<.01 and p<.05). More errors were made on literal target words than metaphorical ones and this difference approached significance (p=.086). When interactions between sentence type and target type were considered, accuracy rates for targets again differ according to sentence context showing the pattern demonstrated across all experiments. For conventional metaphors, significantly more errors were made on literal related targets than metaphorical ones (p<.01) while unrelated target errors were significantly fewer than both related types (p<.001). For novel metaphorical sentences, this pattern was reversed with significantly more errors being made with metaphorical targets compared to literal ones (p<.05). Again, errors to unrelated target were significantly fewer than both related types (p<.001). In literal sentences, significantly more errors were made with literal related targets than unrelated ones (p<.001).

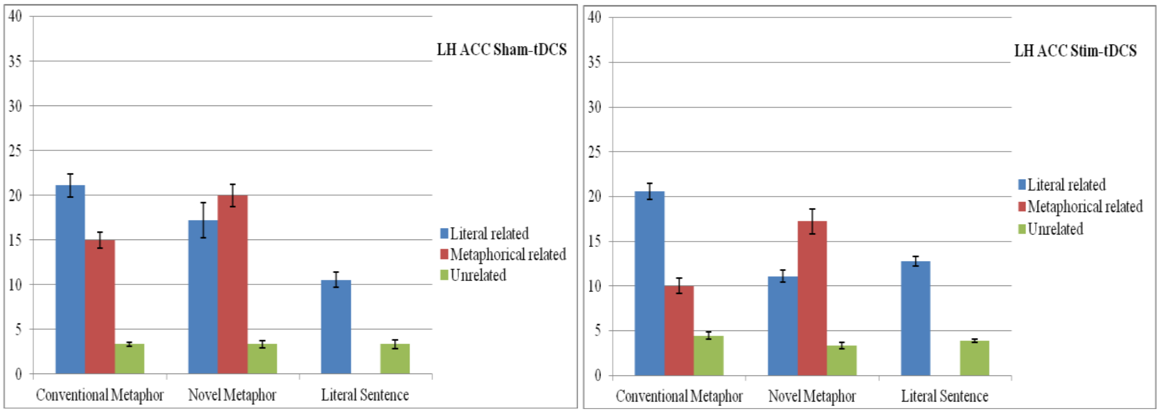


**Figure 10: Mean percentage distribution of errors (with standard error) for LH 'simulated-stroke' participants**

*RH 'simulated-stroke' participants*

Reaction Time ANOVA

The Condition (Sham-tDCS, Stimulation-tDCS) x Sentence type (conventional metaphor, novel metaphor, literal sentence) x Target type (literal related, metaphorical related, unrelated word) ANOVA carried out with reaction time (RT) data for the RH 'simulated-stroke' participants revealed a marginal main effect of Condition [*F*1(1,5)=4.78, p=.081; *F*2(1,522)=18.71, *p*<.0001]. Importantly, there were also significant interaction effects of Condition x Sentence type [*F*1(2,10)=4.43, *p*<.05; *F*2(2,522)=3.54, *p*<.05] and Sentence type x Target type [*F*1(4,20)=3.53, *p*<.05; *F*2(4,522)=5.79, *p*<.001]. Figure 11 displays mean reaction times with standard error bars for both the sham and stimulation conditions of this participant group.

Post-hoc comparisons using the Newman-Keuls test (p<.05) to further explore all significant effects revealed a different pattern of effects when compared to Experiments One and Two. Overall, reaction times were longer in the Stimulation-tDCS than the Sham-tDCS condition (p=.081). The Condition x Sentence type interaction revealed that in the sham condition (Sham-tDCS) both conventional and novel metaphors took longer than literal sentences (p<.05 and p<.01). Once Stimulation-tDCS was applied, however, this difference disappeared. In fact, conventional metaphors, novel metaphors as well as literal sentences were processed significantly slower than in the Sham-tDCS condition, indicating that the 'simulated stroke' had indeed disrupted processing. When interactions between sentence type and target type were considered for conventional metaphors, unrelated targets were numerically faster than metaphorical ones which in turn were faster than literal ones though none of the differences were significant. For novel metaphors, unrelated targets were again faster than metaphorical ones (not significant) which in turn were faster than literal ones (p=.098). For literal sentences unrelated words were slower than related ones but not significantly so.

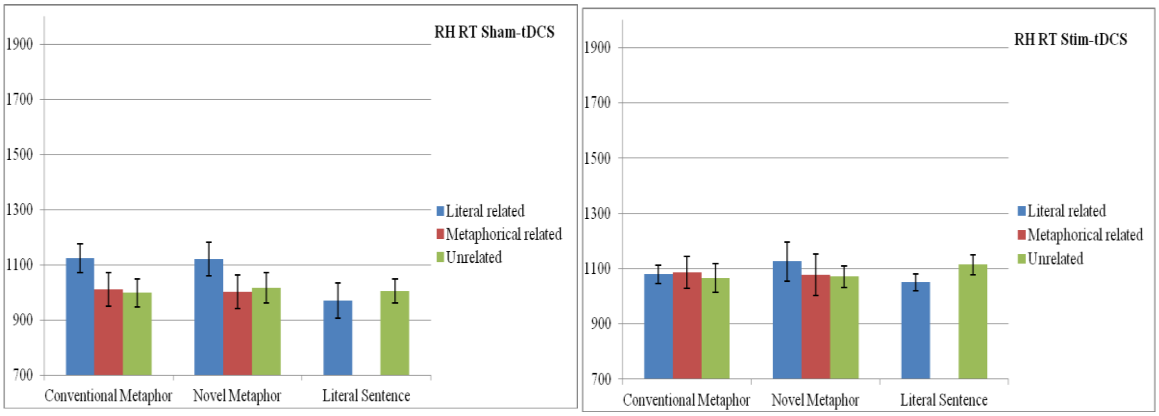


**Figure 11: : Mean reaction time data (with standard error) for RH 'simulated-stroke' participants**

Accuracy ANOVA

The Condition (Sham-tDCS, Stimulation-tDCS) x Sentence type (conventional metaphor, novel metaphor, literal sentence) x Target type (literal related, metaphorical related, unrelated word) ANOVA carried out with accuracy (ACC) data for the RH 'simulated-stroke' participants revealed significant main effects of Sentence type [*F*1(2,10)=16.34, *p*<.001; *F*2(2,522)=16.32, *p*<.0001] and Target type [*F*1(2,10)=32.37, *p*<.001; *F*2(2,522)=79.35, *p*<.0001], as well as a Sentence type x Target type interaction [*F*1(4,20)=6.62, *p*<.001; *F*2(4,522)=8.26, *p*<.0001]. Figure 12 displays mean percentage distribution of errors with standard error bars for both the sham and stimulation conditions of this participant group

Post-hoc comparisons using the Newman-Keuls test (p<.05) to further explore the significant effects revealed differences of interest as follows. For sentence type, there was no difference between accuracy for conventional and novel metaphors. Both, however, had significantly more errors than literal sentences (p<.001 and p<.01) indicating increased processing difficulties in metaphoricity. The post-hoc tests on the significant main effect of Target type revealed that unrelated target words had significantly less errors than both literal and metaphorical ones (p<.001 and p<.01). Additionally, significantly more errors were made on literal target words than metaphorical (p<.01). When the interaction between sentence type and target type was considered, in conventional metaphors, significantly more errors were made on literal related targets than metaphorical ones (p<.001) while errors on unrelated target were significantly less than both literal and metaphorical related types (p<.001 and p<.01). For novel metaphorical sentences, this pattern was reversed with more errors being made with metaphorical targets compared to literal ones though this difference was not significant. Again, unrelated target errors were significantly fewer than both related types (p<.001). In literal sentences, significantly more errors were made with literal related targets than with unrelated ones (p<.01).

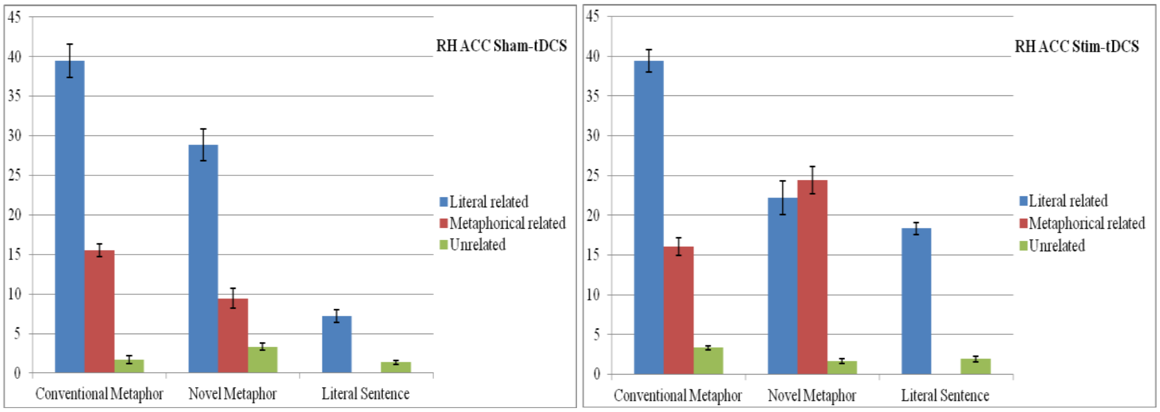


**Figure 12: Mean percentage distribution of errors (with standard error) for RH 'simulated-stroke' participants**

### *Experiment 3 Summary*

In conclusion, then, for Experiment 3, no differences were found between the sham and stimulation condition for the left-hemisphere ‘simulated-stroke’ participants. Overall, the results for this group mirrored the patterns identified with the young healthy adult baseline/control group in Experiment 2. In contrast, for the right-hemisphere ‘simulated-stroke’ participants, there was an effect of condition indicating that language processing overall was impaired when cathodal stimulation was applied to the right hemisphere in concert with the findings from participants with RHD in such tasks.

# DISCUSSION

This study set out to test the two dominant hypotheses purported to explain communication/language disorders in individuals with right hemisphere damage, namely the “coarse semantic coding” hypothesis (Beeman, 1993) and the “suppression deficit” hypothesis (Tompkins and Lehman, 1998). The predictions of these hypotheses were investigated by comparing the processing abilities of individuals with unilateral brain damage, either caused by stroke or mimicked by simulated-stroke using transcranial direct current stimulation (tDCS), with that of non-brain damaged individuals on semantic judgement tasks using metaphorical language. The “coarse semantic coding” hypothesis proposes that damage to the right hemisphere causes an over reliance on the fine coding assumed to be undertaken by the left hemisphere in the comprehension of language, implying the recall of most literal interpretations. The “suppression deficit” hypothesis proposes damage in the right hemisphere results in multiple activations of meanings of words not being attenuated which leads to ineffective suppression of inappropriate interpretations. The experimental designs employed by this study enabled us to apply the specific predictions of each hypothesis to the performance of the different participant groups on semantic relatedness tasks, thus rendering it possible to test between the hypotheses.

## Experiment 1

The main differences between the participant groups in Experiment 1 (participants with right hemisphere damage, left hemisphere damage and non-fluent aphasia and non-brain damaged age matched control participants) were mainly seen in the reaction time data and these differences will be explored in more detail for each participant group in the following sections. In terms of accuracy, largely similar patterns of errors were observed across all participant groups and this will be revisited throughout the discussion. For reference, error rates mainly showed that overall more errors were made with literal targets than metaphorical ones for conventional metaphors with the reverse being true for novel metaphors. In literal sentences more errors were made with related than unrelated targets. The findings from Experiment 1 allow for examination of the effects of sentence metaphoricity and the predictions of each hypothesis.

### *Non-brain damaged healthy older control participants*

For non-brain damaged older control participants processing times for conventional metaphors and literal sentences did not differ - as predicted. It is possible to assert that conventional metaphors, for example ‘spilled beans’, become permanently linked in semantic memory, similar to individual word definitions due their frequency of occurrence (Diaz, Barrett and Hogstrom, 2011). The present findings corroborate previous studies (Coulson and Van Petten, 2002) suggesting that conventional metaphors are understood as quickly as literal sentences due to their familiarity. In contrast, in order to process novel metaphors, for example ‘rocky cushions’, the listener is required to carry out more complicated processing as different semantic interpretations are applied and discarded or chosen as appropriate to context. Indeed, we found novel metaphors were harder to process, as evidenced by the longer reaction times, when compared to the other sentence types. This finding is in line with earlier research (Lai, Curran and Menn, 2009) which demonstrated that event related potentials associated with conventional metaphors and literal sentences converged whereas those related to novel metaphors remained anomalous indicating that novelty is more taxing cognitively.

The idea that the reaction times are affected by the effort needed to process and recall the appropriate interpretation (see also Blasko, 1999) will be revisited when the data for Experiment 2 is discussed. However, it is important to note that research demonstrates that it is specifically the effort or novelty that affects performance as opposed to processing capacity per se. Tompkins, Bloise, Timko and Baumgaertner (1994) demonstrated, for example, that there were no correlations between working memory capacity and task performance on discourse comprehension tasks. Thus, it is possible that the differences in reaction time between sentence types observed in this study are due to the characteristics of the metaphors employed.

In addition to sentence type, the inter-stimulus interval (ISI) between sentence prime and target word played a role in the processing of novel metaphors for the older non-brain damaged adults such that at the short ISI metaphorical targets were slower than literal ones while at the long ISI they were faster, i.e. the pattern was reversed. This indicates that ‘controlled’ or delayed processing improved the interpretation of the novel metaphors for the older control group. Looking at the literal sentences in detail revealed that, as expected, related targets were more quickly identified than unrelated ones as it takes more processing time to eliminate unrelated words as these are not semantically primed (Holcomb and Neville, 1990; Chiarello, Church and Hoyer, 1985). Although these data do not make it possible to differentiate between the "coarse semantic coding" and the "suppression deficit" hypotheses since both either predicted, or could be extrapolated to predict, similar outcomes for non-brain damaged individuals, it does contribute to our understanding of how metaphors are processed. In contrast with previous research, the present findings show that comprehension of novel metaphoric language specifically is more effortful than literal language or conventional metaphoric language (Gibbs, Bogdanovich, Sykes, and Barr, 1997; Inhoff, Lima, and Carroll, 1984; Ortony, Schallert, Reynolds, and Antos, 1978). The results suggest that, in the case of novel metaphors, metaphors are not processed directly as proposed by Ortony (1979) and Glucksberg and Kaysar (1990). The increased processing time for novel metaphors in this study indicates that some indirect processing is occurring and it might be that, as Searle (1979) suggests, the listener is first literally interpreting the metaphor and only when this interpretation is discarded attending to a metaphorical meaning.

### *Left hemisphere damaged participants*

The analysis of the data from the non-fluent aphasic left-hemisphere damaged participants showed that they maintained processing patterns largely similar to those of the non-brain damaged control group (despite largely taking longer overall) and that their post-stroke language impairment did not appear to affect a single aspect of their performance. Previous research has demonstrated poorer performance overall for individuals with brain damage relating this to a paucity in cognitive resources as a consequence of the damage and the increased effort needed to understand language (Tompkins, 1990; Monetta, Ouellet-Plamondon, and Joanette, 2006). Of interest is the performance on identifying the unrelated word target after any sentence prime where one of the participants with LHD continued to perform as well as their NBD counterparts suggesting that, whilst their ability to identify any related word target was significantly impaired after stroke, semantic priming continued to be in evidence (Bowles and Poon, 1985). The pattern of a large increase in the number of errors made by this group overall has also been demonstrated elsewhere, for example in Brownell et al., 1990, whose control participants and those with RHD made one and two errors respectively compared to 24 errors made by the participants with LHD in their experiments testing metaphorical language understanding. The evidence from this study will now be considered in light of the competing "coarse semantic coding" and "suppression deficit" hypotheses with two important caveats; firstly, the “suppression deficit” hypothesis does not make specific predictions about the left hemisphere and its relation to non-literal language and has been extrapolated for the purposes of this study, and secondly given the small sample size assumptions made are tentative.

The similar processing patterns of participants with LHD to the NBD control participants are not wholly consistent with the “coarse semantic coding” hypothesis. In its purest form, this hypothesis would predict that participants with LHD would take longer for both literal and novel metaphorical sentences due to fine coding being compromised thus slowing reaction times as individuals have to make semantic relatedness decisions from larger, coarser semantic fields (Jung-Beeman, 2005) which is what was observed. However, it would also predict that that their performance would be similar to non-brain damaged peers for conventional metaphors as the reliance on memory of metaphorical word pairs and phrases would benefit from the coarse coding semantic activation being relied upon in the intact right hemisphere of these individuals. Yet this was not the case as participants with LHD also took longer to process conventional metaphors.

In contrast, the “suppression deficit” hypothesis could be extrapolated to predict intact processing and a similar response to that of the NBD participants as the role of the RH in attenuation on inappropriate meanings should not be compromised (Tompkins and Lehman, 1998). In fact, it may be suggested that the performance of participants with LHD at interpreting novel metaphors should be significantly better since they would be solely relying on the multiple semantic activations in the RH thus allowing the less obvious related word to be more easily or readily identified. However, support is not demonstrated for the purest predictions of this hypothesis either as these participants were significantly slower at metaphorical relatedness tasks than the non-brain damaged control participants.

On reflection, neither the “coarse semantic coding” nor the “suppression deficit” hypothesis is strongly supported by the data of this participant group and the findings remain ambiguous for the limited data available. The paucity in numbers of this group makes any more than a cautious analysis inappropriate at this time and contributes to the uncertainty. However it must be noted that the reduction in overall performance displayed by these participants is both supported by and is that which the literature predicts for both post-stroke individuals with LHD and older adults (Grindrod and Baum, 2003; Hagoort, Brown, and Swaab, 1996; Tompkins, 1990), allowing for relative confidence in the results discussed.

### *Right hemisphere damaged participants*

The key result for this experimental group was that participants with right hemisphere damage due to stroke found both conventional and novel metaphorical sentences significantly harder to process than literal sentences as evidenced by the longer reaction times. This is in line with much of the existing research supporting the RH contribution to non-literal language understanding (Winner and Gardner, 1977; Beeman and Chiarello, 1998; Tompkins and Lehman, 1998) and is in direct contrast to the performance of the other participant groups allowing the two competing hypotheses to be compared and contrasted in more detail in this section. To recall, the “coarse semantic coding” hypothesis predicted that these participants with RHD would be relying on the fine coding being carried out in the intact LH in their understanding of semantic relatedness. This should cause novel metaphors to be more difficult to interpret and they would be more likely to take the non-literal meaning, hence the choice of the literal word target following a novel metaphorical prime. However, their performance on conventional metaphors and literal sentences should have been similar and comparable, albeit slower than the non-brain damaged control participants. This was not the case as the participants with RHD found *all* types of metaphorical sentences more difficult than literal ones.

Another important finding to highlight is that in contrast to previous studies (Tompkins, 1990; Tompkins and Lehman, 1998) the participants with RHD did choose both denotative and connotative target words when a uniform preference for denotative would have been predicted overall by the “suppression deficit” hypothesis. This is most clearly demonstrated within the accuracy data where participants with RHD did show preference for metaphorical targets following conventional metaphors but literal targets following novel metaphor primes similar to that of their peers, both individuals with LHD and NDB control participants, indicating that, at the target word level, differences in metaphoricity (i.e., conventional vs. novel) affect choice. The evidence in support of individuals with RHD for insensitivity for metaphoric alternative words has provided mixed findings (Brownell et al., 1990; Klepousniotou and Baum, 2005a) whereas evidence for the influence of sentential context is stronger (e.g. Blasko and Connine, 1993) for manipulating the listener in their decisions of metaphoricity.

In addition to the longer reaction times for metaphorical sentences (and again in contrast to the non-brain damaged older control participants) no effects of varying the inter-stimulus interval (ISI) were observed for participants with RHD which allows for a number of observations. Firstly, this condition was designed to test for the distinction between automatic and controlled processing as previous experiments had shown that there were differences between the two hemispheres in processing the metaphoricity of primed targets when longer ISIs are used (Anaki, Faust and Kravetz, 1998). In particular, Anaki et al. (1998) in a divided visual fields study with healthy young adults demonstrated that at a short ISI, priming effects for metaphorically related targets occurred in both the LH and RH whilst literal related targets were primed in the LH only. At the longer ISI, however, they showed metaphorical targets only being primed in the RH and literal only in the LH. It is this continuum of activation that Tompkins (1990) describes in allocating the role of the RH to language understanding. The central tenet of her "suppression deficit" hypothesis would suggest that at the shorter ISI condition the participants with RHD should retain sensitivity to conventional metaphorical sentences as processing should be relatively automatic. At the longer ISI the other semantic activations caused by the sentence prime, i.e. literal targets, would not be attenuated and thus impaired performance would be observed. This was not the case as no differences between the ISI conditions were found in this study. This finding for no ISI interaction allows an observation to be made, namely, that if there is no difference between on-line or automatic processing and off-line or controlled processing then it is unlikely that difficulty due to a deficit in the suppression of inappropriate or incorrect responses explains the results as would have been predicted by the "suppression deficit" hypothesis.

A second observation connected to the lack of ISI interaction variance for this participant group relates to the model of indirect processing (Searle, 1979). It would seem that for individuals with RHD, in contrast to their non-brain damaged peers, indirect processing applies to both conventional and novel metaphors; however, even with the increased processing time in the longer ISI, participants with RHD were unable to perform the task of discarding the initial literal interpretation in order to attend to the metaphorical one. The "suppression deficit" hypothesis would explain this as a failure to attenuate, quickly, the inappropriate activations, i.e. literal related words in this case of a metaphor prime and would have predicted improved performance at the longer ISI. In contrast, the "coarse semantic coding" hypothesis would explain this by an over reliance on fine coding in the left hemisphere, i.e. those semantic fields related to wider interpretations would never have been activated regardless of ISI length.

Visual inspection of the data provided some additional observations when the groups were compared. As was noted previously, in the case of NBD participants, unrelated targets took longer than related ones following literal sentences in the region of 200ms. However, for participants with RHD the reverse was true numerically with unrelated targets being chosen in the region of 40ms faster than related ones. If these participants were suffering from a "suppression deficit" this is not what would be expected as a lack of attenuation of semantically activated fields should mean that unrelated targets would have taken longer for participants with RHD (Tompkins, 1990). The response pattern for these sentence and target interactions also differed in the accuracy data such that participants with RHD made far fewer errors for unrelated targets than their NBD peers, 2% errors vs. 10% respectively. This observation suggests further support for the "coarse semantic coding" hypothesis, as the decision of relatedness would be made with reference to a smaller semantic field since this hypothesis predicts that, due to damage in the RH, these participants would be relying on the fine coding (strong activation of small semantic fields) portrayed to occur in the LH (Beeman, 1993; Beeman, 1998).

Overall, then, it seems that although neither hypothesis can exclusively explain the deficits in metaphor language understanding observed after RH damage and that consideration of the model of processing also needs to be taken into account, thus far the strongest evidence exists in support of the "coarse semantic coding" hypothesis for individuals with RHD following stroke.

### *Summary of Experiment 1*

The findings of Experiment 1 provide support for the role of the right hemisphere in metaphorical language understanding and help explain the communication and processing deficits experienced by individuals following stroke. Neither of the hypotheses proposed to explain this deficit in right hemisphere damaged individuals were supported in their purest form when the evidence from individuals with left hemisphere and no brain-damage was inspected. However, when the performance of individuals with right hemisphere damage was evaluated it appears that the least ambiguous evidence was demonstrated for the “coarse semantic coding” hypothesis (Beeman, 1993) as shown by the lack of differences across the two inter-stimulus intervals used in the study and inconsistencies in pattern of errors for unrelated targets when compared to the other groups.

## Experiments 2 and 3

The primary aim of Experiment 2 was to complement and extend the findings of Experiment 1. Experiment 2 was designed to inform the best experimental methods to be used to establish baseline performance and to identify which inter-stimulus interval, if any, would show strongest processing differences in young healthy adults so that the tDCS participants were not subjected to unnecessary experimental procedures in Experiment 3. Experiment 3 set out to simulate stroke-like effects with healthy young adults employing the tDCS technique with cathodal stimulation which has been shown to inhibit cognitive processing (Marshall, Molle, Siebner and Born, 2005).

### *Experiment 2 (Young healthy adults)*

The results of the young healthy adults in Experiment 2 indicated that, at the short inter-stimulus interval (ISI), novel metaphors took significantly longer to process than both conventional metaphors and literal sentences which did not differ from each other, indicating that novelty in metaphoricity is more taxing cognitively. This finding is in line with previous studies with younger adults (e.g. Lai, Curran and Menn, 2009), which have demonstrated that because novel metaphors are unfamiliar they are harder to interpret; it is also consistent with the patterns demonstrated by the older adult participants in Experiment 1. However, at the longer ISI, the significant effects were lost and only marginal effects remained indicating that by 1000 ms young healthy adults have resolved meaning for both literal and metaphorical sentences. It is interesting that the differences between literal and metaphorical sentences decayed at the longer ISI as it implies that young healthy adults process metaphors more quickly and that the added processing time offered by the longer ISI does not improve performance unlike the older healthy adults. This finding contrasts with earlier work that demonstrated consistent semantic priming effects across ISI and age groups when words are used as primes (Burke, White and Diaz, 1987). In Burke et al.’s study, participants were required to judge relatedness of a target word to a category prime in two ISIs, 410ms and

1550ms. The results showed that although younger adults were faster than older ones overall, there was no interaction for ISI and age. However latencies for participants increased overall with longer ISI for an expected category target which the authors attributed to attentional processes. The reaction time difference between younger and older adults has been widely reported in semantic processing tasks and is acknowledged to be due to a generalised reduction in attentional resources with increasing age (Hasher and Zacks, 1979). In an effort to distinguish between the automatic and attentional mechanisms of semantic priming, Howard, Shaw and Heisey (1986) used three different inter-stimulus intervals in a word relatedness task with both younger and older adults. Whilst no differences were seen at the medium and long ISI only younger adults showed priming effects at the short (150ms) ISI indicating that older adults may require more time than younger ones for automatic activation. This effect is often explained by the process of spreading activation, whereby semantic priming increases activation at semantically related nodes, which is an automatic process (Collins and Loftus, 1975). The implication for semantic processing is thus that if age related decline shows a slowing of automatic activation it therefore follows that priming effects should emerge at a shorter ISI for younger adults than older ones (Madden, Pierce and Allen, 1993). Therefore these automatic activations are likely to have decayed at the longer ISI as has been seen in the present study. In addition, it seems that all controlled processing has also been completed well within the 1000 ms delay for the young healthy adult group, indicating that in order to observe the effects of controlled processing for this group, a shorter long ISI (less than 1000 ms) might be necessary.

It is important to note that the experimental paradigm used in this study was optimised for older adults and stroke patients and hence the inter-stimulus intervals chosen might have not been ideal for younger healthy adults. Although none of the processing involved in this study is conscious, i.e. the semantic tasks tap into largely unconscious processing (whether it is automatic or controlled), it is clear that the shorter ISI, as defined by this study, allows for exploration of language processing in younger healthy adults. Additionally, the materials are effective with and understandable by young healthy adults and the consistency in findings with the previous experiment justifies their use with this new participant group. Finally, it has been useful to identify that effects of metaphoricity have decayed at the longer inter-stimulus interval indicating that for this participant group there is no benefit of delayed and effortful processing. This allows for the confident decision of using the shorter (100ms) inter-stimulus interval in Experiment 3 to observe the effects of simulated stroke in young healthy adults.

*Experiment 3 (Simulated stroke participants)*

Experiment 3 was designed to use the tDCS technique with cathodal (inhibitory) stimulation to simulate stroke effects in young healthy adult participants to further explore right hemisphere contributions to language understanding. It was predicted that the application of cathodal (inhibitory) stimulation to the left hemisphere, in particular over Broca's area, of healthy young adults would be unlikely to differentially affect their processing of non-literal language, in this case metaphorical sentences. On the other hand, it was predicted that inhibiting the homologous area in the right-hemisphere should lead to disrupted non-literal language processing in line with previous research in patients with RHD (Klepousniotou and Baum, 2005b) and the findings of Experiment 1.

Experiment 3 revealed no differences between the sham and stimulation conditions for the left-hemisphere 'simulated-stroke' participants. Overall, the results for this group mirrored the patterns identified with the young healthy adult baseline/control group in Experiment 2 such that literal sentences and conventional metaphors were quicker to process than novel metaphors and literal targets were identified faster than metaphorical ones. The results for the accuracy directly mirrored that of all groups of participants discussed thus far. Previous research has asserted that anodal (excitatory) stimulation may increase neuronal firing of a previously activated region, e.g. language, and thus provide greater facilitation of cognitive performance (Jacobson, Koslowsky and Lavidor, 2012). The activation of the LH in processing of metaphorical sentences has been previously established (Rapp et al., 2007; Stringaris et al., 2007). Since the participants in this study were already involved with a language orientated task the decreased neuronal firing, resulting from inhibitory stimulation, was not sufficient as the initial arousal state was already high in the language dominant hemisphere. An alternative explanation for reduced effects of tDCS in cognitive studies comes from Fox, Narayana, Tandon, Fox, Sandoval et al. (2006) who assert that, due to cognitive tasks generally involving several regions, modulating one area is unlikely to effect change of the magnitude observed in studies focussing on motor areas. The role of the left hemisphere in language production and understanding is firmly established, especially for those who are right-handed, therefore, it would be highly unlikely to effect large magnitudes of change in healthy young adults using the small transient currents deployed in tDCS.

In contrast, for the right-hemisphere ‘simulated-stroke’ participants, there was an effect of condition indicating that language processing overall was impaired when cathodal stimulation was applied to the anterior right hemisphere, the homologue of Broca’s area, such that all types of sentences, literal and metaphorical, showed increased processing times. Of particular note is the numerical increase in mean reaction time for metaphorical related targets following conventional and novel metaphors after stimulation was applied (75ms on average) compared to their literal targets (24ms on average) indicating that the inhibition of this area of the right-hemisphere has disrupted metaphorical language processing in particular. In general, these results support previous neuroimaging studies with healthy young participants that show greater involvement of the anterior region of the RH in complex language understanding (Bottini et al., 1994; Marshal, Faust, Hendler and Jung-Beeman, 2007; Schmidt, Debuse and Seger, 2007). More specifically, these results support the role of the right hemisphere in the indirect processing of metaphor, as described by Searle (1979), evidenced by the increased processing times when this hemisphere is inhibited. By implication this also supports the right hemisphere’s contribution to “coarse semantic coding” since reliance on the fine coding in the un-inhibited left hemisphere has impacted the ability to disregard inappropriate, literal meanings (Taylor, Brugger and Regard, 1999). When the accuracy data for this participant group were considered there was no effect for condition and this group largely showed similar patterns of responses as described earlier. Although a visual inspection of the graphs shows a different pattern in the sham condition to other groups, it is not statistically different to the stimulation condition. Of note though is the increased percentage of errors for metaphorical targets following novel metaphor sentences further indicating that inhibitory stimulation in the RH increased difficulty for this semantic task.

### *Summary of Experiments 2 and 3*

These results support the use of tDCS to simulate stroke-like effects in the RH of healthy young adults. Due to differences in the groups reactions to tDCS it may be beneficial in future studies to explore stimulation in both hemispheres using a within subjects design similar to that of hemifield studies like DVF methodology. In addition, the results complement those found with individuals with right-hemisphere damage following actual stroke in their tentative support for the “coarse semantic coding” hypothesis and an indirect model of metaphor processing.

# General Discussion

In summary, these experiments were designed to explore the role of the right hemisphere in complex language understanding by studying the performance of processing metaphors. As identified in the Introduction of this thesis, complementary evidence from both young and older adults, both with damage and without, provides the richest of data to help us understand how the brain processes language. In particular, the current study aimed to investigate the competing evidence for the two dominant hypotheses proposed to explain language disorders in individuals with right hemisphere damage,  the "coarse semantic coding" hypothesis (Beeman, 1993) and the "suppression deficit" hypothesis (Tompkins and Lehman, 1998). Evidence from healthy participants, young and older, and those with left-hemisphere damage did not render it possible to firmly discriminate between the two hypotheses with neither one being supported in its purest form. In contrast, evidence from participants with damage to the right hemisphere, both caused by stroke and simulated by tDCS, allowed for several key observations to be made. Firstly, older participants with RHD did not benefit from increased processing time provided by the longer ISI indicating that their difficulties were not due to a suppression deficit. Secondly, both groups of participants (individuals with RHD through stroke and RH tDCS simulated-stroke) demonstrated no difference between novel and conventional metaphors as would have been predicted by both hypotheses. Finally, participants with RHD identified unrelated targets far faster than their control counterparts indicating a reliance on fine-coding known to occur in the left-hemisphere. Thus, it would seem that on balance, at least for the participants with right hemisphere damage, be it due to stroke or simulated by tDCS, that the strongest of evidence is found for the "coarse semantic coding" hypothesis which holds that due to the division of fine and coarse coding across the hemispheres if there is damage to the right hemisphere then coarse coding (strong activation of large semantic fields) is compromised and over reliance of fine coding (strong activation of small semantic fields) in the left hemisphere occurs (Jung-Beeman, 2005).

It has been noted throughout this study that individuals who suffer damage in the right hemisphere due to stroke often exhibit communication difficulties; it is estimated that this occurs for between 50 and 78% of those who suffer RHD (Ferre, Ska, Lajoie, Bleau and Joanette, 2011). It has been established that four different components of verbal communication are likely to be affected, namely pragmatics, semantics, discourse and prosody (Johns et al., 2008).  The present study has focussed on one aspect of communication, that of non-literal language and more specifically metaphor. The justification behind this focus is the sheer volume of metaphorical references that are made in everyday language, which is known to be 4.08 conventional metaphors and 1.80 novel metaphors per minute of conversation (Pollio, Barlow, Fine and Pollio, 1977). Since the difficulty with metaphorical language, both conventional and novel, in individuals with RHD has been firmly established (as evidenced from previous studies as well as the findings of the current set of studies), it is appropriate to look at the practical implications of this for professionals working with this patient population.

The experience of this author during data collection for this study was that many of the individuals with RHD tested were unaware of or denied any communication difficulties. The denial of difficulties is a well established impairment following stroke and right hemisphere damage in particular (Hartman-Maeir, Soroker, Oman, and Katz, 2003). In fact, three of the seven participants held this belief so firmly that they both did not wish to discuss their performance during testing and disagreed firmly with any suggested findings, although interestingly continued to fully consent to take part in the study saying they ‘wished to help others’. The other participants were happy to discuss their experiences and after testing reflected on their difficulty with identifying the less obvious, non-literal interpretations required both during the screening and experimental tasks. All participants with right hemisphere damage performed similarly on the screening tests such that their performance on the auditory sentence comprehension task, both for simple constrained sentences and more complex reversible ones was as good as the participants with left hemisphere damage and their performance on the other screening tasks was comparable with the non-brain damaged control participants. Despite this, and whether acknowledged verbally or not, all participants with right hemisphere damage demonstrated a preference for literal interpretations on the test of Language Competence-Expanded Edition (Wiig and Secord, 1987) which was also used in the screening. This then would appear to be a key place to start in helping those who suffer RHD - in raising the awareness of such possible deficits through the dissemination of research, such as has been carried out here, and also in discussing performance on assessment measures with individuals.

It is important to highlight the paucity of referrals to this project. Despite verbal assurances of support a single referral alone was received from NHS sources with the remainder of stroke participants being recruited from existing studies. Discussions with NHS professionals carried out to ascertain reasons for this highlighted difficulties with changes to NHS stroke services within Leeds such that patients are seen over a shorter period of time and there is a pressure to discharge from services more quickly. Patients who are well are, rightly, no longer involved with services, those who are still involved have co-morbidities making them unsuitable for participation. Additional feedback from psychologists based within Stroke services informed that many patients suffer from depression – notably after significant language loss, i.e. non-fluent aphasia, meaning that despite their continued involvement and suitability in all other areas they could not be referred to this study.

Nevertheless, the results obtained were significant, even with small sample sizes, and thus it has been possible to meaningfully discuss differences and similarities for the groups. In addition, the numbers reported in this study are very similar to much of the published research that has been referred to throughout.

# REFERENCES

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

Andersen, K.K., Olsen, T.S., Dehlendorff, C., and Kammersgaard, L.P. (2009). Hemorrhagic and ischemic strokes compared: stroke severity, mortality, and risk factors, *Stroke*, 40, 2068 – 2072.

Audacity Team (2008): Audacity: Version 1.3.4-beta, computer program, retrieved 5th December 2010, from http://audacity.sourceforge.net/.

Bamford, J., Sandercock, P., Dennis, M., Warlow, C., Jones, L., McPherson, K., Vessey, M., Fowler, G., Molyneux, A., and Hughes, T. (1988). A prospective study of acute cerebrovascular disease in the community: the Oxfordshire Community Stroke Project 1981-86. 1. Methodology, demography and incident cases of first-ever stroke, *Journal of Neurology, Neurosurgery and Psychiatry*, 51, 1373-1380.

Bastini, A. and Jaberzadeh, S (2012). Does anodal transcranial direct current stimulation enhance excitability of the motor cortex and motor function in healthy individuals and subjects with stroke: A systematic review and meta-analysis, *Clinical Neurophysiology*, 123, 644-657.

Beeman, M. (1993). Semantic processing in the right hemisphere may contribute to drawing inferences from discourse. *Brain and Language*, 44, 80-120.

Beeman, M. (1998). Coarse semantic coding and discourse comprehension. In Beeman, M and Chiarello, C (eds), *Right hemisphere language comprehension: Perspectives from cognitive neuroscience*, Mahwah, NJ: Erlbaum.

Beeman, M and Chiarello, C (1998). *Right hemisphere language comprehension: Perspectives from cognitive neuroscience*, Mahwah, NJ: Erlbaum.

Been, G., Ngo, T. T., Miller, S. M., and Fitzgerald, P. B. (2007). The use of tDCS and CVS as methods of non-invasive brain stimulation, *Brain Research Reviews*, 346-361.

Benton, E and Bryan, K. (1996). Right cerebral hemisphere damage: incidence of language problems. *International Journal of Rehabilitation Research*, 19, 47-54.

Berryhill, M. E., Wencil, E. B., Coslett, H. B., and Olsen, I. R. (2010). A selective working memory impairment after transcranial direct current stimulation to the right parietal lobe, *Neuroscience Letters*, 479, 312-316.

Blake, M.L., Duffy, J.R., Myers, P.S., and Tompkins, C.A. (2002). Prevalence and patterns of right hemisphere cognitive/communication deficits: Retrospective data from an inpatient rehabilitation unit. *Aphasiology*, 16, 537-548.

Blasko, D.G. (1999). Only the tip of the iceberg: who understands what about metaphor? *Journal of Pragmatics*, 31, 1675-1683.

Blasko, D.G. and Connine, C.M. (1993). Effects of familiarity and aptness on metaphor processing, *Journal of Experimental Psychology: Learning Memory and Cognition*, 19, 295-308.

Bottimi, G., Corcoran, R., Sterzi, R., Paulesu, E., Schenone, P., Scarpa, P., Frackowiak, R.S.J., and Frith, C.D. (1994). The role of the right hemisphere in the interpretation of figurative aspects of language: A positron emission tomography activation study. *Brain*, 117, 1241-1253.

Bowles, N. L, and Poon, L. W. (1985). Aging and retrieval of words in semantic memory, *Journal of Gerontology,* 40, 71-77.

Briggs, G. G., and Nebes, R. D. (1975). Patterns of hand preference in a student population, *Cortex*, 11, 230- 223.

Brownell, H. H., Potter, H.H., Michelow, D., and Gardner, H. (1984). Sensitivity to lexical denotation and connotation in brain-damaged patients: A double dissociation? *Brain and Language*, 22, 253-265.

Brownell, H.H., Potter, H.H., Birhle, A.M., and Gardner, H. (1986). Inference deficits in right brain-damaged patients. *Brain and Language*, 27, 310-321.

Brownell, H.H., Simpson, T.L., Bihrle, A.M., Potter, H.H., and Gardner, H. (1990). Appreciation of metaphoric alternative word meanings by left and right brain-damaged patients. *Neuropsychologia*, 28(4), 375-383.

Burke, D. M., White, H., and Diaz, D. L. (1987). Semantic priming in young and older adults: Evidence for age constancy in automatic and attentional processes, *Journal of Experimental Psychology: Human Perception and Performance*, 13, 79-88.

Caplan, D. (1992). *Language: Structure, Process, and Disorders*. Cambridge, MA: MIT Press.

Cattaneo, Z., Pisoni, A., and Papagno, C. (2011). Transcranial direct current stimulation over Broca's region improves phonemic and semantic fluency in healthy individuals, *Neuroscience*, 183, 64-70.

Cerruti, C. and Schlaug, G. (2008). Anodal transcranial direct current stimulation of the prefrontal cortex enhances complex verbal associative thought, *Journal of Cognitive Neuroscience*, 21, 1980-1987.

Chiarello, C., Church, K. L. and Hoyer, W. J. (1985). Automatic and controlled semantic priming: Accuracy, response bias and aging, *Journal of Gerontology*, 40, 593-600.

Chiarello, C, Lui, S., Shears, C., Quan, N., and Kacinik, N. (2003). Priming of strong semantic relations in the left and right visual fields: a time-course investigation, *Neuropsychologia*, 41, 721-732.

Collins, A.M. and Loftus, E. F. (1975). A spreading activation theory of semantic processing, *Psychological Review*, 82, 407-428.

Coltheart, M. (1981). The MRC psycholinguistic database. *Quarterly Journal of Experimental Psychology*, 33, 497-505.

Coulson, S. and Van Petten, C. (2002). Conceptual integration and metaphor: An event-related potential study. *Memory and Cognition*, 30, 958-968.

Coulson, S. and Van Petten, C. (2007). A special role for the right hemisphere in metaphor comprehension. *Brain Research*, 1146, 128-145.

Coulson, S., Federmeier, K.D., Van Petten, C., and Kutas, M. (2005). Right hemisphere sensitivity to word- and sentence-level context: Evidence from event-related brain potentials, *Journal of Experimental Psychology: Learning, Memory and Cognition*, 31, 129-147.

Crawford, J. R. (2012). SingleBayes_ES.exe, computer programme, retrieved June 2012 from http://homepages.abdn.ac.uk/j.crawford/pages/dept/SingleCaseMethodsComputerPrograms.HTM.

Crawford, J. R., and Garthwaite, P. H. (2007). Comparison of a single case to a control or normative sample in neuropsychology: Development of a Bayesian approach. *Cognitive Neuropsychology*, 24, 343-372.

Crawford, J. R., Garthwaite, P. H., and Porter, S. (2010). Point and interval estimates of effect sizes for the case-controls design in neuropsychology: Rationale, methods, implementations, and proposed reporting standards. *Cognitive Neuropsychology*, 27, 245-260.

De Vries, M.H., Barth, A.C.R., Maiworm, S., Knecht, S., Zwitserlood, P., and Floel, A. (2009). Electrical Stimulation enhances implicit learning of an artificial grammar, *Journal of Cognitive Neuroscience*, 22, 2427-2436.

Diaz, M. T., Barrett, K. T., and Hogstrom, L. J. (1994). The influence of sentence novelty and figurativeness on brain activity, *Neuropsychologia*, 49, 320-330.

Eisenson, J (1962). Language Modification associated with right cerebral damage, *Language and Speech*, 5, 49-53.

Ferre, P., Ska, B., Lajoie, C., Bleau, A., and Joanette, Y. (2011). Clinical focus on prosodic, discursive and pragmatic treatment for right hemisphere damaged adults: What's right*?, Rehabilitation, Research and Practice*, 1-10.

Floel, A., Rosser, N., Michka, O., Knecht, S., and Breitenstein C. (2008). Non-invasive brain stimulation improves language learning, *Journal of Cognitive Neuroscience*, 20, 1415-1422.

Fonseca, R.P., Fachel, J.M.G., Chaves, M.L.F., Liedtke, F.V., and Parente, M.A.P. (2007). Right hemisphere damage: Communication processing in adults evaluated by the Brazilian Protocole MEC – Bateria MAC, *Dementia and Neuropsychologia*, 3, 266-275.

Fox, P. T., Narayana, S., Tandon, N., Fox, S. P., Sandoval, H., Kochunov, P., Capaday, C., and Lancaster, L. (2006). Intensity modulation of TMS induced cortical excitation: primary motor cortex. *Human Brain Mapping*, 27, 478-487

Fregni, F., Boggio, P.S., Lima, M.C., Ferreira, M.J.L., Wagner, T., Rigonatti, S.P., Castro, A.W., Souza, D.R., Riberto, M., Freedman, S.D., Nitsche, M.A., Pascual-Leone, A., (2006). A sham-controlled, phase II trial of transcranial direct current stimulation for the treatment of central pain in traumatic spinal cord injury. *Pain* 122, 197-209.

Gagnon, L., Goulet, P., Giroux, F., and Joanette, Y. (2003). Processing of metaphoric and non-metaphoric alternative meanings of words after right- and left-hemispheric lesion, *Brain and Language*, 87, 217-226.

Gandiga, P.C., Hummel, F.C., and Cohen, L.G., (2006). Transcranial DC stimulation (tDCS): a tool for double-blind sham-controlled clinical studies in brain stimulation. *Clinical Neurophysiology*, 117, 845-850.

Geschwind N. (1965). Disconnection syndromes in animals and man: Part 1, *Brain,* 88, 237-294.

Gernsbacher, M.A. and Faust, M.E. (1991). The mechanism of suppression: A component of general comprehension skill. *Journal of Experimental Psychology: Learning, Memory and Cognition,* 17, 245-262.

Gibbs, R.W., Bogdanovich, J. M., Sykes, J. R., and Barr, D. J. (1997). Metaphor in idiom comprehension. *Journal of Memory and Language,* 37, 141-154.

Giora, R. (2007). Is metaphor special? *Brain and Language,* 100, 111-114.

Glucksberg, S. (2001). *Understanding figurative language: from metaphors to idioms*, New York: Oxford University Press.

Glucksberg, S., and Keysar, B. (1990). Understanding metaphorical comparisons: Beyond similarity. *Psychological Review, 97,* 3-18.

Glucksberg, S. and Keysay, B. (1993). How metaphors work. In Ortony, A (ed) *Metaphor and Thought,* New York: Cambridge University Press.

Goodglass, H., Kaplan, E. and Barresi, B. (2001). *The Assessment of Aphasia and Related Disorders*. Lippincott, Williams and Wilkins.

Grindrod, C. M., and Baum, S. R. (2003). Sensitivity to local sentence context information in lexical ambiguity resolution: Evidence from left- and right-hemisphere-damaged individuals. *Brain and Language,* 85, 503-523.

Hagoort, P., Brown, C. M., and Swaab, T. Y. (1996). Lexical-semantic event-related potential effects in patients with left hemisphere lesions and aphasia, and patients with right hemisphere lesions without aphasia. *Brain,* 119, 627-649.

Hasher, L., and Zacks, R. T (1979). Automatic and effortful processes in memory, *Journal of Experimental Psychology: General,* 108, 356-388.

Hartman-Maeir, A., Soroker, N., Oman, S. D., and Katz, N. (2003). Awareness of disabilities in stroke rehabilitation--a clinical trial, Disability and Rehabilitation, 2003, 25, 35-44.

Holcomb, P. J and Neville, H.J. (1990). Auditory and visual semantic priming in lexical  decision: A comparison using event-related brain potentials, *Language and Cognitive Processes*, 5, 281-312.

Hough, M. S. (1990). Narrative comprehension in adults with right and left hemisphere damage: Theme organisation. *Brain and Language*, 38, 253-277.

Howard, D. V., Shaw, R. S., and Heisey, J. G. (1986). Aging and the time course of semantic activation. *Journal of Gerontology*, 41, 195-203.

Inhoff, A. W., Lima, S. D., and Carroll, P. J. (1984). Contextual effects on metaphor comprehension in reading. *Memory and Cognition*, 12, 558-567.

Iyer, M.B., Mattu, U., Grafman, J., Lomarev, M., Sato S. and Wassermann, E.M. (2005). Safety and cognitive effect of frontal DC brain polarization in healthy individuals, *Neurology*, 64, 872-875.

Jacobson, L., Koslowsky, M.,  and Lavidor, M. (2012). tDCS polarity effects in motor and cognitive domains: a meta-analytical review, *Experimental Brain Research*, 216, 1-10.

Johns, C.L., Tooley, K.M. and Traxler, M.J. (2008). Discourse impairments following right hemisphere brain damage: A critical review, *Language and Linguistics Compass*, 2(6), 1038-1062.

Jung-Beeman, M. (2005). Bilateral brain processes for comprehending natural language, *Trends in Cognitive Sciences*, 9(1), 512-518.

Jung-Beeman, M., Bowden, E.M., and Gernsbacher, M.A. (2000). Right and left cooperation for drawing predictive and coherence inferences during normal story comprehension. *Brain and Language*, 71, 310-366.

Kacinik, N.A. and Chiarello, C. (2007). Understanding metaphors: Is the right hemisphere uniquely involved? *Brain and Language*, 100, 188-207.

Kandhadai, P. and Federmeier, K.D. (2008). Summing it up: semantic activation processes in the two hemispheres as revealed by event-related potentials. *Brain Research*, 1233, 146-159.

Katz, A. N., Paivio A., Marschark, M., and Clark J. M. (1988). Norms for 204 literary and 260 non-literary metaphors on 10 psychological dimensions, *Metaphor and Symbolic Activity*, 3, 191-214.

Klepousniotou, E and Baum, S.R. (2005a). Unilateral brain damage effects on processing homonymous and polysemous words. *Brain and Language*, 93(3), 308-326.

Klepousniotou, E. and Baum, S.R. (2005b). Processing homonymy and polysemy: Effects of sentential context and time-course following unilateral brain damage. *Brain and Language*, 95, 365-382.

Klepousniotou, E and Baum, S.R. (2007). Disambiguating the ambiguity advantage effect in word recognition: An advantage for polysemous but not homonymous words, *Journal of Neurolinguistics*, 20, 1-24.

Lai, V. T., Curran, T., and Menn, L. (2009). Comprehending Conventional and Novel Metaphors: An ERP Study. *Brain Research*. 1284, 145-155.

Laidlaw, K and Panchana, N.A. (2009). Aging, mental health and demographic change: Challenges for psychotherapists. *Professional Psychology: Research and Practice*, 40, 601-608.

Lehman-Blake, M. (2007). Perspectives on treatment for communication deficits associated with right hemisphere brain damage. *American Journal of Speech-Language Pathology*, 16, 331-342.

Lehman-Blake, M. and Lesniewicz, K.S. (2005). Contextual bias and predictive inferencing in adults with and without right hemisphere brain damage. *Aphaisiology*, 19, 423-434

Lippold, O.C. and Redfearn, J. W. (1964). Mental changes resulting from the passage of small direct currents through the human brain, *British Journal of Psychiatry*, 110, 768-772.

Love, R. and Webb, W. (2001). *Neurology for the Speech-Language Pathologist*. Boston: Butterworth-Heinemann.

Lundgren, K., Brownell, H., Roy, S., and Cayer-Meade, C. (2006). A metaphor comprehension intervention for patients with right hemisphere brain damage: A pilot study. *Brain and Language*, 99, 69-70.

Mackenzie, C. and Brady, M. (2004). Communication ability in non-right handers following right hemisphere stoke, *Journal of Neurolinguistics*, 17, 301-313.

Madden, D. J., Pierce, T. W. and Allen, P. A. (1993). Age-related slowing and the time course of semantic priming in visual word identification, *Psychology and Aging*, 8, 490-507.

Marshall, L., Molle, M., Siebner, H., and Born, J. (2005). Bifrontal transcranial direct current stimulation slows reaction time in a working memory task, *BMC Neuroscience*, 6, 23-31.

Marshal, N, Faust, M., Hendler, T., and Jung-Beeman, M. (2007). An fMRI investigation of the neural correlates underlying the processing of novel metaphoric expressions. *Brain and Language*, 100, 115-126.

Miller, G. (1979). Images, models, similes and metaphor. In Ortony, A. (ed.) *Metaphor and Thought*, pp 202-250, London: Cambridge University Press.

Monetta, L., Hamel, K., and Joanette, Y. (2001). Accounting for verbal communication impairments among brain-damaged individuals: The challenge of evaluating cognitive resource sharing, *Brain and Language,* 79, 61-64.

Monetta, L., Ouellet-Plamondon, C., and Joanette, Y. (2006). Stimulating the pattern of right hemisphere-damaged patients for the processing of the alternative metaphorical meanings of words: Evidence for favour of a cognitive resources hypothesis, *Brain and Language*, 96, 171-177.

Monti, A., Cogiamanian, F., Marceglia, S., Ferrucci, R., Mameli, F., Mrakic-Sposta, S., Vergari, M., Zago, S., and Priori, A. (2008). Improved Naming After Transcranial Direct Current Stimulation in Aphasia, *Journal of Neurology, Neurosurgery and Psychiatry*, 79, 451-453.

Moulin, C.J.A., Conway, M.A., Thompson, R.G., James, N., and Jones, R.W. (2005). Disordered memory awareness: recollective confabulation in two cases of persistent d´ej`a vecu, *Neuropsychologia*, 43, 1362-1378.

Murray, L. L. (2000). The effects of varying attentional demands on the word retrieval skills of adults with aphasia, right hemisphere brain damage, or no brain damage, *Brain and Language*, 72, 40-72.

Nasreddine ZS, Phillips NA, Bédirian V, Charbonneau S, Whitehead V, Collin I, Cummings JL, Chertkow H (2005). The Montreal Cognitive Assessment (MoCA): A Brief Screening Tool for Mild Cognitive Impairment, *Journal of the American Geriatrics Society*, 53, 695-699.

Nichelli, P.J., Grafman, P., Pietrini, K., Clark, K., Lee, Y., and Miletich, R. (1995). Where the brain appreciates the moral of a story. *Neuroreport*, 6, 2309-2313.

Nitsche, M. A., and Paulus,W. (2000). Excitability changes induced in the human motor cortex by weak transcranial direct current stimulation, *Journal of Physiology, 527*, 633-639.

Nitsche, M.A., and Paulus, W., (2001). Sustained excitability elevations induced by transcranial DC motor cortex stimulation in humans. *Neurology*, 57, 1899-1901.

Nitsche, M. A., Seeber, A., Frommann, K., Klein, C. C., Rochford, C., Nitsche, M. S., et al. (2005). Modulating parameters of excitability during and after transcranial direct current stimulation of the human motor cortex, *Journal of Physiology, 568*, 291-303.

Ortony, A. (1979). *Metaphor and Thought*, London: Cambridge University Press.

Ortony, A., Schallert, D., Reynolds, R., and Antos, S. (1978). Interpreting metaphors and idioms: Some effects of context on comprehension. *Journal of Verbal Learning and Verbal Behaviour*, 17, 465-477.

Oxford Dictionaries. April 2010. Oxford University Press, retrieved 14th February 2001 from http://oxforddictionaries.com/view/entry/m_en_gb0514520.

Pollio, H., Barlow, J., Fine, H., and Pollio, M. (1977). *Psychology and the poetics of growth: figurative language in psychology and education*, Hillsdale, New Jersey: Lawrence Erbaum Associates.

Poreisz, C., Boros, K., Antal, A., Paulus, W., 2007. Safety aspects of transcranial direct current stimulation concerning healthy subjects and patients. *Brain Research Bulletin*, 72, 208-214.

Rapp, A.M., Leube, D.T., Erb, M., Grodd, W., and Kircher, T.T.J. (2007). Laterality in metaphor processing: Lack of evidence from functional magnetic resonance imaging for the right hemisphere theory. *Brain and Language*, 100, 142-149.

Rorden, C. and Karnath, H. (2004). Using brain lesions to infer function: a relic from a past era in the fMRI age? *Nature Reviews: Neuroscience*, 5, 813-819.

Schmidt, G.L., Debuse, C.J. and Seger,, C.A. (2007). Right hemisphere metaphor processing? Characterising the lateralisation of semantic processes. *Brain and Language*, 100, 127-141.

Schneider, W., Eschman, A., and Zuccolotto, A. (2002). E-Prime user’s guide. Pittsburgh: Psychology Software Tools Inc.

Searle, J. (1979). Metaphor. In A. Ortony (Ed.), *Metaphor and thought* (pp. 92-123). Cambridge, England: Cambridge University Press.

Shields, J. (1991). Semantic-pragmatic disorder: A right hemisphere syndrome? *British Journal of Disorders of Communication*, 26, 383-392.

Sparing R., Dafotakis, M., Meister I. G., Thirugnanasambandam, N., and Fink, G. R. (2008). Enhancing language performance with non-invasive brain stimulation: A transcranial direct current stimulation study in healthy humans, *Neuropsychologia*, 46, 261-268.

St. George, M., Kutas, M., Martinez, A., and Serono, M.I. (1999). Semantic integration in reading: engagement of the right hemisphere during discourse processing, *Brain*, 122, 1317-1325.

Stringaris, A.K., Medford, N.C., Giampietro, V., Brammer, M.J., and David, A.S. (2007). Deriving meaning: Distinct neural mechanisms for metaphoric, literal, and non-meaningful sentences. *Brain and Language*, 100, 150-162.

Swaab, T. Y., Brown, C., and Hagoort, P. (2003). Understanding words in sentence contexts: The time course of ambiguity resolution, *Brain and Language*, 86, 326 – 343.

Taylor, K.I., Brugger, P., Weniger, D., and Regard, M. (1999). Qualitative hemispheric differences in semantic category matching. *Brain and Language*, 70(1), 119-131.

Tompkins, C.A. (1990). Knowledge and strategies for processing lexical metaphor after right or left hemisphere brain damage. *Journal of Speech and Hearing Research*, 33, 307-316.

Tompkins, C.A. and Lehman, M.T. (1998). Interpreting intended meanings after right hemisphere brain damage: An analysis of evidence, potential accounts and clinical implications, *Topics in Stroke Rehabilitation*, 5(1), 29-47.

Tompkins, C.A., Bloise, C.G.R., Timko, M.L., and Baumgaertner, A. (1994). Working memory and inference revision in brain damaged and normally aging adults. *Journal of speech and hearing research*, 37, 896-912.

Van Lancker, D., and Kempler, D. (1987). Comprehension of familiar phrases by left- but not by right-hemisphere damaged patients. *Brain and Language*, 32, 265-277.

Wapner, W., Hamby, S. and Gardner, H., 1981. The role of the right hemisphere in the apprehension of complex linguistic materials. *Brain and Language*, 14, 15-32.

Wechsler, D., (1997). *WAIS-III administration and scoring manual*, The Psychological Corporation, San Antonio, TX.

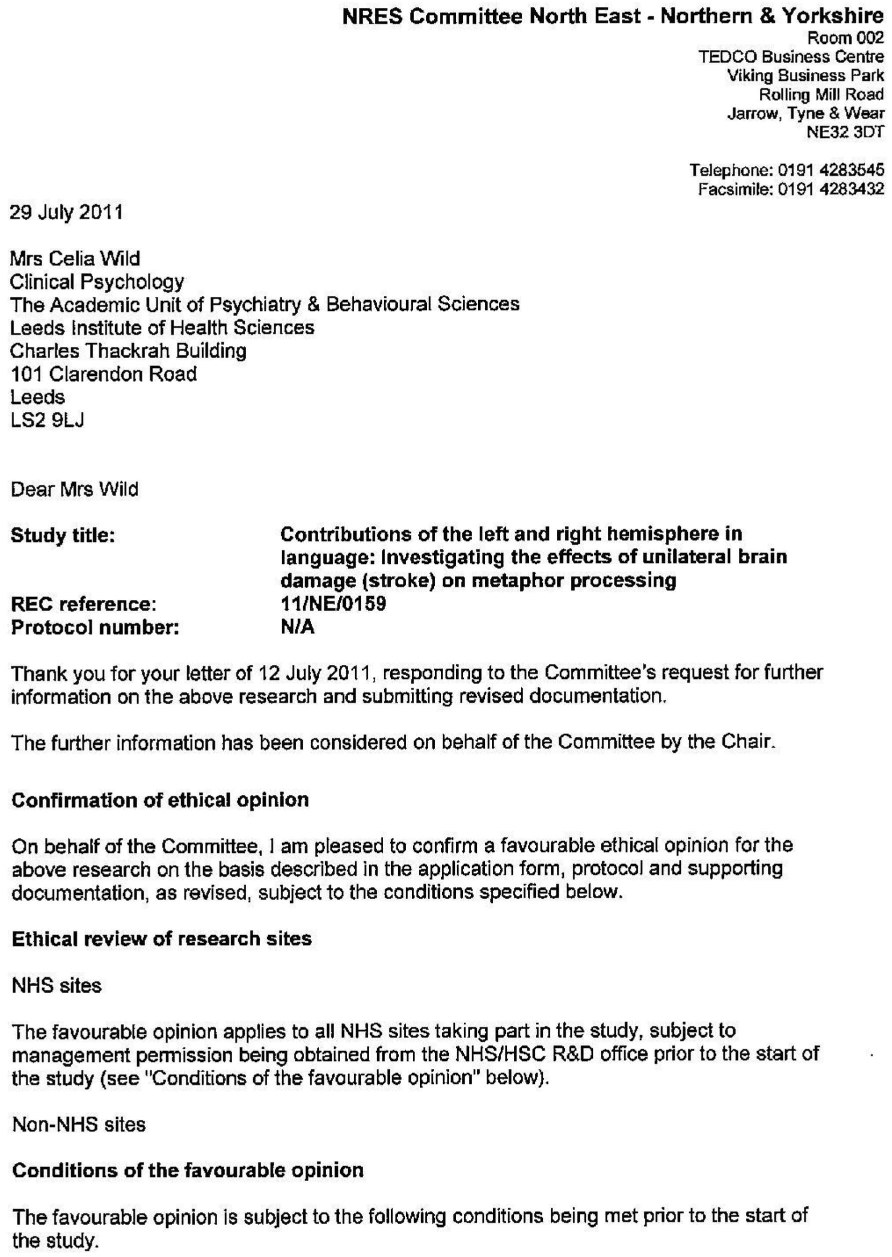
Wiig, E.H. and Secord, W. (1987). *Test of Language Competence-Expanded Edition*. San Antonio, TX: Harcourt, Brace and Jovanovich.

Winner, E. and Gardner, H. (1977). The comprehension of metaphor in brain-damaged patients. *Brain*, 100, 717-729.

# APPENDIX

# Appendix 1 – Ethical approval letters

## *NHS Ethical Approval Letter*



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29 July 2011

Mrs Celia Wild
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LS2 9LJ

Dear Mrs Wild

| | |
|---|---|
| **Study title:** | **Contributions of the left and right hemisphere in language: Investigating the effects of unilateral brain damage (stroke) on metaphor processing** |
| **REC reference:** | **11/NE/0159** |
| **Protocol number:** | **N/A** |

Thank you for your letter of 12 July 2011, responding to the Committee's request for further information on the above research and submitting revised documentation.

The further information has been considered on behalf of the Committee by the Chair.

**Confirmation of ethical opinion**

On behalf of the Committee, I am pleased to confirm a favourable ethical opinion for the above research on the basis described in the application form, protocol and supporting documentation, as revised, subject to the conditions specified below.

**Ethical review of research sites**

NHS sites

The favourable opinion applies to all NHS sites taking part in the study, subject to management permission being obtained from the NHS/HSC R&D office prior to the start of the study (see "Conditions of the favourable opinion" below).

Non-NHS sites

**Conditions of the favourable opinion**

The favourable opinion is subject to the following conditions being met prior to the start of the study.

Management permission or approval must be obtained from each host organisation prior to the start of the study at the site concerned.

*Management permission ("R&D approval") should be sought from all NHS organisations involved in the study in accordance with NHS research governance arrangements.*

Guidance on applying for NHS permission for research is available in the Integrated Research Application System or at http://www.rdforum.nhs.uk.

*Where a NHS organisation's role in the study is limited to identifying and referring potential participants to research sites ("participant identification centre"), guidance should be sought from the R&D office on the information it requires to give permission for this activity.*

*For non-NHS sites, site management permission should be obtained in accordance with the procedures of the relevant host organisation.*

*Sponsors are not required to notify the Committee of approvals from host organisations*

**It is the responsibility of the sponsor to ensure that all the conditions are complied with before the start of the study or its initiation at a particular site (as applicable).**

**Approved documents**

The final list of documents reviewed and approved by the Committee is as follows:

| *Document* | *Version* | *Date* |
|---|---|---|
| Advertisement | 1 | 04 May 2011 |
| Covering Letter | | 19 May 2011 |
| Evidence of insurance or indemnity | Zurich | 10 September 2010 |
| Investigator CV | Wild | 17 May 2011 |
| Other: CV Academic Supervisor | Klepousniotou | 17 May 2011 |
| Other: Home Visit Protocol | 1 | 01 July 2005 |
| Other: Research process diagram | Version 4 | 07 February 2011 |
| Participant Consent Form | 3 | 10 January 2011 |
| Participant Information Sheet | Version 4 | 11 July 2011 |
| Protocol | Version 2 | 12 July 2011 |
| REC application | 3.1 | 18 May 2011 |
| Referees or other scientific critique report | | 19 November 2010 |
| Response to Request for Further Information | Cover letter | 12 July 2011 |

**Statement of compliance**

The Committee is constituted in accordance with the Governance Arrangements for Research Ethics Committees (July 2001) and complies fully with the Standard Operating Procedures for Research Ethics Committees in the UK.

**After ethical review**

Reporting requirements

The attached document *"After ethical review – guidance for researchers"* gives detailed guidance on reporting requirements for studies with a favourable opinion, including:

- Notifying substantial amendments
- Adding new sites and investigators
- Notification of serious breaches of the protocol
- Progress and safety reports
- Notifying the end of the study

The NRES website also provides guidance on these topics, which is updated in the light of changes in reporting requirements or procedures.

Feedback

You are invited to give your view of the service that you have received from the National Research Ethics Service and the application procedure. If you wish to make your views known please use the feedback form available on the website.

Further information is available at National Research Ethics Service website > After Review

| | |
|---|---|
| **11/NE/0159** | **Please quote this number on all correspondence** |

With the Committee's best wishes for the success of this project

Yours sincerely

pp

**Professor Peter Heasman**
**Chair**

Email: kerri.jude@sotw.nhs.uk

*Enclosures:* "After ethical review – guidance for researchers"

*Copy to:* *Mrs Rachel De Souza, Faculty Research Office, Room 10.110, Level 10, Worsley Building, Clarendon Way, Leeds, LS2 9NL*

*Dr Derek Norfolk, Leeds Teaching Hospitals Trust, 34 Hyde Terrace, Leeds, LS2 9LN*

*University Ethical Approval for Experiment One*

Certificate of ethical approval
#11-0257

Title: Contributions of the left and right hemisphere
in language: Investigating the effects of unilateral

Researcher(s):

Supervisor: Ekaterini Klepousniotou

Date of approval: 29 November 2011

Ethics committee of the Institute of Psychological Sciences, Leeds University

*University Ethical Approval for Experiment 3*

Certificate of ethical approval
#12-0072

Title: Contributions of the left and right hemisphere
in language: Investigating hemispheric effects on
Supervisor: Ekaterini Klepousniotou

Date of approval: 17 March 2012

This certificate confirms that the named project
has received approval from the ethics committee.
This certificate can be used in student projects.
The name of the student will not be listed, but
can be requested from the ethics committee.

Ethics committee of the Institute of Psychological Sciences, Leeds University

## Appendix 2: Consent Form Example

Leeds Institute of
Health Sciences
FACULTY OF MEDICINE AND HEALTH

UNIVERSITY OF LEEDS

**CONSENT FORM: Version 3: 10/01/11**

Participant Identification Number for this study : ☐

Research Study Title: Contributions of the left and right hemisphere in language: Investigating the effects of unilateral brain damage (stroke) on metaphor processing

Name of Researcher: Celia Wild

Please initial box

I confirm that I have read and understand the information sheet dated ________ for the above study. I have had the opportunity to consider the information, ask questions and have had these answered satisfactorily. ☐

I understand that I have been asked to participate in a research study that explores how damage to the brain after stroke affects language understanding. ☐

I have been fully informed of the purpose of the research by the researcher undertaking the work and it has been explained to me that my participation is entirely voluntary. I understand that I am entitled to withdraw from the study at any time without prejudice. ☐

I give permission for the researcher to have access to my records. ☐

I also understand that any information I offer will be treated anonymously and all material arising out of the study will be dealt with on a confidential basis by the researcher involved. The research complies with the Data Protection Act (1998). ☐

I have read and understood the above information and agree to participate in the named study. ☐

| | | |
|---|---|---|
| ________________ | ________________ | ________________ |
| Name of Participant | Date | Signature |
| ________________ | ________________ | ________________ |
| Name of researcher | Date | Signature |

Appendix 3: Participant Information Sheet Example

Leeds Institute of
Health Sciences
FACULTY OF MEDICINE AND HEALTH

UNIVERSITY OF LEEDS

## Participant Information Sheet
## Version 4: 11/07/11

Research Study Title: Contributions of the left and right hemisphere in language: Investigating the effects of unilateral brain damage (stroke) on metaphor processing

### Invitation paragraph

I would like to invite you to take part in a research study. Before you decide you need to understand why the research is being done and what it would involve for you. Please take time to read the following information carefully. Talk to others about the study if you wish. Ask me if there is anything that is not clear or if you would like more information. Please take time to decide whether or not you wish to take part.

### What is the purpose of the study?

I am a PhD researcher in the Leeds Institute of Health Sciences at the University of Leeds. I am interested in finding out how the brain processes language. This is of use when thinking about assessment and treatment for people who have suffered a stroke. Little is currently known about how the right side of the brain processes language although it is acknowledged that people who suffer damage do show difficulties.

### Why have I been invited?

If you have suffered a stroke, you have been asked to take part so that we can investigate how you process language.

If you have not suffered a stroke, you have been asked to take part so that we can investigate how normal language processing occurs in healthy adults compared to people who have suffered a stroke. You have been identified as being demographically similar in many ways, e.g. age, background, education etc, to the participants of the research who have suffered a stroke.

### Do I have to take part?

It is up to you to decide. I will describe the study and go through this information sheet, which I will then give to you. I will then ask you to sign a consent form to show you have agreed to take part. You are free to withdraw at any time during the project, without giving a reason. This would not affect the standard of care you receive.

**What will happen to me if I take part?**

I will visit you to ask you to take part in a series of experiments using a computer. I will need to see you 2 or 3 times and each visit will take about an hour of your time.

**Will my taking part in the study be kept confidential?**

I will follow ethical and legal practice and all information about you will be handled in confidence. At no time will you be identified by name. No information that I keep will be able to be linked to you personally.

**What are the possible benefits of taking part?**

We hope that your taking part in the study will give you the opportunity to explore any language understanding difficulties you may have further and to inform research into your condition which will be of benefit to services assessing and treating those who have suffered stroke. Results we gather from this project may help to inform future research in this area.

**What if there is a problem/ complaint?**

If you have a concern about any aspect of this study, you should ask to speak to the researcher who will do her best to answer your questions (contact information at the end of the information sheet). If you remain unhappy and wish to complain formally, you can do this through the NHS Complaints Procedure. Details can be obtained from the recruitment centre.

Complainants and Complains Manager
Leeds Teaching Hospitals NHS Trust
Trust Headquarters,
St James University Hospital,
Beckett Street,
Leeds, LS9 7TF
0113 206 6261

**What will happen to the results of the research study?**

The results will be published in medical journals and disseminated at research seminars and conferences. Results from this project may be included in future projects. You will not be identified in any way in the published reports. If you would like me to send you a copy of any papers published, please let me know.

**Who is organising and funding the research?**

The principle investigator for this study is Mrs Celia Wild and the study is being run between the Leeds Institute of Health Sciences at the University of Leeds and the Leeds Teaching Hospitals NHS Trust. The study is funded by a grant from the University of Leeds.

## Who has reviewed the study?

The research has been reviewed by a panel organised by the University of Leeds as part of the requirements of the main researcher's doctoral training. All research in the NHS is looked at by independent group of people, called a Research Ethics Committee to protect your safety, rights, wellbeing and dignity. As such it has also been reviewed by NRES Committee North East- Northern and Yorkshire ethics committee, and was given a favourable ethical opinion for conduct within the NHS. It was also reviewed and approved by Leeds Teaching Hospitals NHS Trust R&D department.

## Where can I find out more information?

If you would like more information about taking part in this project, please contact

Mrs Celia Wild at:

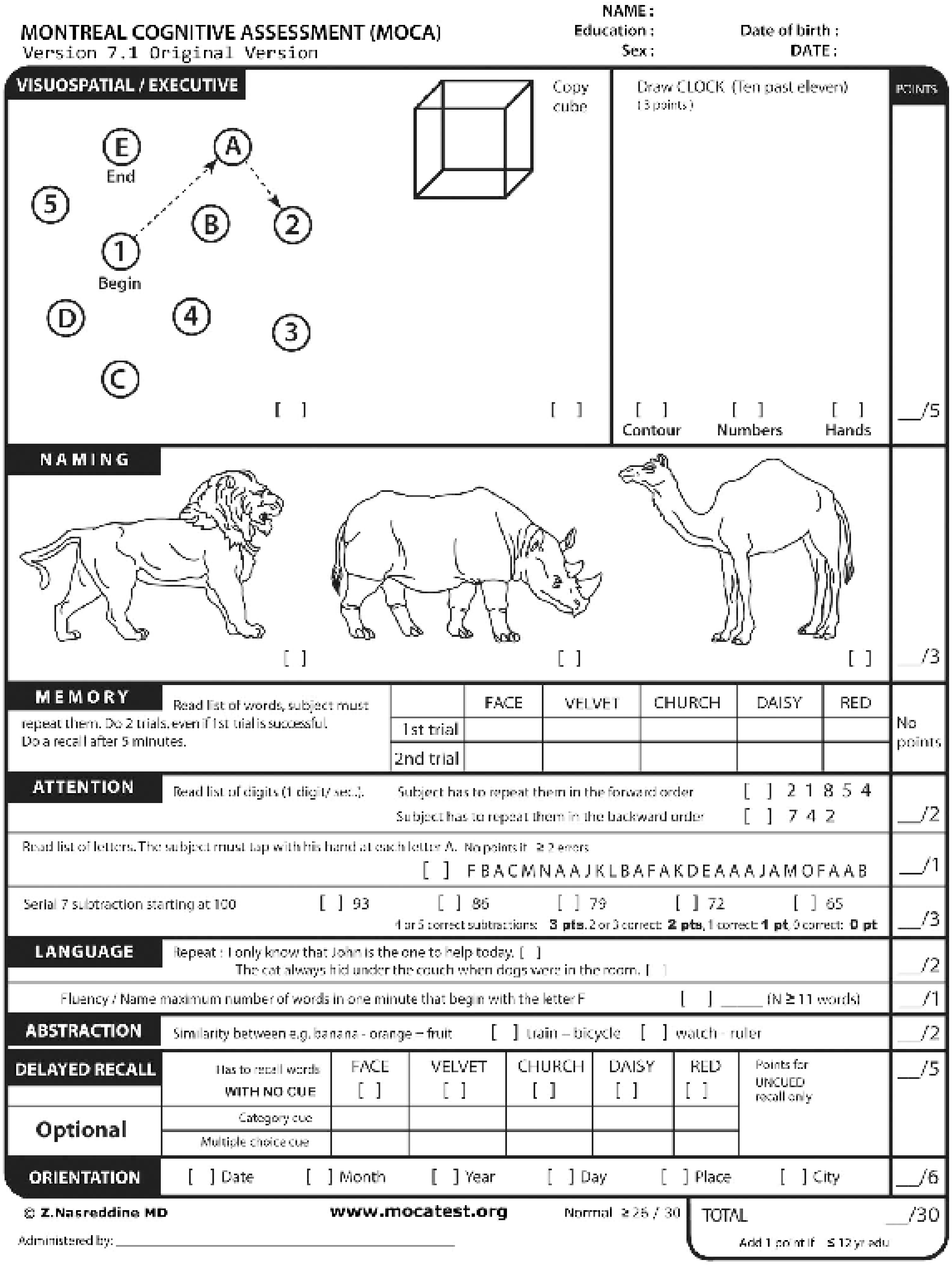
Clinical Psychology Programme
Leeds Institute of Health Sciences
University of Leeds
Charles Thackrah Building
101 Clarendon Road
Leeds LS2 9LJ

Tel: 0113 233 2732 or 07970 820710

Email: umcw@leeds.ac.uk

**Thank you for thinking about taking part in this study**

# Appendix 4: MoCA



NAME :
Education :
Date of birth :
Sex :
DATE :

**MONTREAL COGNITIVE ASSESSMENT (MOCA)**
Version 7.1 Original Version

POINTS

**VISUOSPATIAL / EXECUTIVE**

[ ]

Copy cube

[ ]

Draw CLOCK (Ten past eleven)
(3 points)

[ ] Contour
[ ] Numbers
[ ] Hands

___/5

**NAMING**

[ ]
[ ]
[ ]

___/3

**MEMORY**

Read list of words, subject must repeat them. Do 2 trials, even if 1st trial is successful.
Do a recall after 5 minutes.

| | FACE | VELVET | CHURCH | DAISY | RED |
|---|---|---|---|---|---|
| 1st trial | | | | | |
| 2nd trial | | | | | |

No points

**ATTENTION**

Read list of digits (1 digit/ sec.).
Subject has to repeat them in the forward order [ ] 2 1 8 5 4
Subject has to repeat them in the backward order [ ] 7 4 2
___/2

Read list of letters. The subject must tap with his hand at each letter A. No points if ≥ 2 errors
[ ] F B A C M N A A J K L B A F A K D E A A A J A M O F A A B
___/1

Serial 7 subtraction starting at 100 [ ] 93 [ ] 86 [ ] 79 [ ] 72 [ ] 65
4 or 5 correct subtractions: **3 pts**, 2 or 3 correct: **2 pts**, 1 correct: **1 pt**, 0 correct: **0 pt**
___/3

**LANGUAGE**

Repeat : I only know that John is the one to help today. [ ]
The cat always hid under the couch when dogs were in the room. [ ]
___/2

Fluency / Name maximum number of words in one minute that begin with the letter F [ ] _____ (N ≥ 11 words)
___/1

**ABSTRACTION**

Similarity between e.g. banana - orange = fruit [ ] train – bicycle [ ] watch - ruler
___/2

**DELAYED RECALL**

| | | FACE | VELVET | CHURCH | DAISY | RED | |
|---|---|---|---|---|---|---|---|
| | Has to recall words **WITH NO CUE** | [ ] | [ ] | [ ] | [ ] | [ ] | Points for UNCUED recall only |
| **Optional** | Category cue | | | | | | |
| | Multiple choice cue | | | | | | |

___/5

**ORIENTATION**

[ ] Date [ ] Month [ ] Year [ ] Day [ ] Place [ ] City
___/6

**www.mocatest.org**

Normal ≥ 26 / 30

TOTAL ___/30
Add 1 point if ≤ 12 yr edu

Administered by: ________________________

# Appendix 5: Handedness inventory

**<u>Handedness Inventory</u>** (Modified from Annett, 1967. Source: Briggs & Nebes, 1975)

Participant identifier: Date:

Are either of your parents left handed? If yes, which? ________________________

| **Indicate hand preferences** | **Always left (-2)** | **Usually left (-1)** | **No preference (0)** | **Usually right (1)** | **Always right (2)** |
|---|---|---|---|---|---|
| 1. To write a letter legibly | | | | | |
| 2. To throw a ball to hit a target | | | | | |
| 3. To play a game acquiring the use of a racquet | | | | | |
| 4. At the top of the broom to sweep dust from the floor | | | | | |
| 5. At the top of a shovel to move sand | | | | | |
| 6. To hold a match whilst striking it | | | | | |
| 7. To hold scissors to cut paper | | | | | |
| 8. To hold thread to guide through the eye of a needle. | | | | | |
| 9. To deal playing cards | | | | | |
| 10. To hammer a nail into wood | | | | | |
| 11. To hold a toothbrush while cleaning teeth | | | | | |
| 12. To screw the lid of a jar | | | | | |
| **Column total:** | | | | | |
| **Total score**<br>(range – 24 to +24) | | | | | |
| **Designation:** | Right handed (+9 and above)<br>Mixed handed (-8 - +8)<br>Left handed (-9 and below) | | | | |

How many siblings of each sex do you have? Male _________ Female ____________

How many of each sex are left handed? Male ___________ Female __________

Which eye do you use when only using one? Eg, telescope, keyhole. _____________

Have you ever suffered any severe head trauma? _____________________________

# Appendix 6: Auditory digit span test*

Instructions (to be read to client)

I am going to say some numbers. Listen carefully and when I am finished say them right after me.

(Digits are read at the rate of 1 per second. Pitch of voice should drop on the last digit)

| Item | Stimulus | Response | Y/N |
|---|---|---|---|
| 1 | 2 – 4 | | |
| | 6 – 3 | | |
| 2 | 5 – 8 – 2 | | |
| | 6 – 9 – 4 | | |
| 3 | 6 – 4 – 3 – 9 | | |
| | 7 – 2 – 8 – 6 | | |
| 4 | 4 – 2 – 7 – 3 – 1 | | |
| | 7 – 5 – 8 – 3 – 6 | | |
| 5 | 6 – 1 – 9 – 4 – 7 – 3 | | |
| | 3 – 9 – 2 – 4 – 8 – 7 | | |
| 6 | 5 – 9 – 1 – 7 – 4 – 2 – 8 | | |
| | 4 – 1 – 7 – 9 – 3 – 8 – 6 | | |
| 7 | 5 – 8 – 1 – 9 – 2 – 6 – 4 – 7 | | |
| | 3 – 8 – 2 – 9 – 5 – 1 – 7 – 4 | | |

Discontinue after 2 incorrect trials

*Basic layout taken from WAIS III (Wechsler, 1997)

## Appendix 7: Experimental Stimuli

*Conventional Metaphors*

| Conventional Metaphors | Literal Related Target | Metaphorical related target | Unrelated target |
|---|---|---|---|
| The meringue was a feather on the plate | Wing | Airy | Toilet |
| The corridor was like Piccadilly Circus | Terminal | Hectic | Rinse |
| She danced her socks off to the music | Naked | Swift | Debate |
| The man's face looked as white as a sheet | Linen | Ashen | Banana |
| The snow fell on the hills like a blanket | Cloak | Conceal | Clash |
| He was wet behind the ears in his first job | Damp | Naive | Script |
| She watched her favourite TV programme religiously | Prayer | Routine | Remark |
| Life is no bed of roses | Flower | Tough | Replace |
| That was too much information to digest | Appetite | Absorb | Fusion |
| Helen had green fingers in her garden | Stain | Adept | Symptom |
| The prices in the sale were a steal | Rob | Cheap | Pause |
| The laser printer ate the paper | Food | Ripped | Coarse |
| Her letter was a dagger in his heart | Knife | Broken | Rabbit |
| Jim was spitting feathers after what happened | Bird | Mad | Myth |
| He was the brightest student in the class | Gleam | Talented | Prophet |
| He sank into the featherbed, enjoying its soft embrace | Squeeze | Luxury | Ashamed |
| It was hard to see the road, the air was so soupy | Broth | Foggy | Huddle |
| This game isn't over till the fat lady sings | Choir | Whistle | Squat |
| Robert didn't spill the beans | Careful | Secret | Settled |
| The Christmas stocking was stuffed to the gills | Lungs | Excess | Locking |
| The teacher had trouble with the student’s hieroglyphics | Egypt | Scribbled | Hinted |
| He wore his clothes like a tent | Camping | Obesity | Turmoil |
| Her jeans fitted like a glove | Mitten | Snug | Batter |
| Harry told Peter to take a hike | Ramble | Dismiss | Gravy |
| After the party he was a bear with a sore head | Forest | Pain | Mission |
| His heart flooded with emotion | Pond | Overcome | Tribute |
| The shop keeper bent over backwards for the woman | Flexible | Helpful | Insist |
| She had a reputation for speaking her mind | Whisper | Truthful | Gunfire |
| After a mistake Jane was back at square one | Dice | Onset | Tangent |
| Janet was the light of John's life | Lamp | Passion | Plaster |

*Novel metaphors*

| Novel metaphors | Literal Related Target | Metaphorical related target | Unrelated target |
|---|---|---|---|
| This city is a chimney | Hearth | Grubby | Winder |
| The politician who didn't give straight answers was jumping ditches | Sport | Dodge | Nurse |
| The meaning of life is an itch you can't scratch | Rash | Arduous | Biscuit |
| The newly wed's heart was a lovebird's egg | Shell | Fragile | Compose |
| The stubborn old man was a tram | Transport | Rigid | Cannon |
| The student had a headache a yard wide | Mile | Huge | Fill |
| Paul has the sense of a goose | Duck | Foolish | Curtain |
| The pretentious young lady was 100% polyester | Nylon | Inane | Bribe |
| The conceited boy could put out Hell with one bucket of water | Blaze | Cocky | Tasty |
| The close friends were a bag of toffees | Sticky | Faithful | Wicked |
| The situation yielded a crop of stars | Planet | Fortune | Circuit |
| Their cross mother was an elastic band | Stationery | Snap | Shrine |
| The shoppers at the sale were ants at a picnic | Insect | Devour | Scandal |
| The man who won the pools was a dog with the biggest bone | Canine | Bliss | Shred |
| The lady's jewels were bursting stars | Satellite | Sparkle | Uneven |
| The outlandish model was a blue canary | Pigeon | Vibrant | Chilly |
| Their style has a new direction | Map | Vogue | Rack |
| The flowers were watered by nature’s tears | Crying | Shower | Razor |
| The teenager’s face was a coral reef | Pink | Spot | Hero |
| In the photograph he was doing a Napoleon | Duke | Salute | Circus |
| The cheap cushion seemed stuffed with old rocks | Pebble | Lumpy | Cremate |
| In the spring the brown branches are covered in tiny emeralds | Gem | Leaf | Hips |
| A night of heavy drinking makes your stomach a whirlpool | Swim | Upset | Lever |
| Before gargling his breath smelled swampy | Soil | Sick | Gold |
| After a week of no rain the plants were panting | Breathe | Wilt | Plead |
| Alzheimer’s slowly destroys one’s hard-drive | Storage | Brain | Lawyer |
| The therapist helped the patient reach shore | Travel | Solution | Circle |
| Tower blocks are the giraffes of the city | Zebra | Lofty | Tripod |
| Sermons are like sleeping pills | Medicine | Dull | False |
| Many mountain roads seem like snakes | Serpent | Twisty | Cinder |

*Literal Sentences*

| Literal Sentences | Literal Related Target | Unrelated target 1 | Unrelated target 2 |
|---|---|---|---|
| The little girl observed that keys make good rattles | Toy | Nun | Keg |
| The singer realised that the men were fans | Cheer | Arctic | Loaf |
| Joe used his fingers as signals showing the way | Route | Inch | Intense |
| The interior designer used cubes as tables | Creative | Bread | Funny |
| The boy used a plastic bag as a rain hat | Protect | Arrive | Seized |
| The young musician used shells as instruments | Bell | Realm | Hostile |
| The hunter used the tiger as a rug | Carpet | Tennis | Boost |
| The office boy used stones as paper weights | Gust | Baron | Banjo |
| The old man used a branch as a walking stick | Prop | Halt | Coin |
| The gardener used buckets as plant pots | Pitcher | Auto | Motive |
| Jane opened the box of biscuits | Cookie | Envy | Strive |
| Henry bought fish and chips for tea | Lunch | Mature | Gallery |
| Helen is a talented pianist | Skill | Hurt | Drunk |
| Sarah used a folder to keep papers together | Tidy | Garbage | Blossom |
| The garden was covered with a thick layer of leaves | Mulch | Cable | Bargain |
| Sue was happy Santa had only left crumbs | Scrap | Brisk | Postal |
| The baby cried and upset her mother | Misery | Potato | Lawn |
| Seals swim better than they can walk | Crawl | Tackle | Hunt |
| The chef used tongs to grip the food | Clutch | Prompt | Infant |
| The hairdresser styled Jane's hair | Clean | China | League |
| The athlete usually swims for two hours | Muscle | Spoken | Belong |
| She was cooking dinner a while ago | Eating | Damage | Affair |
| Jim's girlfriend dances at school | Tango | Robin | Ranger |
| Sue always buys milk for the children | Cow | Motel | Jump |
| Jane was very sad five days ago | Emotion | Pencil | Beer |
| Frank watches TV quietly and alone | Lonely | Laugh | Cloud |
| Fred counts his money very carefully | Thrift | Badge | Marrow |
| Sue's boyfriend is playing tennis | Racket | Fairy | Garlic |
| The dog enjoyed digging a hole | Hide | Frozen | Suite |
| Alice is very kind to her sister | Loving | Killer | Protein |

## Appendix 8: Single Case Analysis Results

Results from computer programme designed by Crawford implementing Bayesian methods for comparison of a single-case's score to scores obtained in a control sample. The interval estimate of the effect size for the difference between case and controls is obtained using Bayesian methods. Programme freely available on the internet (Crawford, 2012).
Results in the tables are described as follows:

- Column One: Sentence type (CM, conventional metaphor; NM, novel metaphor; LS, literal sentence) and Target type (LR, literal related; MR, metaphorical related; UR, unrelated)
- Column Two: One tailed probability refers to the probability that a member of the control population would obtain a lower score than the participant (Bayesian hypothesis test).
- Column Three: Effect Size is the effect size (Z-CC) for difference between case and controls (plus 95% CI) – significant effect size at 2 and over marked with **, approaching this marked as *
- The final 3 columns refer to a Bayesian point estimate of percentage of control population falling below case's score, 95% lower credible limit on the percentage and 95% upper credible limit on the percentage.

Tables 11-14 present the results for the first left-hemisphere damaged participant (LHD01) at 100ms and 1000ms time intervals, while Tables 15-18 present the results for the second left-hemisphere damaged participant (LHD02) at 100ms and 1000ms time intervals.

| | One-tailed probability | Z-Score Effect size | Bayesian point estimate % | 95% lower credible limit | 95% upper credible limit |
|---|---|---|---|---|---|
| **CM-LR** | 0.008 | 2.710**<br>(1.740 to 3.659) | 99.20% | 95.90% | 99.99% |
| **CM-MR** | 0.010 | 2.613**<br>(1.670 to 3.536) | 99.02% | 95.25% | 99.98% |
| **CM-UR** | 0.338 | 0.436<br>(-0.030 to 0.889) | 66.22% | 48.82% | 81.31% |
| **NM-LR** | 0.000 | 5.084**<br>(3.416 to 6.737) | 100.00% | 99.97% | 100.00% |
| **NM-MR** | 0.122 | 1.234<br>(0.637 to 1.809) | 87.83% | 73.81% | 96.48% |
| **NM-UR** | 0.302 | 0.540<br>(0.062 to 1.003) | 69.78% | 52.49% | 84.21% |
| **LS-LR** | 0.001 | 3.793**<br>(2.511 to 5.056) | 99.92% | 99.40% | 100.00% |
| **LS-URA** | 0.274 | 0.627<br>(0.138 to 1.101) | 72.62% | 55.50% | 86.45% |
| **LS-URB** | 0.330 | 0.457<br>(-0.011 to 0.91) | 66.96% | 49.57% | 81.92% |

**Table 11: Single case analysis of LHD01 reaction time data at 100ms**

| | One-tailed probability | Z-Score Effect size | Bayesian point estimate % | 95% lower credible limit | 95% upper credible limit |
|---|---|---|---|---|---|
| **CM-LR** | 0.000 | 4.628**<br>(3.098 to 6.142) | 99.99% | 99.90% | 100.00% |
| **CM-MR** | 0.001 | 3.829**<br>(2.537 to 5.104) | 99.93% | 99.44% | 100.00% |
| **CM-UR** | 0.186 | -0.938<br>(-1.458 to -0.40) | 18.57% | 7.24% | 34.45% |
| **NM-LR** | 0.000 | 5.046**<br>(3.390 to 6.687) | 100.00% | 99.97% | 100.00% |
| **NM-MR** | 0.002 | 3.474**<br>(2.286 to 4.644) | 99.85% | 98.89% | 100.00% |
| **NM-UR** | 0.490 | -0.025<br>(-0.463 to 0.41) | 49.03% | 32.16% | 66.04% |
| **LS-LR** | 0.003 | 3.250**<br>(2.127 to 4.354) | 99.75% | 98.33% | 100.00% |
| **LS-URA** | 0.216 | -0.823<br>(-1.324 to -0.31) | 21.59% | 9.27% | 38.01% |
| **LS-URB** | 0.146 | -1.113<br>(-1.665 to -0.54) | 14.55% | 4.79% | 29.41% |

**Table 12: Single case analysis of LHD01 accuracy data at 100ms**

| | One-tailed probability | Z-Score Effect size | Bayesian point estimate % | 95% lower credible limit | 95% upper credible limit |
|---|---|---|---|---|---|
| **CM-LR** | 0.061 | 1.661*<br>(0.968 to 2.334) | 93.93% | 83.34% | 99.02% |
| **CM-MR** | 0.024 | 2.157**<br>(1.338 to 2.956) | 97.56% | 90.95% | 99.84% |
| **CM-UR** | 0.420 | -0.209<br>(-0.649 to 0.237) | 42.03% | 25.81% | 59.37% |
| **NM-LR** | 0.010 | 2.604**<br>(1.663 to 3.524) | 99.00% | 95.18% | 99.98% |
| **NM-MR** | 0.003 | 3.133**<br>(2.043 to 4.203) | 99.68% | 97.95% | 100.00% |
| **NM-UR** | 0.455 | -0.117<br>(-0.555 to 0.325) | 45.53% | 28.96% | 62.73% |
| **LS-LR** | 0.000 | 6.097**<br>(4.120 to 8.060) | 100.00% | 100.00% | 100.00% |
| **LS-URA** | 0.459 | -0.106<br>(-0.544 to 0.335) | 45.93% | 29.32% | 63.11% |
| **LS-URB** | 0.487 | 0.035<br>(-0.404 to 0.473) | 51.34% | 34.31% | 68.19% |

**Table 13: Single case analysis of LHD01 reaction time data at 1000ms**

| | One-tailed probability | Z-Score Effect size | Bayesian point estimate % | 95% lower credible limit | 95% upper credible limit |
|---|---|---|---|---|---|
| **CM-LR** | 0.000 | 4.394**<br>(2.934 to 5.837) | 99.98% | 99.83% | 100.00% |
| **CM-MR** | 0.133 | 1.176<br>(0.592 to 1.740) | 86.74% | 72.30% | 95.91% |
| **CM-UR** | 0.135 | -1.167<br>(-1.729 to -0.584) | 13.46% | 4.19% | 27.94% |
| **NM-LR** | 0.000 | 4.073**<br>(2.708 to 5.419) | 99.96% | 99.66% | 100.00% |
| **NM-MR** | 0.006 | 2.866**<br>(1.852 to 3.860) | 99.42% | 96.80% | 99.99% |
| **NM-UR** | 0.167 | -1.018<br>(-1.552 to -0.465) | 16.66% | 6.04% | 32.10% |
| **LS-LR** | 0.000 | 4.246**<br>(2.830 to 5.645) | 99.97% | 99.77% | 100.00% |
| **LS-URA** | 0.281 | -0.605<br>(-1.075 to -0.119) | 28.11% | 14.12% | 45.25% |
| **LS-URB** | 0.258 | -0.678<br>(-1.158 to -0.183) | 25.81% | 12.34% | 42.75% |

**Table 14: Single case analysis of LHD01 accuracy data at 1000ms**

| | One-tailed probability | Z-Score Effect size | Bayesian point estimate % | 95% lower credible limit | 95% upper credible limit |
|---|---|---|---|---|---|
| **CM-LR** | 0.015 | 2.420**<br>(1.529 to 3.289) | 98.55% | 93.69% | 99.95% |
| **CM-MR** | 0.071 | 1.571*<br>(0.899 to 2.222) | 92.91% | 81.58% | 98.68% |
| **CM-UR** | 0.034 | 1.987*<br>(1.212 to 2.741) | 96.62% | 88.72% | 99.69% |
| **NM-LR** | 0.007 | 2.789**<br>(1.797 to 3.762) | 99.32% | 96.38% | 99.99% |
| **NM-MR** | 0.013 | 2.485**<br>(1.577 to 3.372) | 98.73% | 94.26% | 99.96% |
| **NM-UR** | 0.153 | 1.080<br>(0.514 to 1.625) | 84.74% | 69.64% | 94.79% |
| **LS-LR** | 0.005 | 2.959**<br>(1.918 to 3.979) | 99.53% | 97.25% | 100.00% |
| **LS-URA** | 0.116 | 1.266<br>(0.663 to 1.849) | 88.42% | 74.64% | 96.78% |
| **LS-URB** | 0.065 | 1.625*<br>(0.940 to 2.288) | 93.53% | 82.65% | 98.89% |

**Table 15: Single case analysis of LHD02 reaction time data at 100ms**

| | One-tailed probability | Z-Score Effect size | Bayesian point estimate % | 95% lower credible limit | 95% upper credible limit |
|---|---|---|---|---|---|
| **CM-LR** | 0.076 | 1.533*<br>(0.870 to 2.174) | 92.44% | 80.78% | 98.52% |
| **CM-MR** | 0.021 | 2.242**<br>(1.400 to 3.063) | 97.93% | 91.93% | 99.89% |
| **CM-UR** | 0.000 | 4.104**<br>(2.730 to 5.459) | 99.96% | 99.68% | 100.00% |
| **NM-LR** | 0.453 | 0.123<br>(-0.318 to 0.562) | 54.72% | 37.51% | 71.29% |
| **NM-MR** | 0.008 | 2.739**<br>(1.761 to 3.697) | 99.25% | 96.09% | 99.99% |
| **NM-UR** | 0.002 | 3.282**<br>(2.150 to 4.396) | 99.77% | 98.42% | 100.00% |
| **LS-LR** | 0.038 | 1.917*<br>(1.159 to 2.652) | 96.15% | 87.69% | 99.60% |
| **LS-URA** | 0.000 | 4.266**<br>(2.845 to 5.671) | 99.97% | 99.78% | 100.00% |
| **LS-URB** | 0.000 | 4.541**<br>(3.037 to 6.028) | 99.99% | 99.88% | 100.00% |

**Table 16: Single case analysis of LHD02 accuracy data at 100ms**

| | One-tailed probability | Z-score Effect size | Bayesian point estimate % | 95% lower credible limit | 95% upper credible limit |
|---|---|---|---|---|---|
| **CM-LR** | 0.006 | 2.878**<br>(1.860 to 3.875) | 99.44% | 96.86% | 99.99% |
| **CM-MR** | 0.003 | 3.102**<br>(2.021 to 4.162) | 99.65% | 97.83% | 100.00% |
| **CM-UR** | 0.016 | 2.357**<br>(1.484 to 3.209) | 98.35% | 93.11% | 99.93% |
| **NM-LR** | 0.003 | 3.237**<br>(2.117 to 4.337) | 99.74% | 98.29% | 100.00% |
| **NM-MR** | 0.008 | 2.710**<br>(1.740 to 3.659) | 99.20% | 95.90% | 99.99% |
| **NM-UR** | 0.029 | 2.065**<br>(1.270 to 2.839) | 97.09% | 89.79% | 99.77% |
| **LS-LR** | 0.000 | 7.149**<br>(4.848 to 9.436) | 100.00% | 100.00% | 100.00% |
| **LS-URA** | 0.014 | 2.452**<br>(1.553 to 3.330) | 98.64% | 93.98% | 99.96% |
| **LS-URB** | 0.014 | 2.428**<br>(1.535 to 3.299) | 98.57% | 93.76% | 99.95% |

**Table 17: Single case analysis of LHD02 reaction time data at 1000ms**

| | One-tailed probability | Z-Score Effect size | Bayesian point estimate % | 95% lower credible limit | 95% upper credible limit |
|---|---|---|---|---|---|
| **CM-LR** | 0.151 | 1.088<br>(0.521 to 1.635) | 84.92% | 69.88% | 94.89% |
| **CM-MR** | 0.389 | -0.294<br>(-0.738 to 0.158) | 38.87% | 23.03% | 56.27% |
| **CM-UR** | 0.000 | 6.167**<br>(4.168 to 8.151) | 100.00% | 100.00% | 100.00% |
| **NM-LR** | 0.218 | 0.815<br>(0.297 to 1.313) | 78.17% | 61.69% | 90.55% |
| **NM-MR** | 0.062 | 1.646*<br>(0.957 to 2.315) | 93.77% | 83.06% | 98.97% |
| **NM-UR** | 0.000 | 3.982**<br>(2.645 to 5.302) | 99.95% | 99.59% | 100.00% |
| **LS-LR** | 0.395 | 0.278<br>(-0.173 to 0.721) | 60.54% | 43.15% | 76.47% |
| **LS-URA** | 0.000 | 5.040**<br>(3.386 to 6.680) | 100.00% | 99.96% | 100.00% |
| **LS-URB** | 0.003 | 3.107**<br>(2.025 to 4.170) | 99.66% | 97.86% | 100.00% |

**Table 18: Single case analysis of LHD02 accuracy data at 1000ms**