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EXPLORING THE ROLE OF THE TEMPORAL LOBES IN RELATIONAL MEMORY

BY

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Contents

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Thesis Abstract

Understanding the architecture of human memory has been a topic that researchers have endeavoured to research for over a hundred years. The first paper reviews a number of studies on human memory disorder following temporal lobe pathology. It demonstrates the importance of the medial temporal lobe structures in memory operations. Theoretical frameworks which have attempted to account for amnesic deficits and spared abilities are also reviewed. Whilst it is widely agreed that the medial temporal lobes are critical structures in memory functioning, controversy still exists regarding which conceptual framework can best account for human memory disorder. A number of research studies suggest that an important mechanism underlying memory functioning is one where memories are represented relationally (i.e. binding of memories to the context in which they occur). Evidence to support such a claim is critically reviewed and is shown to be limited and inconsistent. The paper concludes that supportive studies need to be replicated and relational theories made more precise for further advances to be made in this field.

The second paper describes a study which investigates different types of relational memory deficits in individuals with lesions to the temporal lobes and in healthy controls. The results suggested that implicit relational memory functioning may occur when damage to the medial temporal lobe is sustained, with left and right temporal groups performing at a similar level. The findings suggest that certain forms of relational memory deficit may therefore be lesion specific.

Literature Review Paper

The Temporal Lobes and Memory

Sarah J. Walker

This paper has been prepared for submission to Brain (see Appendix I for instructions for authors).

Running head: The Temporal Lobes and Memory

Volume I

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Summary

Human memory organisation has intrigued researchers for many years. Early studies conducted with humans who have suffered brain damage provided insight into the neural structures that are involved in memory, and these are generally agreed to be the medial temporal lobes. Lesions to this area result in the individual being unable to access some types of memory, whilst their ability to learn other skills is spared. The present paper reviews the literature surrounding human memory disorder following temporal lobe pathology. It begins by examining the neural structures associated with memory and residual memory functioning subsequent to temporal lobe damage. A number of theoretical frameworks have attempted to explain the deficits and spared learning abilities observed in individuals with amnesia. Particular frameworks are discussed, beginning with one that emphasises a distinction between declarative and procedural memories (Cohen and Squire, 1980). However, it is the mechanism that relates this information together so that it is accessible in normal memory functioning, which is of particular interest. Theories are discussed in relation to such a mechanism, especially that of the 'Relational Representation theory' (Eichenbaum *et al.* 1992a, b). This is an extension of the declarative-procedural framework, which suggests that relational memories are dependent upon the hippocampal system for successful binding of multiple arbitrary items. Whilst some suggestive findings support the notion of relational memory, in general evidence is lacking and inconsistent. It is proposed that studies require replicating and theoretical formulations made more precise to develop the notion of relational representation further.

Introduction

Historical perspective

"Our memories reflect the accumulation of a lifetime of experience and, in this sense, our memories are who we are." (Eichenbaum, 2002; p1.).

Understanding the nature of memory has been a topic of investigation in neuropsychology for many years. Researchers have puzzled over the sort of systems that could possibly encode the mass of information that we experience, and organise it efficiently so that it may be retrieved and utilised again in the future. Early theorists (e.g. Atkinson and Shiffrin, 1968) attempted to explain the architecture of memory as being divided up into different types of stores – a sensory store, which would hold information very briefly, a short-term store with limited capacity, and a long term store, which was defined as having essentially unlimited capacity and could hold information for extremely long periods of time. Little consideration was given to the type of information that these memory systems may handle, potentially resulting in further divisions in the memory systems.

Towards the middle of the twentieth century, research into memory processes and neural structures began to emerge in neuropsychology. Memory loss resulting from new surgical procedures and specific neurological disorders provided insight into the nature of memory deficits, and helped to define what such individuals were and were not able to do. Combined with advances in brain imaging, this research not only helped to challenge the idea of a unitary memory system but also highlighted specific brain structures that were thought to be essential for aspects of learning and memory. At the current time, it is generally agreed that the medial temporal lobes (MTL) are

involved in memory operations, in particular the hippocampus and associated MTL structures (known as the hippocampal system).

The exact role of the hippocampal system is still the focus of current research efforts. Numerous neuropsychological theories have been formulated in an attempt to account for the deficits that are exhibited by individuals with lesions to this brain region. The focus of this review paper will be to examine such issues that are pertinent in understanding memory functioning and organisation. Initially, the neuroanatomy of memory will be considered, including the structures that are critical to normal memory functioning and the neurological conditions which may disrupt memory functioning. Anatomical terminology that will be employed throughout this review will also be explained. Subsequently, the most relevant single-case studies in the field will be described, accompanied by an examination of impaired and spared memory functions that typically arise in individuals with hippocampal system lesions.

The major part of the paper will concentrate on understanding the typical memory deficits that are shown by individuals with amnesia. Although a variety of theories have attempted to do just this, special attention will be paid to a few. This includes an in-depth discussion of the declarative-procedural framework (Cohen and Squire, 1980), its features, the evidence for it and its problems. Further consideration will be given to those theories that extend this framework. In particular, those which focus on the representation of memories and the relationship between them will be discussed, including the configural-association theory (Sutherland and Rudy, 1989) and the relational representational theory (Eichenbuam *et al.*, 1992 a, b), with special

attention paid to the latter. Finally, consideration will be given to the evidence that is provided for the notion of relational memories, highlighting areas of disagreement and where issues have been neglected.

Neuroanatomy

Basic brain anatomy

Together with the spinal cord, the brain regulates bodily processes and co-ordinates voluntary movements. The cerebrum is the largest part of the brain and is divided into two hemispheres (the left and right) by a large crevice running from front to back known as the 'longitudinal fissure'. Despite this division, the hemispheres remain connected further down into the brain by a dense mass of fibres called the 'corpus callosum'. The cerebrum is also divided into four lobes – the frontal lobe, the temporal lobe, the parietal lobe and the occipital lobe. The outer layer of the cerebrum is known as the cortex or neocortex (both names are often used interchangeably). The cerebrum is thought to mediate complex conscious behaviour (Kolb and Whishaw, 1996).

Research into the localisation of cognitive functions within the brain is still far from conclusive. Many functions are not strictly assigned to one single localised brain region and hence abnormalities of such functions are often a result of fairly extensive, usually bilateral damage (Hodges, 1994). However, some specific cognitive functions have been found to be primarily associated with each of the four lobes identified within the cerebrum. Generally speaking, the frontal lobe is involved in higher-order cognitive functions such as planning, problem solving and motivation. The temporal lobe is associated with memory and language functions.

The parietal lobe includes such functions as perception and interpretation of sensory information and the occipital lobe detects and processes visual images (Smart, 2001). The temporal lobe is the structure that will be the focus of this paper, given its association with the memory system.

Structures associated with the memory

The medial structures of the temporal lobe have been demonstrated to be associated with the memory system. One of the major structures of the memory system within this region is that of the hippocampus. As well as being associated with learning and memory, the hippocampus also forms part of the limbic system, along with other structures such as the amygdala, the parahippocampal gyrus, the cingulate gyrus, the fornix and the midbrain. The limbic system plays an important role in the expression and drive of emotion and controls instinctive behaviour such as the fight/flight response.

Early studies into hippocampal damage and the resulting effects indicated that bilateral damage produced a global memory deficit (Eichenbaum and Cohen, 2001). However, from studies of humans with hippocampal damage, it became clear that the effects of damage were dependent on location of the lesion, in particular reflecting hemisphere specialisation of functioning. Functional imaging studies suggest that the left MTL is associated with verbal memory (e.g. learning lists of unrelated words (Kelley *et al.*, 1998)) and the right MTL is associated with nonverbal memory (e.g. learning spatial routes (Maguire *et al.*, 1997)). Therefore, unilateral damage to either of these regions is likely to result in deficits of verbal or nonverbal memory respectively.

Diseases that affect the MTL and memory

The medial temporal structures are vulnerable to many forms of brain injury. Aside from traumatic brain injury, cerebral anoxia is also a common cause of memory impairment. Various clinical situations produce hypoxia including cardiac arrest or anaesthetic accidents (e.g. Medalia *et al.*, 1991)

Autopsy studies have indicated that damage from anoxia is usually restricted to the hippocampal area, although it can occasionally be more extensive. Research suggests that a set of neurons in the hippocampus called the CA1 cells are particularly vulnerable to ischemic damage (Parkin and Leng, 1993). Cell death following ischemia is linked with the release of glutamate, which acts at the N-methyl-D-aspartate (NMDA) receptor. This receptor is thought to be involved in the memory consolidation process. There is a high concentration of NMDA receptors in CA1 cells of the hippocampus, thus accounting for its vulnerability to memory loss (Auer *et al.*, 1989).

Herpes simplex encephalitis (HSE) is a viral infection, which is characterised by initial symptoms of fever, headache and vomiting (Parkin and Leng, 1993). Rapid treatment is essential, otherwise severe brain damage may result (Schlitt *et al.*, 1986). Initially HSE attacks temporal lobe structures, presumably because this is near the site of infection entry near the cranial cavity (Davis and Johnson, 1979) or because the virus has a specific affinity to this brain region (Damasio and Van Hoeson, 1985). Therefore, memory impairment is commonly associated with the virus. The impairment is typically characterised by anterograde amnesia (i.e. memory for new information) and retrograde amnesia (i.e. memory for events that occurred prior to

the onset of the memory deficit). However, HSE may also attack other cortical structures (e.g. orbito-frontal cortex) resulting in symptoms of dysexective syndrome (such as poor word fluency and behavioural inhibition, Parkin and Leng, 1993).

Temporal lobe epilepsy (TLE) can also affect the MTL structures. Complex partial seizures in TLE usually have an epileptogenic focus in one of the hippocampi and neuroimaging also often demonstrates unilateral hippocampal pathology (Savage *et al.*, 2002). Treatment of epilepsy would typically involve medication for seizure control. However, in cases of intractable epilepsy that are medication resistant, surgery is considered (Cull and Goldstein, 1997). This involves the removal of pathological tissue and may include the anterior temporal neocortex, varying amounts of the hippocampus, the parahippocampus and the amygdala. In some cases a selective amygdala-hippocampectomy is preferred without the removal of adjacent neocortex (Smith, 1989). Surgery will only be considered where clear lateralisation of brain pathology is present.

Memory impairment represents the most common cognitive problem in patients with epilepsy (e.g. Broughton *et al.*, 1984). This is thought to be attributable to the loss of CA1 cells in the hippocampus (Smith, 1989). If surgery is an option, every effort is made to ensure that the patient's memory does not deteriorate post-operatively. The use of an intracarotid injection of sodium Amytal can provide information that may help to safeguard against this. This fast-acting drug is used to temporarily deprive patients of most cognitive functions in one hemisphere. If cognitive testing demonstrates that the remaining temporal lobe is unable to support memory

sufficiently, then surgery is usually precluded as a treatment option (Ojemann and Dodrill, 1985).

Should surgery be deemed appropriate, the extent of memory impairment post-operatively is likely to be dependent on a number of factors, in addition to the original damage to the hippocampal system (Eichenbaum, 1994). These factors include level of pre-operative memory functioning, the surgery itself (e.g. size of excision or amount of tissue resected. Olivier, 1987), and the extent to which patients are seizure free even when the hippocampus has been surgically spared (Ojemann and Dodrill, 1985).

Terminology

In the literature on the neural basis of human memory, there is often a lack of clarity in the terminology used. Many regard the hippocampus as the main structure involved in the memory system and thus only refer to this structure when discussing such issues. However, it is likely that other neighbouring structures also play a role. Eichenbaum and Cohen (2001) refer to the critical structures that are likely to be involved in memory as the 'hippocampal memory system'. From their research, they conclude that the major medial temporal lobe structures involved in memory include the hippocampus itself (comprises the CA fields, the dentate gyrus and the subiculum), the parahippocampal region (including the entorhinal and perirhinal cortex and the parahippocampal gyrus) and areas of the neocortex which are in close connection with the hippocampus and parahippocampal region. For the purposes of the present paper, when referring to the hippocampus and associated medial temporal structures the term 'hippocampal system' will be used.

The temporal lobes and memory

Single case studies and deficits in memory

Individuals with lesions to the hippocampal system have been the major source of insight into human memory functioning. One of the first major breakthroughs in the study of human amnesia arose from investigations of a patient known as HM (Scoville and Milner, 1957). He suffered from severe epileptic seizures for many years, thought to be precipitated by a childhood head injury. In an attempt to alleviate his intractable epilepsy, HM underwent an experimental surgical procedure, designed to stop his seizures. This included the removal of structures within the medial temporal lobe (i.e. hippocampus, parahippocampal cortex, the amgydala, piriform gyrus and uncus). The procedure was successful in that it largely relieved the epilepsy but it also left HM severely amnesic with hardly any other neurological deficit.

Another well studied single case was that of RB. He developed amnesia at the age of 52 years old following an ischemic event during open-heart surgery (Zola-Morgan *et al.*, 1986). He survived for 5 years, during which his cognitive functioning was assessed extensively, with the main finding being one of moderately severe memory impairment. Post-mortem examinations revealed a bilateral lesion in the CA1 area of the hippocampus.

When lesions occur in the hippocampal system, patients commonly exhibit certain characteristics. There is a marked impairment in the ability to learn new information after the onset of the memory deficit, known as anterograde amnesia (Eysenck and Keane, 1990). This impairment may be demonstrated by tasks requiring the

individual to recall or recognise new material, with poorer performance on recall than recognition (Hirst, 1982). These individuals also tend to experience varying degrees of difficulty in remembering information acquired before the brain injury, known as retrograde amnesia (Kolb and Whishaw, 1996).

As a point of clarity, individuals with damage to the hippocampal system are often referred to as 'amnesic' within the literature. Throughout this review both the terms of individuals with 'amnesia' or 'hippocampal system damage' will be used interchangeably to refer to this syndrome.

Spared learning

Surprisingly, some aspects of memory and skill learning are spared in individuals with damage to the hippocampal system. Short-term memory capacity remains intact, unless a delay in recalling information is added, in which case it deteriorates (Eichenbaum, 1994). It is also possible for individuals with damage to the hippocampal system to learn new skills. This is often characterised by using motor, perceptual and even cognitive procedures that tend to be acquired via repetition and incremental learning (Eichenbaum and Cohen, 2001). An example of the acquisition of motor skills would be learning to mirror draw. It was noticed that HM was able to learn to draw the contours of a five-point star only by seeing his hand in a mirror, and thus learning to make the movements in reverse. His performance improved with practice as did that of normal participants, although HM was unaware of having performed the task previously (Milner, 1962).

Individuals with amnesia may also learn skills relating to analysis and discrimination of perceptual information. This has included learning to respond to a repeated sequence of visual stimuli (e.g. asterisks), with learning being reflected in reduced response time, even though participants failed to notice the repeated pattern (Nissen and Bullemer, 1987). Furthermore, individuals with amnesia have been trained to read mirror-reversed words, where their learning rate (i.e. reduced reading time) was similar to controls (Cohen and Squire, 1980).

An example of learning cognitive skills would include HM's ability to learn the complex puzzle, 'the Tower of Hanoi'. Here, subjects are faced with a stack of five blocks on one of three pegs on a board. Their task is to move and restack the blocks on another peg by using certain rules: only one block may be moved at a time and a larger block may never be placed on a smaller one. HM and other individuals with similar deficits have been able to learn this task when they were consistently refocused on the strategy of repetitively restacking the sets of blocks as they went along (Cohen *et al.*, 1985).

Conditioning is another area where individuals with amnesia are able to show evidence of spared learning. This is defined as the acquisition of reflexive responses to stimuli that are repeatedly paired with an unconditioned stimulus, which elicits the reflex (Eichenbaum, 1994). One of the earliest demonstrations of this was provided by Claparede (1951), who hid a needle between his fingers and pricked the hand of an individual with Korsakoff's syndrome on greeting her with a handshake. After this, the individual was wary of shaking hands again although she could not recall a specific incident that would explain her behaviour. Conditioning has been

demonstrated several times in individuals with amnesia, including the measurement of eye-blinking, which was evoked by associating a tone-light (conditioned stimulus) with a puff of air in the eyes (unconditioned stimulus). Eye-blinking was measured during the conditioned stimulus condition in comparison to the unconditioned stimulus condition (Weiskrantz and Warrington, 1979). Intact conditioning was found in individuals with amnesia.

Individuals with amnesia have also been demonstrated to have intact performance on repetition priming tasks. This type of task would typically involve the presentation of 'target' items (e.g. words, line drawings). At a later time, stimuli with less information are displayed (old targets and new items). At short exposure durations, the stimuli would be presented subsequently in a priming paradigm which does not explicitly require a reflective response. If priming is established, then the presence of the stimulus will influence the participant's performance (e.g. reduced response time), even without conscious recollection (Vallar, 1999).

Priming has been demonstrated frequently using tasks such as 'word stem completion'. Participants are exposed to a list of words and are then subsequently shown fragmented parts of the words or are given the first three letters of the word. In either case they are asked to complete the word with the first word that comes to mind (e.g. Tulving and Schacter, 1990). Individuals with amnesia are able to produce the same amount of priming as controls when these conditions are met (Gardner *et al.*, 1973). However, if participants are explicitly instructed to complete the word by recalling one of the words from the list learnt earlier, individuals with amnesia do not show improved performance in comparison to the controls (Graf *et*

al., 1984). Some researchers also suggest that people with amnesia will not be successful at priming if the words presented are non-words (i.e. nonsensical strings of letters) (Shimamura and Squire, 1989). However, other research has demonstrated that non-word priming is possible in cases where participants have only mild memory impairment (Graf and Schacter, 1985).

From the evidence presented, it would appear that individuals with damage to the hippocampal system experience quite severe memory deficits for some information whilst their ability to learn certain new skills remains intact. These findings helped to support the notion of multiple systems involved in memory instead of a single solitary unit as previously thought. Furthermore, it also highlighted that these systems are reliant upon particular brain structures for their successful performance. Some types of memory appear to be dependent on the hippocampal system with other types being independent of it. But what is the nature of temporal lobe memory disorder? How can it be accounted for? Theoretical aspects will be discussed next.

Understanding the memory deficit in temporal lobe damage

Many theoretical formulations have been developed in an attempt to define and understand the exact nature of the memory deficit seen in individuals with damage to the hippocampal system. Early writings were supported by animal studies, which suggested that damage to the hippocampal system resulted in problems in the stage of memory processing, including consolidation (see Milner, 1970) or retrieval (see Gaffan, 1972). Alternative explanations examined the specific type of memory that individuals with amnesia were unable to process, for example place learning in the form of cognitive maps (see O'Keefe and Nadel, 1978). One of the most popular and

widely accepted accounts of hippocampal memory system impairment in humans was provided by Cohen and Squire (1980). This built on the finding that certain types of memory are inaccessible to those with amnesia (i.e. declarative memories) and some types of memory may be learned like anyone else (i.e. procedural memory). The details of this framework will be discussed next.

Declarative and procedural memory (Cohen and Squire, 1980)

This framework is based upon the premise that there are two distinct types of memory to account for the deficits and spared learning abilities that individuals with lesions to the hippocampal system show. Cohen and Squire (1980) differentiated between declarative and procedural memories as not only two distinct types of memory but also as differences in the nature of memory representation. Declarative memory is viewed as being similar to what Ryle (1949) referred to as 'knowing that'. It supports the ability to learn facts and knowledge, which may be applied flexibly to solve novel problems, and is subject to verbal reflection (Manns and Squire, 2001). Declarative memory relies upon an explicit or conscious awareness of what has been learnt, for successful recollection. The importance of conscious awareness in memory functioning was originally highlighted by Graf and Schacter (1985) but is often incorporated into the declarative-procedural framework in attempt to further explain the deficits in amnesia.

Additional theoretical distinctions have been made within the declarative system. Tulving (1984) distinguished between episodic and semantic memory. Episodic memory has an autobiographical flavour. It is viewed as containing an individual's personal experiences, permitting the ability to re-experience aspects of their own life.

On the other hand, semantic memory is thought to represent information about the world and factual knowledge that an individual acquires. Both episodic and semantic memories are thought to be available to conscious awareness and are dependent on the hippocampal system.

The alternative memory system to that of declarative memory is the procedural memory system. This type of memory is not available to conscious awareness and is acquired without deliberate effort (Beatty *et al.*, 1987), classified as an implicit memory (Graf and Schacter, 1985). These memories *can* be acquired by individuals when they experience damage to the hippocampal system, with the three major categories of procedural memory being skill acquisition, conditioning and priming (see earlier detailed discussion). Procedural memory is demonstrated by an improvement in specific task performance. Hence application of such knowledge is more rigid than that of declarative knowledge (Eichenbaum, 2002). Nevertheless, the fact that these memories are accessible to individuals with lesions to the hippocampal system implies that the procedural memory system is independent of this brain region (Cohen and Eichenbaum, 1991). The evidence suggests that this type of memory may rely on different brain regions such as the basal ganglia for the acquisition of motor skills, the cerebellum for successful conditioning and the neocortex for priming (Hodges, 1994). (Please see Appendix II for a visual taxonomy that represents the above framework as proposed by Squire (1998)).

Considerable amounts of evidence exist which demonstrate that declarative memory is impaired when the hippocampal system is damaged. Tests of recall and recognition are used as methods of measuring the acquisition of new declarative

memories as it requires the individual to reflect upon a specific episode. Findings in animal and human studies indicate that lesions to the hippocampal system result in fair performance in recall and recognition tasks if they are conducted immediately, given the intact state of the short-term memory. However, when a delay is added and participants are required to consciously reflect on the learning experience to provide an answer, then performance is poor. To investigate this idea in animals, Mishkin (1978) used a type of recognition task known as the 'delayed-non-matching/matching-to-sample'. This involves exposure to a series of stimuli and then the stimulus that matches/does not match the items that were learnt previously must be chosen. Mishkin discovered that monkeys with lesions to the hippocampal system were able to do this task reasonably well until a delay was added, when their performance deteriorated.

Although many have questioned the generalisability of animal studies to human performance, a similar paradigm to that used by Mishkin was conducted with HM showing similar effects (Milner, 1970). Difficult to verbalise auditory and visual stimuli were presented to HM and he was required to state whether the stimuli were the same or different. On immediate recall, HM's performance was normal but deteriorated with delay intervals longer than 10 – 60 seconds. Similar effects have been illustrated in individuals with amnesia for many recall and recognition studies, which include the recall and recognition of prose passages, or verbal paired-associate learning (Gloor, 1997).

Despite the wealth of evidence that supports the declarative-procedural memory distinction, some controversy exists within the literature regarding the subdivision of

declarative memory, namely the distinction between episodic and semantic memory. Given that both are considered to be subsystems of declarative memory and individuals with amnesia are supposedly poor at acquiring declarative memory, both episodic and semantic memories should also be impaired. Some research suggests that episodic and semantic memories are interdependent in functioning and that semantic memories arise as a result of episodic memories (Eysenck and Keane, 1990). Does this mean that without episodic memory, new semantic memories are inaccessible to individuals with amnesia, that the semantic knowledge that such individuals hold is learnt premorbidly?

The evidence suggests that it is possible for new semantic memories to be acquired in the absence of episodic memory. Gabrieli, *et al.* (1988) assessed HM to investigate his ability to acquire semantic knowledge whilst suffering from dense amnesia. Their findings suggested that HM incurred a slight increase in information such as recognising famous faces and recognising and defining words post-1950, although he had no episodic memories for this time.

Further evidence which suggests that semantic memories are accessible to the individual with amnesia is provided by the literature surrounding acquired amnesia in children. Vargha-Khadem *et al.* (1997) have described three children who at birth or at a young age suffered from hypoxia and were discovered as experiencing memory problems in childhood. All three experienced a severe impairment of episodic memory skills, as demonstrated by poor scores on recall and recognition tests. However, their normal performance on subtests of the Weschsler Intelligence Scale

for Children (WISC-III; Wechsler, 1992) such as the 'information' subtest indicated that their semantic skills had developed better than their episodic memories.

The difference in spared memory may suggest that semantic and episodic memory systems are stored independently. However critics remain sceptical of such a feat. Some have suggested that semantic information can be learnt using the known memory systems that are left intact in cases of hippocampal system lesions, namely procedural or implicit memories. For example, Maurer (1992) taught another individual with amnesia to learn names and even read, by embedding the information in stimulus-response sets of pairings that were repeated daily. However, these explanations cannot explain HM's performance. The gains that he made were too small to be feasibly attributed to the functioning of implicit learning, given that his performance for implicit memory tasks in other situations was at a normal level (Gabrieli *et al.*, 1988). An alternative explanation to such findings has been contributed by Vargha-Khadem *et al.* (1997). They suggest that although the episodic memory is impaired, enough functioning may be retained for the individual to acquire knowledge through repeated exposure in different contexts, thus providing the individual with context-free, factual information. Regardless of how the systems operate, semantic memory is accessible to consciousness and therefore remains characterised as an explicit memory, a component of the declarative memory along with episodic memory (Gloor, 1997).

The declarative-procedural framework as a whole is not without its drawbacks either. Many have argued that the distinctions made between the systems are too simplistic. In its basic form, the framework claims that differences in the systems lay in how the

memory skills are categorised, in particular, their availability to individuals with amnesia. However, this does not clearly explain the nature of memory processing deficits in amnesia (Eysenck and Keane, 1990). Despite its controversies, this framework has been useful and successful in understanding normal memory processes as well as those with damage to the hippocampal memory system.

One of the fundamental aspects of declarative memory is that these facts and personal experiences can be brought into consciousness to be expressed in a variety of different ways. Episodic and semantic memories appear to co-operate together, so that information can be compared and contrasted, thus enabling the individual to use the knowledge to make inferences and solve problems in novel situations (Cohen, 1984). The property of declarative memories that is thought to permit this process is that memories are encoded in terms of the *relations* among the many facts or events that are learnt, which is dependent on the hippocampal system (Cohen and Eichenbaum, 1993). The relational aspect of declarative memories is an important component of everyday memory, which, in its broadest sense, enables the individual to remember events or information in context. Examples of such memories may include recalling an event in the day, which is perhaps accompanied by visual images, tastes and smells (Tsukiura *et al.*, 2002). In addition, relational representation permits new memories to be combined with previous, related memories.

Several theories have attempted to explore the relational dimension of memories. It is beyond the scope of the paper to consider all theories that investigate such an area. Thus only the 'configural-association theory' (Sutherland and Rudy, 1989) and the

'relational representation theory' (Cohen and Eichenbaum, 1993; Eichenbaum *et al.*, 1992a, b) will be discussed in detail.

Configural-association theory (Sutherland and Rudy, 1989)

Configural-association theory suggests that during memory functioning, associations are made between stimuli, which may be multiple or simple. Sutherland and Rudy (1989) distinguish between two systems that they propose as important in the normal functioning of memory. The 'simple association system' is one system, thought to facilitate the development of elementary associations between stimuli. An example would be a typical conditioning situation, where perhaps a light and tone were presented in association with food, eventually resulting in a conditioned response (e.g. salivation) if either the light or tone were revealed.

The alternative system is that of the 'configural associations system'. These are considered to be more complex than simple associations, in that they consist of unique combinations of two or more elemental stimuli that stand in specific relationship to each other. This may include simultaneous occurrence, sequential occurrence or relative location. For example, simple associative learning may include simple conditioning, in which an auditory stimulus is paired with food and then a different stimulus is followed by the absence of food. However, the situation becomes more complex when these conditions are reversed with the addition of a light. Configural learning allows the complex relationship between all conditions to be stored. Once a configural association is created, then it may be evoked by only the presence of one of the elemental components that constitute it. Sutherland and

Rudy argue that the hippocampal system is essential for the construction of configural associations and without this only simple associations may be formed.

To illustrate their claims, Sutherland and Rudy used the 'negative patterning problem', in which two different stimuli are presented with a positive association when shown separately (e.g. reward of food), but a negative association when presented together (e.g. punishment by shock). They found that rats with lesions to the hippocampal memory system were unable to form the complex configural associations needed to solve this problem successfully, but were limited to developing simple associations only.

Rudy and Sutherland (1994) have also applied their configural-association theory to understanding human amnesia. Patient RB (described earlier) sustained selective damage to the hippocampal system bilaterally. Although his amnesia was not as dense as that of HM's, he still performed poorly on tasks such as verbal paired-associate learning and also on tests such as delayed story recall or word recognition. Rudy and Sutherland accounted for RB's performance by firstly noting that he had previous extensive experience with the material used to assess him (i.e. words), which were likely to be embedded in their own associative network with semantic links to other words. However, the problem that he had after his injury was his inability to determine whether the word that he retrieved was in fact related to a previous memory or was the newly acquired memory trace. Normal participants are able to conduct this task with ease, as they are able to create configural associations within the material learnt and reject those that are inappropriate on the basis of the

associative strength. Thus, RB was considered to be impaired in forming and retrieving configural associations.

However, this theory it is not without its criticisms. Several studies have attempted to replicate Sutherland and Rudy's findings but to no avail. Gallagher and Holland (1992) compared spatial learning with configural associations in animals with lesions to the hippocampal system. Their studies revealed that animals with hippocampal lesions performed worse than controls in a version of the Morris water maze, where animals were required to locate a platform submerged in opaque water from different starting points. However, the use of an operant discrimination task, which utilised light and tone conditions, resulted in animals with the hippocampal system lesions performing *better* than the controls. On this basis, it has been suggested that the configural-association theory may better account for spatial memory than it can configural learning (Nadel, 1994).

Relational representation theory (Cohen and Eichenbaum, 1993; Eichenbaum et al., 1992a, b)

Eichenbaum *et al.* (1992a, b) based their 'relational representational theory' upon an extension of the declarative-procedural memory framework, in order to examine the representational mechanisms that underlie these memories. They emphasised that declarative memories are relationally represented, defined as the encoding of memories according to the relationships among multiple arbitrary items and events. An example of such memory function includes remembering a particular scene, whereby the physical aspects such as the spatial layout or texture need to be retained (Ryan *et al.*, 2000). As a matter of clarification the terms relational memory,

representation and processing are used throughout the literature to denote the same meaning. These terms will also be used in the remainder of this review to express the relational notion that Eichenbaum *et al.* were attempting to describe.

Relational memories are thought to be stored within a highly interconnected network of common elements – 'a memory space' (Eichenbaum, 2002). Activation of one set of information easily goes on to activate other similar elements (i.e. those activated at the time of learning and other stored items) and therefore, declarative memories may be activated by a multitude of different external sensory and internal inputs. This is known as 'representational flexibility', and is thought of as the central property of relational networks that facilitates solving novel problems (Cohen and Eichenbaum, 1993). The properties of the hippocampal system are essential in permitting this binding process of relations to occur (Eichenbaum *et al.*, 1992a, b). Therefore, lesions in this area are likely to result in impaired performance on memory tasks with a relational component. For example, in tasks of spatial or place learning, the position of the external cues with respect to the individual need to be related and remembered for an accurate memory of the layout to be created (Gloor, 1997).

Eichenbaum *et al.* have argued that, by contrast, procedural memories are individually represented. These memories are relatively isolated from other memories and are only encoded within the brain modules that are involved in conducting the task originally (Eichenbaum, 1994). In that sense, procedural memories are considered to be inflexible, by only being activated by engaging in the initial learning task. This type of memory representation is thought to be *independent* of the hippocampal system (Cohen and Eichenbaum, 1993).

On a superficial level, it would appear that the configural-association theory (Sutherland and Rudy, 1989) and the relational representation theory (Eichenbaum *et al.*, 1992 a, b) are similar, given that they are both concerned with how stimuli are combined by the hippocampal system. However, the similarities end there. They postulate differing mechanisms, in that configural-association theory is mostly concerned with stimulus-response and relational representation theory originates from large scale memory organisation such as schemas defined by Bartlett (1932) (Eichenbaum and Cohen, 2001). Furthermore, configural theory focuses on stimulus cues which have ambiguous reinforcement histories (which are required to be disambiguated by the configural cue) and do not consider novel configurations (Eichenbaum, 1994). Relational representation does address flexible use of knowledge to novel situations by the very way in which the network supporting the memories is interconnected.

In view of this, the relational representation framework of memory will be considered further in an attempt to account for deficits made by lesions to the hippocampal system. How this occurs through encoding and retrieval will be considered next, paying particular attention to the anatomical structures involved. Subsequently, evidence that supports or contradicts this theory will be scrutinised.

Relational memory – how information is processed through the hippocampal memory system

As previously stated, three major components are considered to constitute the overall hippocampal memory system. This includes the hippocampus itself (the Ammons horn, the dentate gyrus, the subiculum and the fornix), the parahippocampal region

(entorhinal, perirhinal and parahippocampal cortices) and the areas of the neocortex with close connections to the hippocampus and parahippocampal regions. Eichenbaum and Cohen (2001) have proposed a model through which they believe information is processed within the memory system.

Information enters the system via the neocortex where it is processed, given that only highly pre-processed information proceeds to the medial temporal lobes. Following this, certain areas of the neocortex are involved in projecting the processed information onto the parahippocampal region. One of these areas is that of the inferior temporal cortex, which is often responsible for visually guided learning or responding to specific patterns (e.g. faces) (Eichenbaum and Cohen, 2001). The posterior parietal cortex receives input from visual and somesthetic areas and damage to this area may result in impairment in tactile discrimination (e.g. Mountcastle *et al.*, 1975). The prefrontal cortex is also involved, in view of its connections with both neocortical processing areas and limbic structures such as the hippocampus.

Following processing at the neocortex, information is passed on to the parahippocampal region. This area is thought to support intermediate-term memory storage for specific items, where information is held in a 'buffer' for several minutes before relational processing and before memory is transferred into the permanent store (Eichenbaum and Cohen, 2001). Evidence from studies conducted with rats supports this notion. Otto and Eichenbaum (1992b) investigated the differences between severe lesions to the parahippocampal region and fornix transactions in rats. To explore this, they used a transformed version of the 'delayed-non-match-to-sample' test used with monkeys, called the 'continuous-delayed-non-match-to-

sample' task. Numerous odour cues are presented and the rat is rewarded if it chooses an odour different to the immediately preceding one (i.e. a non-match). The delay between presentations is manipulated to vary in retention length.

Otto and Eichenbaum found that both intact and lesioned rats had no impairment in acquiring this task. Normal rats performed at 90% accuracy level with performance gradually declining with increase in delay. Rats with fornix transections performed at a similar level. However, those rats with lesions to the parahippocampal area demonstrated good retention with short delays but an abnormally fast deterioration in performance after 1 minute. This suggests that the parahippocampal area is critical for creating a memory representation that exists beyond immediate memory and that this region (along with its neocortical connections) is able to mediate the representation of single-item memories independent of the hippocampus, which is sufficient to support the delayed-to-non-match-sample task (Eichenbaum and Cohen, 2001).

At the point where information reaches the parahippocampal region, the hippocampus becomes involved. As previously stated, the hippocampal system is thought to be essential for relational processing and organisation of memories, which facilitates flexible declarative expression. Therefore, the hippocampus becomes involved to make comparisons between the current stimuli and representations of the previous stimuli in the neocortex (Eichenbaum and Cohen, 2001). However, this new information to be stored needs to be woven into existing memories. Therefore, it is presumed that the hippocampus modifies the cortical inputs and then binds this information to the associated cortical area for storage (Shimamura, 2002).

The hippocampus makes an associative link with activated cortical areas via the parahippocampal region. This link remains open, which may decay or strengthen depending on how many times it is activated. Furthermore, this process can make links with more remote memories that share similar elements to the new incoming information. Therefore, not only does the hippocampal system help to bind new information with older memories but it also provides a way of making cortical-cortical activations with more remote memories connected to this information (Shimamura, 2002). Therefore, full relational memory organisation involves journeys of information to and from the neocortex, the parahippocampal region and the hippocampus and back (Eichenbaum and Cohen, 2001).

Is the hippocampal system responsible for relational memory?

On the basis of the literature review above, there is no doubt that the hippocampal system plays a critical role in some types of memory. The question to be asked now is whether there is evidence to support the notion of the hippocampal system being involved in relational memory?

A variety of studies have been found to support the hypothesis that the hippocampal system is involved in relational processing. Ryan *et al.* (2000) examined the processing of novel and previously presented scenes, where eye movements were monitored to assess memory for the scenes implicitly. A decrease in eye movements around repeated scenes in comparison to novel scenes was observed, and also an increase in eye movements where regions of these scenes had been manipulated. These eye movements may reflect the need for a greater number of relationships to be developed for novel stimuli than in already seen stimuli. Studies that have used a

similar paradigm in conjunction with functional MRI scans have indicated that greater hippocampal activation for novel items occurs more often than for previously seen ones (e.g. Stern *et al.,* 1996), thus supporting the notion of the hippocampal system being involved in relational processing.

Further evidence is provided by Cohen *et al.* (1999), who presented participants with stimuli composed of three related pieces of information – face, name, and icon. The task was to recognise the previously presented triplets of information from re-pairings of the same stimuli or to make a judgement about gender whilst having a functional MRI scan. The results demonstrated that greater hippocampal activation occurred for remembering the triplets than the gender judgements, again suggesting that the hippocampal system is involved in relational processing.

Strong evidence for the relational processing hypothesis is also provided by Henke *et al.* (1997) in another PET scan study. They showed participants simultaneous pictures of a person and a house (either the exterior or interior). Participants were required to either decide whether the person was an inhabitant of, or visitor to, the house (i.e. making an association between or 'binding' the person and house stimuli) or to make separate decisions regarding each stimulus (i.e. was the gender of the person male or female; was the picture of the house of the exterior or the interior?). They discovered greater hippocampal activation when the stimuli were processed together than separately. This finding, like other neuroimaging studies, appears to yield evidence that the hippocampal system is involved in relational processing. Whilst this evidence is clear, it should also be noted that the tasks seen to support relational processing appear to be more complex for the individual to execute than

the other tasks conducted in comparison to them (e.g. a recognition judgement). Thus, there is a possible confound related to difficulty level and amount of 'cognitive effort' involved in task performance.

Lesion studies also provide evidence in support of a link between relational processing and the hippocampal system. The Morris water maze task, used to demonstrate spatial learning in rats, has also supplied data in support of relational processing. Morris (1981) demonstrated that once intact rats had found a hidden platform in an opaque swimming pool, they could learn to do so from any starting point. However, those with hippocampal system lesions were unable to do so, although they could locate the platform when it was visible (i.e. using external cues). A similar result has been discovered in humans with hippocampal system damage. Astur *et al.* (2002) used a computer-based Morris water task, which required participants to manipulate a joystick to manoeuvre the computer character around the swimming pool to locate the hidden platform. Participants with unilateral hippocampal resections showed marked impairment in spatial navigation around the pool, just as the rats had indicated previously. This supports the notion that the hippocampal system is necessary for building up relationships between certain points of information to facilitate performance on a memory task.

Relational memory –significant findings and future directions

The investigation of relational memory has revealed many interesting findings which contribute to and also conflict with the understanding gained of the memory system so far. One of the principle features of relational memories is that they are available to conscious awareness. Chun and Phelps (1999) sought to further explore the notion

of conscious availability in relational processing. They used a contextual search task, in which participants had to locate targets amongst distractor items in sets of stimuli. Some of the sets were repeated and some were not. This memory for spatial context is implicit, because participants are not aware of the stimulus repetitions. Participants without hippocampal damage performed better in the search task where displays were repeated from earlier trials. Participants with amnesia showed normal implicit perceptual learning by improvements in search reaction time throughout the task. However, their performance *was not* facilitated by contextual cuing (i.e. unlike control participants, they did not show faster performance for detecting targets in old displays in comparison to new displays) even though this task was not accessible to conscious awareness. Therefore, Chun and Phelps concluded that the hippocampal system was critical for relational processing, and that this may occur without having to evoke conscious awareness. This seems to contradict the previously stated requirement of the hippocampal system in only processing explicit memories.

However, conflicting observations were reported in a subsequent study. Manns and Squire (2001) highlighted that Chun and Phelps' use of individuals with brain damage of mixed aetiologies may have confounded their conclusion that the hippocampal system plays a role in implicit contextual cuing. They repeated the study and found that participants with lesions purely to the hippocampus *did* benefit from contextual cuing. Participants who did not benefit were those who had extensive damage to the medial temporal lobe area, including the entorhinal and perirhinal cortices and the parahippocampal region. Perhaps these structures also play an important role in relational processing.

The contribution of hemispheric lateralisation has also been investigated with respect to hippocampal system involvement in relational memory. Savage *et al.* (2002) used a verbal paired-associate learning paradigm to investigate hemispheric differences between those participants who had undergone left and right anterior lobectomies. In addition, the study also considered the possibility that some hippocampal-dependent tasks may be performed without requiring conscious memory processing. Their task used direct and indirect measures. *Direct* measures involved the use of a verbal paired-associate learning paradigm, in which participants were explicitly required to recall word pairs that had been presented. The *indirect* measure incorporated the use of a masked priming task, which would implicitly facilitate reaction time and accuracy in a subsequent recognition task if a relation between the word pairs had been formed initially.

Savage *et al.* found that participants with left temporal lobectomies performed significantly worse than those who underwent right temporal lobectomies, as might be expected given the verbal nature of the task. This occurred for the explicit paired-associate task and also for the masked priming relational processing task. The right temporal lobectomy participants showed evidence of learning via both direct and indirect measures. Savage *et al.* concluded that both conscious and unconscious relational memory is dependent upon medial temporal lobe structures.

Being able to represent memories relationally is considered an aspect of normal memory functioning. However, there are occasions when relational memories may interfere with performance and evoke false recognition in participants. This has been investigated by studies which have created multiple relations between stimuli.

Research suggests that false recognition of stimuli believed to have been seen previously can be evoked in healthy control participants if semantic or perceptual similarities exist between several stimuli presented (e.g. the word '*sleep*' may be falsely recognised as having occurred if the words '*rest, bed, awake, tired, dream*' were presented; Schacter *et al.*, 1996). This has been interpreted as the ability of participants to build up a 'gist' of the stimuli presented, making it difficult to reject semantically or perceptually related stimuli (Koutstaal *et al.*, 1999).

In face processing research, this effect is referred to as the 'prototype effect' – the tendency to refer to the central ('prototype') value of all the stimuli presented instead of the actual one (Cabeza *et al.*, 1999). Healthy control participants will falsely identify a face that combines all the common features of the group of faces shown (i.e. the prototype) over an exemplar that was actually presented earlier (Solso and McCarthy, 1981). These errors occur despite changes to the angle of faces shown or alterations in shape and colour of the face via 'morphing' techniques (Cabeza *et al.*, 1999). Up to now, however, the prototype effect with faces has not been investigated using groups of memory disordered participants.

Where the literature does investigate the gist or prototype effect with individuals with amnesia, results are variable. Schacter *et al.* (1996) presented participants with lists of words that are related to an unseen 'critical lure'. For example, they may be given words such as *bed, rest, awake, tired, dream* without being exposed to the critical lure of *sleep.* The group of individuals with amnesia showed a reduced level of false recognition in comparison to control participants (i.e. the people with amnesia made fewer false recognition errors than controls). This implies that the

individuals with amnesia were less likely to choose the related lure as a word they had been exposed to previously than controls, although the individuals with amnesia were also less likely to accurately respond to originally presented items.

An analogous study by the same group of researchers used complex shapes as stimuli. Koutstaal *et al.* (1999) presented participants with several similar groups of complex visual stimuli and then tested their recognition memory for the shapes seen earlier. They discovered that the greater the number of perceptually overlapping stimuli that were presented, the higher the level of false recognition or stronger the gist that was built up by controls. However, individuals with amnesia appeared to demonstrate less false recognition when they were exposed to larger numbers of similar stimuli. Controls would choose the 'prototype' that had not been shown before but captured the common features of the group of stimuli shown. The individuals with amnesia chose the prototype stimuli less often but were also generally less accurate in their recognition. Nevertheless, the individuals with amnesia did demonstrate some gist-like behaviour and therefore it was concluded that people with amnesia develop weaker gist formation than controls (Koutstaal *et al.*, 1999).

Koutstaal *et al.*'s results conflict with those from earlier studies. Cermak *et al.* (1973) discovered that when only one related item was presented in a recognition paradigm, participants with amnesia would demonstrate a *higher* level of false recognition than their controls. Other studies have found normal levels of false recognition in individuals with amnesia (e.g. Kolodny, 1994). This controversy continues in the literature to date.

Conclusions

Numerous studies have been conducted to try and understand memory organisation and the critical brain structures that are involved in successful memory functioning. Initial studies on humans demonstrated that when the hippocampal system is damaged, some memory systems become impaired, whilst others are spared. This indicated the presence of multiple memory systems, a different way of thinking compared to the previously hypothesised single unit memory system.

Various theories have been offered to explain the deficits and spared learning abilities of individuals who sustain lesions to the hippocampal system. One viewpoint that has generated wide support is the declarative-procedural memory framework (Cohen and Squire, 1980). Whilst this can account for the types of memories that are or are not available to individuals with damage to the hippocampal system, other theories have extended this notion. Theories such as the 'configural-association theory' (Sutherland and Rudy, 1989) and the 'relational representational theory' (Eichenbaum *et al.*, 1992 a, b) have suggested that it is the binding or relation between and within information that is vital for the formation of memories, and that this processing is dependent upon the hippocampal system for intact functioning. Without this, memories become impoverished.

In general, the theories that describe relational approaches to memory are not well defined or formulated. Furthermore, evidence that can unequivocally confirm or refute such theoretical formulations is lacking. There are some suggestive findings that are consistent with relational processing theories, whilst some contradict earlier observations. Furthermore, not all types of relational memory tasks have been

investigated using groups of participants with lesions to the hippocampal system. Further research is required to replicate and extend these ideas using a range of cognitive paradigms.

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Empirical Paper

The Role of the Temporal Lobes in Relational Processing

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This paper has been prepared for submission to Brain (see Appendix I for instructions for authors).

Running Head: The Role of the Temporal Lobes in Relational Processing.

Volume II

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Summary

Memory deficits are common following lesions to the medial temporal lobes. Research has identified that some types of memory are likely to be more disrupted than others, for example declarative memories that consist of knowledge and personal experiences are impaired, whilst procedural memories that involve skill learning remain intact. The important mechanism thought to be deficient in disrupted memories is that they are not bound together or represented relationally (i.e. relationships are not formed within and between memories). Supportive evidence to date has been somewhat limited and inconsistent. The present paper focussed on two relational memory paradigms; one using a verbal memory task, with both an explicit (paired-associate learning paradigm) and implicit (i.e. masked priming task) measure of relational memory. The second employed a non-verbal component to examine the extent of relational memories in face processing. Participants were those with left or right temporal lobe damage, as well as healthy controls. It was expected that the left and right temporal groups would perform at a lower level than controls overall and that the effects within the temporal groups would be consistent with known laterality effects. The results suggested that even with temporal lobe damage, participants could still develop relational memories, potentially regardless of whether these were below the level of conscious awareness. Furthermore, the left and right temporal group performed at a similar level. Differences with earlier studies are discussed, and it is suggested that certain forms of relational memory deficit may therefore be lesion-specific.

Introduction

Background information

The organisation of long term memories has been a topic of interest to neuroscientists for many years. Two important questions appear to have emerged from the literature: does the organisation of memory consist of a single unitary system or multiple systems and which anatomical brain regions underlie the organisation of memory?

Human memory disorder became a focus of interest to researchers when the difficulties of the patient known as HM were reported in the 1950s (Scoville and Milner, 1957). After experiencing a traumatic head injury as a child, HM suffered from intractable epileptic seizures during his teens and early adulthood. To relieve such persistent seizures, HM underwent experimental brain surgery, which involved bilateral resection of the hippocampal system. This alleviated HM's epilepsy but also produced severe amnesia. He was unable to learn new information ('anterograde amnesia') and had some difficulty in recalling past events known to him prior to surgery ('retrograde amnesia'). However, some learning and memory capacities were spared, including the ability to learn new motor and perceptual skills and habits, which tended to be learnt implicitly or via a process that was unavailable to conscious awareness (Eichenbaum and Cohen, 2001). He also retained his other cognitive functions and short-term memory

Research into human amnesia helped to address important issues in memory research at the time. Firstly, the 'multiple memory system' view of memory organisation became increasingly popular in light of evidence provided by individuals such as

HM. Such studies highlighted the fact that following brain pathology, some memory systems were impaired and some were spared. This finding suggested that multiple systems were responsible for different types of memory.

Secondly, it became clear that damage to the medial temporal lobes resulted in deficits characterised by amnesia. Specifically, further investigations indicated that it was the hippocampus and surrounding structures that were essential for long-term memory. Subsequently, research seemed to focus on a key question – what role does the hippocampal system play in long-term memory?

Terminology and methodological issues within the research

1. Terminology

Throughout the literature, the terminology used to define certain constructs and anatomical structures is often rather unsatisfactory. For example, the term 'memory' may refer to an individual's internal representation of a specific event, the process that leads to remembering or as a place of storage for past experiences (Spear and Riccio, 1994). Therefore, it is clear to see how the same term could imply a variety of meanings with the potential for each to be misused or misinterpreted.

The same principle would appear to apply to the definition of the 'amnesic syndrome'. Generally speaking, this is defined as "a permanent, stable and global disorder of the memory due to organic brain dysfunction which occurs in the absence of any other extensive perceptual or cognitive disturbance" (Parkin and Leng, 1993; p.6). Whilst this description can account for the classic impairments demonstrated by HM and other individuals with hippocampal system lesions, it also appears to be

rather broad and vague. This definition lacks clarity in determining the severity of the memory disorder or brain dysfunction required to be diagnosed with an amnesic syndrome. Perhaps further clarification is required for the definition of amnesia.

Reference to anatomical structures associated with the memory is not without its ambiguity either. Many regard the hippocampus as the main structure involved in memory functioning and thus only refer to this structure when discussing such issues. However, it is likely that other neighbouring structures to the hippocampus also play some role. Eichenbaum and Cohen (2001) have concluded that the major medial temporal lobe structures involved in the process of memory include the hippocampus itself and the parahippocampal region (including the entorhinal and perirhinal cortex). The neocortex is also included by Eichenbaum and Cohen as a part of the memory system, although it is not part of the medial temporal lobes. For the purposes of the present study, the term 'hippocampal system' will be used when referring to the hippocampus and associated medial temporal lobe structures.

2. Methodological issues

In an attempt to explore the deficits demonstrated in humans with amnesia, researchers tried to recreate lesions in animals to observe subsequent memory impairments. It was thought that in doing so, this would provide greater anatomical specificity than that provided by humans with damage as a result of disease or accident. Also, increased control over the environment and experiential history could be obtained in animals rather than humans (Eichenbaum, 2002).

Although popular at the time in generating and testing models of amnesia, animal studies were limited in the evidence that was accumulated and the conclusions that could be drawn. Such studies were heavily criticised due to the lack of perceived similarity between animal and human brains, which were thought to limit generalisability of findings (Eichenbaum, 1994). Furthermore, many of the models developed to explain amnesia defined memory as requiring conscious recollection and the ability to verbally express memories, which animals are unable to do (Eichenbaum, 2002).

Single-case studies using humans as participants also have their drawbacks. Damage to the brain may transpire for numerous reasons including disease, accident or surgery. Therefore, it is critical to remember that damage rarely occurs in isolation to one particular structure but is likely to also affect many surrounding structures (Eichenbaum, 1994). For example, a typical temporal lobectomy to alleviate epilepsy often involves the removal of several structures including varying amounts of the anterior temporal neocortex, the hippocampus, rhinal cortex, the parahippocampal gyrus and the amygdala (Smith, 1989). Given that damage of any kind would appear to affect multiple structures, this sets limits to the research that attributes localisation of cognitive functioning like memory to discrete brain structures.

The technology used to measure such damage to the brain has advanced in recent decades, with the introduction of MRI, CT and PET scanners that can localise damaged brain areas. Even with such technology, some might state that a definitive assessment of damage depends on an autopsy and given that the majority of the

results are provided by living patients, this sets further qualifications for research to fulfil in the future (Spear and Riccio, 1994).

Finally, not all clinical factors can necessarily be taken into account in lesion studies of human memory. The type of cerebral pathology that has occurred (e.g. sudden versus acute, traumatic versus non-traumatic) may play a role in determining the pattern and severity of cognitive deficits that follow (Anderson *et al.*, 1990). Furthermore, by testing individuals after damage has occurred, information is seldom available regarding premorbid level of functioning (Spear and Riccio, 1994). However, this is usually indirectly inferred on the basis of factors such as age or education level.

Understanding the memory deficit in temporal lobe damage

Over the years, researchers have continually strived to explore the role that the medial temporal lobes or more specifically, the hippocampal system, plays in memory. Many theories have attempted to answer this by providing accounts that explain the deficits found in those individuals with hippocampal system lesions. One of the most popular and widely accepted accounts of hippocampal memory system impairment was provided by Cohen and Squire (1980). This framework suggests that the hippocampal system is responsible for encoding and retrieving memories that involve the acquisition of new knowledge and experiences, referred to as 'declarative' memories. Declarative memory relies on explicit or conscious awareness for successful recollection and is thought to be dependent on the hippocampal system. However, skills and habits *can* be learnt when such damage occurs, and these memories are referred to as 'procedural memories'. Such

memories are implicit and are not available to conscious mediation. They are thought to be formed independently of the hippocampal system.

One of the fundamental aspects of declarative memory is that the individual can use the knowledge and experiences they possess to make inferences and solve problems in novel situations (Cohen, 1984). The property of declarative memories that is thought to permit this process is that memories are encoded in terms of the *relations* among the information that is acquired. This is also thought to be dependent on the hippocampal system (Cohen and Eichenbaum, 1993). Relations between memories play an essential role in everyday life, facilitating the recollection of memories in context, for example remembering the food consumed at breakfast on a particular day.

Several theories have attempted to explore the relational dimension of memory. Sutherland and Rudy (1989) proposed the 'configural-association' theory, which distinguishes between two systems considered important in the normal functioning of memory. The simple association system permits elementary associations to be made between stimuli, for example, a typical classical conditioning situation. It is thought that this type of learning is independent of the hippocampal system. The second system is the configural-association system. This is considered more complex, in that memories are formed from two or more elemental stimuli that stand in specific relation to each other (e.g. sequential occurrence or relative location). Configural learning allows the complex relationship between all conditions to be stored. Research suggests that the formation of configural memories is hippocampal system dependent.

Relational representation theory (Cohen and Eichenbaum, 1993; Eichenbaum et al., 1992a, b)

An alternative relational memory framework elaborates on the declarative-procedural account of memory to focus not only on the type of memory to be remembered but also how it is represented. Eichenbaum *et al.* (1992a, b) proposed the 'relational representation' theory, which suggests that declarative memories are encoded according to the relationships between the multiple arbitrary events or items that make them up. Relational memories are stored within a highly interconnected network, which permits similar previously stored information to be easily activated at the same time as the learning event. This is known as 'representational flexibility', the key to relational representation, which can facilitate novel problem solving.

Relational memories are deemed to be dependent on the hippocampal system to function properly. Neuroimaging studies demonstrate that the hippocampal system is activated during tasks that involve relational memory processing, such as learning and remembering related triads of information (Cohen *et al.*, 1999) or recalling familiar routes or landmarks, all of which involve varying degrees of relational processing (Maguire *et al.*, 1997).

Whilst investigating the relational memory hypothesis, some subsets of studies have revealed intriguing results that have formed the background rationale for the studies reported in this thesis. Each will be discussed in turn.

Conscious awareness and relational memory

Relational processing by definition stipulates how declarative memories are relationally represented within a memory space, thus allowing for flexibility of use, which is dependent on the hippocampal system for successful functioning. Theorists supporting this notion agree that declarative memories are dependent on conscious awareness for successful recollection (Eichenbaum, 2002), and are seen as a form of explicit memory. Therefore, relational memories should also represent an explicit kind of memory dependent on conscious awareness. Alternatively, procedural memories are independently represented and are not available to conscious awareness and are seen as a form of implicit memory.

Chun and Phelps (1999) sought to explore the notion of conscious availability in relational processing. They used a contextual cuing task that involved searching for targets ('T') amongst rotated distractors ('L'). On occasions, a set of stimuli were repeated whereby targets appeared consistently in the same location. This is a type of relational processing task, known as contextual cuing. Participants included those who had suffered from hippocampal system damage of mixed aetiology (anoxia and encephalitis) and also included healthy controls.

Chun and Phelps hypothesised that if the important factor for the hippocampal system to become involved in the task was that it was available to conscious awareness, then participants with explicit memory deficits should benefit from the contextual cuing paradigm, given that the task was implicit in nature. However, if the hippocampal system was important for relational processing regardless of the conscious availability of the material, then participants would demonstrate no such

benefit. Indeed, they found that controls benefited from contextual (relational) learning, although they were not aware of the repetition that had occurred (i.e. an implicit task). However, participants with amnesia did not benefit. Therefore, Chun and Phelps concluded that the hippocampal system is necessary to mediate contextual (relational) learning but without necessarily evoking conscious awareness of the memory process.

However, this study has proved to be somewhat controversial. Manns and Squire (2001) claimed that Chun and Phelps's sample of mixed aetiology participants tended to obscure the conclusions that can be drawn from this study. They replicated the study and found that participants with lesions purely to the hippocampus *did* benefit from contextual repetition. Those participants who did not benefit suffered more extensive damage to the hippocampal system and medial temporal lobe (including the entorhinal cortex, perirhinal cortex and parahippocampal gyrus). Perhaps these structures also play an important role in relational processing.

Hemispheric laterality and relational memory

Research into the hippocampal system and memory has revealed that the location of damage corresponds with known laterality effects of lesions (Milner, 1972). Functional imaging studies suggest that the left MTL is associated with verbal memory (e.g. learning lists of unrelated words (Kelley *et al.*, 1998)) and the right MTL is associated with nonverbal memory (e.g. learning spatial routes (Maguire *et al.*, 1997)). Therefore, unilateral damage to either of these regions is likely to result in deficits in verbal or nonverbal memory respectively.

Savage *et al.* (2002) used a verbal paired-associate learning paradigm to investigate hemispheric differences in relational processing between those participants who had undergone left and right anterior lobectomies. In addition, the study also considered the possibility that some hippocampal-dependent tasks may be performed without requiring conscious memory processing. Their task used direct and indirect measures to assess this. Direct measures involved the use of the verbal paired-associate learning paradigm, in which participants were explicitly required to recall the word pairs that had been presented. The test incorporated both concrete and abstract words, since research suggests that memory for concrete, imageable words is superior to memory for abstract words, which are less imageable (e.g. Marschark and Hunt, 1989). This finding has been explained by reference to Paivio's dual coding theory of representation (1971), which proposes that concrete words subscribe to both visual and verbal methods of mental coding, whereas abstract words employ a verbal code only. The indirect measure incorporated the use of a masked priming task, which would implicitly facilitate reaction time and accuracy in a recognition task if a relation between the word pairs had been formed initially.

Their findings indicated that right temporal lobectomy participants showed evidence of steadily learning both concrete and abstract words over time. This group also displayed evidence of forming relations between the words in the learning phase by demonstrating accuracy and savings in reaction time in the priming task, even though they were unaware that the task had primed them. Left temporal lobectomy patients performed worse, especially with abstract words on both the explicit paired-associate task and the implicit masked priming task. The findings support the idea that when

the hippocampal system and surrounding structures are damaged, relational learning is affected, regardless of conscious availability of the memory trace.

Multiple stimuli and relational memory

The ability to represent declarative memories relationally is considered as a normal function of human memory. However, occasionally relational memory may interfere with performance and result in false recognition. Research has been conducted to investigate this notion, using stimuli with overlapping features. Studies indicate that if several stimuli with semantic and perceptual similarity are used in a memory test situation, healthy controls will mistakenly recognise certain stimuli believed to have been seen before, instead of choosing the stimulus that had actually been presented. For example, participants may be shown words such as *bed, rest, awake, tired, dream* without being exposed to the critical lure of *sleep.* On being asked to recognise the words they had seen before, participants would falsely recognise the word *'sleep'* as a word they had seen instead of those they had been exposed to (Schacter *et al.,* 1996). This effect has been attributed to the ability of participants to build up a 'gist' of the stimuli presented making it difficult to reject semantically or perceptually related stimuli (Koutstaal *et al.,* 1999).

In face processing research, this effect is referred to as 'the prototype effect' – the tendency to refer to the central value of all the stimuli presented instead of the actual one seen (Cabeza *et al.,* 1999). This phenomena appears in healthy controls when using a face processing task, even when changes are made to the angle at which the faces are shown or even when the shape or colour of the face are altered via 'morphing' techniques (Cabeza *et al.,* 1999).

There is only limited published evidence referring to participants with memory impairment and the prototype effect. Koutstaal *et al.* (1999) attempted to address this issue by comparing participants with amnesia with healthy controls on the recognition of complex geometric shapes. Certain features of the shapes denoted that they belonged to particular categories. In each shape shown, the features would change slightly making all the shapes or exemplars different whilst retaining some similarity. One shape contained all the features, defined as the prototype, and was not shown in the test situation, whereas all the other exemplars were. Koutstaal *et al.* discovered that when a larger number of perceptually overlapping stimuli were shown, a strong gist or prototype effect was found in healthy controls. Individuals with amnesia showed a reduced level of false recognition by choosing the prototypical shape less often than controls. They were also less accurate in choosing the exemplars that had been presented. Although the individuals with amnesia were less susceptible to the prototype effect, they were not immune and showed some gist-like behaviour where categories of stimuli were larger. The researchers consider that participants with amnesia develop a weaker gist formation than controls (Koutstaal *et al.*, 1999).

Aims of the present study

Research into relational processing has highlighted possible issues that could form the focus of further research:

1. That multiple structures are involved in relational processing, which include the hippocampus and surrounding structures.
2. That some hippocampal-dependent tasks may be inaccessible to awareness and evoked without conscious awareness.

3. The site of the damage corresponds with the lateralisation of the cerebral hemispheres in relational processing.
4. Although a different type of relational processing, the effect of multiple similar stimuli on the prototype effect in participants with amnesia is weaker than in healthy controls. However, this effect has not been investigated in face processing research.

It is generally understood that the temporal lobes and more specifically the medial temporal lobes are important structures involved in relational processing and that damage to these areas will affect performance on tasks of relational processing. The present study was designed to address some of the issues outlined above to further explore the role of the temporal lobes in relational processing.

Two different types of relational processing were examined in the present study – one using a verbal memory test and one using a non-verbal memory test. This provided an opportunity to investigate laterality in relational processing by using groups of patients with left and right temporal lobe damage.

The verbal task was a replication of the Savage *et al.* (2002) study and also used concrete and abstract words to explore the different levels of verbal memory deficits with which patients presented. The concrete and abstract word pairs compiled by Savage *et al.* were used. Participants were comprised of individuals who suffered damage largely to the medial temporal lobes and also healthy controls. This may help to further clarify whether the medial temporal lobe structures are important in relational processing - in Savage *et al.*'s study, lesion pathology included the

removal of the neocortex and so the role of the medial and lateral temporal lobe structures could not be distinguished from other structures. This experiment was also designed to explore whether such a hippocampal-system dependent task can be accessible without conscious awareness, by using Savage *et al.*'s method of direct and indirect measures of memory assessment as described earlier.

The non-verbal task extended the face processing paradigm and prototype effect to individuals with medial temporal lobe damage. Research already suggests that individuals with medial temporal lobe damage exhibit less of a prototype effect than controls. Although face processing tasks have not strictly been defined as 'relational' in nature, it would seem feasible to classify them as such, given that the range of similar stimuli shown will require binding together to form a gist of them.

Hypotheses

Participants with temporal lobe damage will exhibit a deficit in all relational tasks.

- Participants with temporal lobe damage will show less prototype effect than controls (or no effect) in the non-verbal memory task, with the right temporal group demonstrating the most notable deficit.
- Participants with temporal lobe damage will be expected to perform worse than controls using a direct and indirect measure of memory in the verbal paired-associate task, with the left temporal lobe group being selectively impaired.

Methodology

Participants

The same participants took part in both the verbal memory task and the faces memory task. These were comprised of a group of participants with temporal lobe pathology and a group of controls. Ethics Committee approval was obtained from both the School of Psychology at the University of Southampton and the Southampton and South West Hants Local Research Ethics Committee (See Appendix III for approval letter).

1) Recruitment

Participants with brain damage were identified from a number of sources including database information within the Clinical Neuropsychology department and the radiology department of the hospital used. The former were individuals who had entered the clinical service and had already undergone neuropsychological assessment for health care purposes. The clinical database provided an indication of the aetiology of the individual's brain damage and also its location. The radiology database provided demographic information regarding specific individuals who had received particular procedures (i.e. MRI scans). In both cases, the neurological notes were located in search of certain inclusion criteria:

1. The MRI scan to show a focal temporal lobe lesion in either the left or right hemisphere.
2. In participants with epilepsy, the EEG report should be confirmatory of the lesion (i.e. demonstrating epileptogenic electrical activity in this area of the brain).

Participants with brain damage experienced a range of aetiologies, including epilepsy (pre and post-surgery), tumours and infections. Attempts were made to match participants in the left and right temporal lobe groups in terms of their aetiology, unilateral lesion location and age (see Table 1). Education levels were also matched for. This was measured by number of years in education, and also a measure of participant's verbal and non-verbal abilities were estimated by using the National Adult Reading Scale (NART; Nelson, 1991) and the Matrix Reasoning subtest from the Wechsler Adult Intelligence Scale, 3rd Edition (WAIS-III UK; Wechsler, 1997) respectively.

Once participants were deemed appropriate to take part, a letter was written to them from the Consultant Clinical Neuropsychologist in the department, informing them of the research project and providing them with an information sheet that explained the study and its requirements in detail (see Appendix IV). A few days later, the author attempted to contact the individual by telephone, or if this were not possible, another letter was sent to them with a tear off slip to be returned if they were interested in taking part. It was, however, emphasised that non-participation would not affect individual's clinical care in any way. Once the participant had agreed to take part, the author made an appointment to visit them wherever it was more convenient for them, usually at home. Only two participants refused to take part in the study but did not differ in aetiology or other factors in comparison to those that did agree to participate.

Controls were healthy participants, meaning that they had no known brain injury. They were approached directly by the author and given an information sheet for their

perusal. If they agreed to participate, a convenient date and time were made, again usually involving testing them at home. Controls were matched to participants with brain injury using age and education level. The total number of participants who took part in the study reached 32, 11 in the right temporal and control groups and 10 in the left temporal group.

Consent forms were signed by participants and the researcher at the beginning of the test session. It was emphasised that withdrawal from the study was possible at any time (see Appendix V).

2) Demographics

The average age for participants overall was 38.3 years old with a mean of 13.6 years spent in education. Analysis of the demographic data using one-way ANOVAS suggested that participants did not significantly differ in age ($F(2,29)=.156$, $p=.856$), gender ($F(2,29)=1.309$, $p=.286$), full scale IQ (FSIQ) as measured by the NART ($F(2,25)=2.529$, $p=.100$) or non-verbal reasoning ability as measured by the Matrix Reasoning subtest ($F(1,19)=.248$, $p=.624$). However, participants did differ on years of education ($F(2,29)=4.302$, $p=.023$), with controls remaining in education just under 1 year longer than the right temporal group (see Table 2 for a summary of participant demographics). However, since the NART-FSIQ scores are considered to be a better predictor of premorbid ability, this difference was not considered to be troublesome.

Verbal memory test

Design

There were two parts to this task. The purpose of Phase 1 was to examine the explicit memory of learning concrete and abstract word pairs over a series of learning trials. The purpose of Phase 2 of the task was to shed light on implicit relational learning by using a subsequent masked priming task. If learning had occurred initially, then participants would show a priming effect (i.e. faster reaction time (RT) and more accurate answers). It was thought that the type of prime used before the target response word would influence the priming effect. Thus primes and targets were systematically selected to allow for priming effects to be observed.

The types of stimuli presented in the masked priming task were as follows:

1. **Matched prime**:

- **PRIME** = stimulus word from the original word pairs (e.g. DOG)
- **TARGET** = response word from the original word pairs (e.g. TRAIN)

2. **Reassigned prime:**

- **PRIME** = stimulus word from the original word pairs (e.g. DOG)
- **TARGET** = reassigned response word from the original pairs (e.g. FOREST)

3. **Old prime - new target:**

- **PRIME** = stimulus word from the original word pairs (e.g. DOG)
- **TARGET** = response word not presented before (e.g. KEY)

4. **Novel prime – new target:**

- **PRIME** = stimulus word not presented before (e.g. GUN)

- **TARGET** = response word not presented before (e.g. PLANT)

Both concrete and abstract words were used throughout.

The experiment used a mixed design of within-subjects and between-subjects variables.

- Independent variables: group (left temporal lobe pathology/right temporal lobe pathology/control) as the between-subjects variable; word type (concrete/ abstract) and trial (1-4 for phase 1) or priming (matched versus reassigned/old prime-new target versus novel prime-new target for phase 2) as the within-subjects variables.
- Dependent variables: accuracy, RT and ratings.

Materials

Research suggests that memory for concrete words is better than that for abstract words, given that concrete words are more imageable (e.g. Marschark & Hunt, 1989). Therefore, both concrete and abstract words were used in the present study, following the design adopted by Savage *et al.* (2002) in their original study (words listed in Appendix VI). These were 32 arbitrarily paired words divided into four lists. Two extra pairs of words (one concrete and one abstract) were added to each list as 'dummy' pairs serving a dual purpose; they always appeared in the same location in Phase 1 and thus absorbed any primacy effects that occurred, and also served as practice trials in Phase 2, the masked prime task.

Phase 1 of the task involved learning a list of paired-associate words which were presented in a standard test format. Pairs of words were presented followed by the

test of memory for the second (response) word after the participant saw the first (stimulus) word of the pair. Presentation and test trials occurred four times in total for each list.

Phase 2 involved a masked prime task. This entailed the second (response) word of the pairs learnt in phase 1 being preceded by a masked prime. There were four types of prime in total. Matched primes used the original stimulus and response words and reassigned primes consisted of original stimulus words but were reassigned new response words from the original list. Old prime–new target and novel prime–new target conditions were also created. Twelve new words were added to each list (48 in total over all four lists) to create these two conditions. The old prime-new target condition used a stimulus word from the original word list and a new word that had never been seen before. The novel-prime-new target condition used completely new words for both stimulus and response word. Again, each list was allocated two practice items for the reasons explained above. Therefore, during the masked prime task each list contained four practice items, four matched primes, four reassigned primes, four old prime-new target words and four novel prime-new target words, totalling 20 items in each list (80 over all four lists).

Procedure

Presentation of the verbal memory task was conducted on a laptop computer, run by 'Superlab' computer software. Words were presented on a white background using black writing in 60 font for participants to read clearly. Where possible, a quiet room was obtained for testing.

Participants were instructed throughout the task using a standardised testing protocol, (see Appendix VII). In phase 1, participants were instructed to learn the 10 pairs of words that would appear on the computer screen. These appeared one pair at a time in lower-case with a dash separating the words at a rate of one pair every 4 s (2 s on the screen and a 2 s wait before the next pair were presented). After presentation of all 10 word pairs, the first stimulus word of the pair would appear on the screen, acting as a cue for the second response word to be given that was paired with it in the learning phase. Participants were required to indicate their response orally and were given a 5 s time limit to do so. Performance was recorded by the author using a response box as either correct or incorrect. In either case, the correct answer would flash up on the screen as a word pair. All 10 word pairs were tested in this way (i.e. each pair was presented twice in each trial). On finishing the test trial the participant was returned to the learning phase of the same 10 pairs of words, which were exposed each time in a random order generated by the computer. The learning and test trials occurred four times in total.

After the fourth and last paired-associate trial, participants were introduced to the masked prime task. A row of alternate dollar signs and ampersands (i.e. $&$&$&) appeared on the screen for 500ms acting as a forward mask. Participants were told that when this appeared, it indicated that another word would follow it. The masked prime followed the symbols, which was the same length in letters and appeared centrally for 50ms. Immediately following this, the target (response) word replaced the masked prime for a further 500ms. Participants were required to judge whether the target (response) word had featured in the list that they had just learnt or not, by pressing a 'yes' or 'no' button on the response box. They were also asked to decide

how confident they were in their answers by indicating to the tester whether they were 'certain' in their answer, they 'thought' it was correct or it was a 'guess'. Based on the 'remember-know literature' (Tulving, 1985), this scale was used to measure participants' awareness of remembering the actual experience versus a feeling of familiarity, during the recognition task. This scale was presented visually subsequent to their response to the masked prime.

A 30 s delay interval was given between each learning session and test trial session and between the last test trial session and the primed recognition test session. This was executed to ensure that all participants had the same amount of time to wait for the next trial. On completion of the masked prime task, a few minutes break was given to the participant before the next list of words was begun. The same procedure was adopted for each list of words.

Faces memory test

Design

This experiment examined the differences between the groups of participants for the presence of the prototype effect in a non-verbal memory test. It employed a mixed design of within-subjects and between-subject variables.

- Independent variables: group (left temporal lobe pathology/right temporal lobe pathology/controls) as the between-subjects variable; type of face (prototype versus seen exemplar/ prototype versus unseen exemplar) as the within-subjects variable
- Dependent variable: frequency of response chosen (prototype/exemplar seen/exemplar unseen) and ratings.

Materials

Two faces were chosen at random from a database containing male faces. The faces were gradually morphed together using 'Winmorph' computer package over a series of eight stages. Therefore each time, the first face in the set would have a little more of the features of the other faces morphed into them and so on (see Appendix VIII for examples of the faces). This process created the exemplars, which would be shown to the participants during the learning phase. At exactly half way between morphing one face with another, the prototype of the two faces was created, having half the features belonging to one face and half belonging to the other. Unseen exemplars were also created for recognition judgement in the test phase. These typically had features of two of the original faces but were never seen in that combination before, which were obtained at the midpoint between faces along the morphing procedure

Ten pairs of faces were used to create the exemplars and prototypes with an additional ten faces used to combine with these faces for the unseen exemplars. Therefore, 60 exemplars were created and shown in the learning phase, and 10 prototypes and 10 unseen exemplars were created for the test phase, making a total of 80 faces.

Procedure

The faces memory test was presented on a laptop and was executed using 'Superlab' computer software. In the test phase, exemplars were presented on the screen for 5 seconds each. Participants were asked to rate each face they saw on how trustworthy they thought it looked, on a scale of 1–6 where 1 was trustworthy and 6 was

untrustworthy. After 5 s of exposure to the face, it was replaced by the scale on the screen, prompting participants to make a response using the response box provided. It was explained that this was an arbitrary task as participants' memories would be tested subsequently for the faces they had seen amongst some that they had not seen.

In the test phase, three faces were presented on the screen at one time, labelled A, B and C. These comprised of an exemplar (which had been seen in the learning phase), a prototype (containing half the features of one face and half the features of another; not seen) and an unseen exemplar. Participants were asked to choose which face they thought they had seen before from the three presented on the screen, by using the response box as demonstrated. After they had made their choice, they were asked to decide how confident they were in their answer; whether they were 'certain' about it, they just 'thought' so or their response was a 'guess'. The author entered these responses into the response box. Participants were given 10 s to make their decision and were prompted to answer after this time. A delay of 30 s occurred between the learning and test phase so as to allow repetition of instructions for the participant.

The order of the experiments was randomised for each participant to counterbalance for confounding variables (e.g. fatigue).

Statistical analyses

The data were analysed using SPSS 11.0 for Windows (2001). For the statistical analysis an alpha level of .05 was used throughout. One-Sample Kolmogorov-Smirnov tests were performed on all the results to establish whether the assumptions

of a normal distribution were supported. Where the data did not meet the criteria for a normal distribution, the Greenhouse Geisser correction test was applied (see Appendix IX).

Verbal memory test

The aim of phase 1 was to obtain data regarding the degree of participants' learning of word pairs over the four test trials. A total number of correct answers over the four trials were calculated, thus being out of a maximum of 16 in total (as four items were practice items and thus excluded from the analysis). The data were subjected to a three-way mixed ANOVA with within-subjects factors of Word Type (concrete or abstract) and Time (trials 1 – 4) and the between-subjects factor of Group (Left temporal, Right Temporal, Controls).

Phase 2 aimed to investigate the existence of relational learning between the word pairs by using a masked priming task. If a relation had been made between the words initially, then a priming effect would prevail. Two types of prime or stimulus words are used in this task: those that use stimulus and response words from the original learning list and those that use either old or new stimulus words but in combination with new response words. This would tend to affect performance in different ways, with the former facilitating performance (i.e. improve accuracy and reduced RT) and the latter interfering with it (i.e. reduce accuracy and increased RT). The response times taken to measure priming effects were converted into reciprocals of the RT. This method tends to minimise the affects that extreme values may have on the analysis. Both accuracy and RT data were subjected to two three-way ANOVAs each with Prime (matched/reassigned prime; old prime-new target/novel

prime-new target) and Word Type (Concrete/Abstract) as the within-subjects factors and group (Left Temporal, Right Temporal and Controls) as the between-subjects factor. Analyses of the confidence ratings were conducted in the same way for each condition.

Faces memory test

The data for the faces memory test were derived from the frequency with which each type of face was chosen in the recognition memory test. The data were submitted to two, two-way mixed ANOVAs with type of Face (Exemplar, Prototype and Unseen Exemplar) as the within-subjects factors and Group (Left Temporal, Right Temporal, Controls) as the between-subjects factor. The analysis was conducted in this way so that the means were free to vary within the realms of 100% instead of having all the groups together and the means adding up to 100%. Analyses of the confidence ratings were conducted in the same way.

Results

Verbal memory test

Phase 1 – Learning over time with verbal paired-associate learning

Data were analysed in a three-way mixed ANOVA, with a within-subjects factor of 4 (Time: One, Two, Three, Four) x 2 (Word Type: Concrete, Abstract) and a between-subjects factor of 3 (Group: Left Temporal, Right Temporal, Controls). There were significant main effects of Time ($F(3,87)=230.75$, $p=.000$) and Word Type ($F(1,29)=186.84$, $p=.000$), where increasing amounts of words were learnt over the four trials, with more Concrete words being learnt than Abstract words. However, there was no main effect of Group ($F(2,29)=2.44$, $p=.105$). The interaction between

Time and Word was significant ($F(3,87)=3.56$, $p=.048$; see Figure 1). This interaction was broken down using one-way repeated measures ANOVAs. This showed that there was a significant effect of Time for Concrete and Abstract words ($F(3,87) = 99.84$, $p=.000$; $F(3,87) = 134.51$, $p=.000$ respectively). Although the difference between the concrete and abstract words was significant over all trials (Time 1: $F(1,29)=39.26$, $p=.000$; Time 3: $F(1,29)=62.74$, $p=.000$; Time 4: $F(1,29)=27.93$, $p=.000$), the most reliable difference occurred at trial 2 ($F(1,29)=135.29$, $p=.000$). There was no interaction between Group and Word Type ($F(6,87)=1.63$, $p=.174$), Group and Time $F(2,29)=1.01$, $p=.376$) or a three-way interaction between Word Type, Time and Group $F(6,87)=1.01$, $p=.401$) (see figure 2) (Figure 1 and 2 near here).

Phase 2 – Priming effect – matched versus reassigned prime

Data for accuracy, RT and the ratings were analysed using three-way mixed ANOVAs, with within-subjects factor of 2 (Prime: Matched, Reassigned) x 2 (Word Type: Concrete, Abstract) and a between-subjects factor of 3 (Group: Left Temporal, Right Temporal, Controls).

In terms of accuracy, there were no significant main effects for Word Type ($F(1,29)=.03$, p=.876), Prime ($F(1,29)=3.86$, $p =.059$) or Group ($F(2,29)=1.48$, $p=.244$). There were also no significant interactions between Word Type and Group ($F(2,29)=1.20$, $p=.315$, Word Type and Prime ($F(2,29)=2.27$, $p=.143$), Prime and Group ($F(2,29)=.06$, $p=.938$) or Word Type, Prime and Group ($F(2,29)=.04$, $p=.963$) (see Figure 3). However, the main effect of Prime ($p=.059$) approached significance. Matched primes were more accurately recognised than reassigned primes (Figure 3 near here).

In terms of RT, there was a significant main effect of Prime ($F(1,29)=8.47$, $p=.007$), with matched primes being responded to faster than reassigned primes. There was no significant main effect for Word Type ($F(1,29)=1.05$, $p=.314$) or Group ($F(2,29)=1.06$, $p=.358$). There was a significant interaction between Word Type and Prime ($F(1,29)=5.93$, $p=.021$). This interaction was broken down using one-way repeated measures ANOVAs looking at the effect of Word Type on each Prime and the effect of Prime on each Word Type. This revealed that Concrete words were remembered quicker than Abstract words ($F(1,29)=11.26$, $p=.002$) in the Matched Prime condition but not the Reassigned Prime condition ($F(1,29)=3.87$, $p=.059$).

An interaction between Word Type and Group ($F(2,29)=3.60$, $p=.040$) was also significant. This interaction was broken down using one-way repeated ANOVAs separately for each group comparing Concrete and Abstract words. This revealed that the effect of Word Type was most evident for the Control group ($F(1,10)=4.53$, $p=.059$) than the Left Temporal ($F(1,9)=2.10$, $p=.181$) or Right Temporal groups ($F(1,10)=2.30$, $p=.160$). There was no significant interaction between Prime and Group ($F(2,29)=.82$, $p=.451$) and no significant three way interaction between Word Type, Prime and Group ($F(2,29)=.04$, $p=.963$) (see figure 4). Combined with the accuracy data noted above, there would appear to be evidence for a general priming effect for matched prime pairs (Figure 4 near here).

In terms of ratings, there were no significant main effects for Word Type ($F(1,29)=1.18$, p=.189), Prime ($F(1,29)=.09$, p =.772) or Group ($F(2,29)=.72$, $p=.494$). There were also no significant interactions between Word Type and Group ($F(2,29)=1.63$, $p=.213$), Word Type and Prime ($F(2,29)=.21$, $p=.653$), Prime and

Group ($F(2,29)=2.63$, $p=.089$) or a three-way interaction between Word Type, Prime and Group ($F(2,29)=.19$, $p=.824$).

Phase 2 – Priming effect – old versus new prime items

Data for accuracy, RT and ratings were analysed using three-way mixed ANOVAs with within-subjects factor of 2 (Prime: Old Prime-New Target, Novel Prime-New Target) x 2 (Word Type: Concrete, Abstract) and a between-subjects factor of 3 (Group: Left Temporal, Right Temporal, Controls).

In terms of accuracy, there was a main effect of Word Type ($F(1,29)=4.24$, $p=.049$), where participants were more accurate at remembering abstract than Concrete words. There was also a main effect of Prime ($F(1,29)=16.13$, $p=.000$), where Novel Prime words were more accurately remembered than Old Prime words, but there was no main effect for Group ($F(2,29)=1.15$, $p=.332$). There were also significant interactions between Word Type and Prime ($F(1,29)=7.67$, $p=.010$) and three-way interaction for Group, Word Type and Prime ($F(2,29)=4.38$, $p=.022$) (see figure 5), but no significant interactions between Word Type and Group ($F(1,29)=1.61$, $p=.217$) or Prime and Group ($F(2,29)=1.64$, $p=.211$).

The three-way interaction was broken down using two-way repeated measures ANOVAs separately for each group. This indicated no significant interaction between Word Type and Prime for the Control group ($F(1,10)=.00$, $p=1.000$) or Left Temporal group ($F(1,9)=1.00$, $p=.343$), but there was for the Right Temporal group ($F(1,10)=10.20$, $p=.010$). The interaction found between Word Type and Prime for the Right Temporal group was broken down using one-way repeated measures

ANOVAs, to look at the effect of Word Type on Prime and the effect of Prime on Word Type. This revealed that Concrete words were recognised less accurately than Abstract words ($F(1,29) = 13.59$, $p=.001$) in the Old Prime condition but not the Novel Prime condition ($F(1,29) = 6.18$, $p=.019$) (Figure 5 near here).

In terms of RT, there was a significant main effect for Word Type ($F(1,29)= 5.81$, $p=.023$), where Abstract words were recognised faster than Concrete words. There was no main effect for Prime ($F(2,29)=.50$, $p=.483$) or Group ($F(2,29)=1.53$, $p=.233$). There was a significant interaction between Word Type and Prime ($F(1,29)=5.63$, $p=.025$; see Figure 6). The interaction was broken down using one-way repeated measures ANOVAs, looking at the effect of Word Type on Prime and Prime on Word Type. This revealed that Abstract words were recognised faster than Concrete words ($F(1,29)=3.68$, $p=.065$) in the Novel Prime condition but not the Old Prime condition ($F(1,29)=7.42$, $p=.011$). There was no significant interaction between Word Type and Group ($F(2,29)=.81$, $p=.455$), Prime and Group ($F(2,29)=1.26$, $p=.298$) or a three-way interaction for Word Type, Prime and Group ($F(2,29)=.38$, $p=.689$) (see figure 7) (Figure 6 and 7 near here).

In terms of ratings, there were no significant main effects for Word Type ($F(1,29)=1.04$, $p=.316$), Prime ($F(1,29)=.19$, $p=.665$) or Group ($F(2,29)=.71$, $p=.502$). There were also no significant interactions between Word Type and Group ($F(2,29)=1.57$, $p=.225$, Word Type and Prime ($F(1,29)=2.21$, $p=.148$), Prime and Group ($F(2,29)=.76$, $p=.479$) or Word Type, Prime and Group ($F(2,29)=.70$, $p=.503$).

Combined with the accuracy data noted above, there would appear to be evidence of a priming effect, given that participants were slower and less accurate at recognising 'old prime-new target' response words.

Faces memory test

The data for faces and ratings were subjected to two, two-way mixed ANOVAs, with a within-subjects factor of 2 (Faces: Prototype versus Exemplar; Prototype versus Unseen Exemplar) and a between-subjects factor of 3 (Group: Left Temporal, Right Temporal, Controls). There were significant main effects for Face when the Prototype was compared with the Exemplar ($F(2,29)=6.22$, $p=.019$) and when the Prototype was compared to the Unseen Exemplar ($F(2,29)=71.91$, $p=.000$). In both conditions, the Prototype was chosen more often than the Exemplar or Unseen Exemplar (see figure 8). There was no main effect of Group ($F(2,29)=2.39$, $p=.110$; $F(2,29)=1.67$, $p=.206$) nor was there a significant interaction between Group and Face ($F(2,29)=.84$, $p=.444$; $F(2,29)=.55$, $p=.585$) (Figure 8 near here).

In terms of ratings, there were no significant main effects for Face Type (Exemplar versus Prototype: $F(1,29)=.02$, $p=.900$, Unseen Exemplar versus Prototype: $F(1,23)=.19$, $p=.660$) or Group ($F(2,29)=1.08$, p=.354; F(2,23)=1.99, p= .160 respectively). There was no significant interaction between Face Type (Exemplar versus Prototype/Unseen Exemplar versus Prototype) and Group ($F(2,29)=.23$, $p=.796$; $F(2,23)=.64$, $p=.537$ respectively).

Discussion

Summary of findings

The present study sought to investigate aspects of relational representation theory of memories by examining two types of relational memory paradigm – a verbal paired-associate learning task and a faces recognition memory test. Damage to either the left or right temporal lobes was expected to disrupt performance, given that such a theoretical approach advocates the involvement of the hippocampal system in relational memory encoding and retrieval. However, little evidence was found in the present study to suggest that brain damage to the hippocampal system had any significant effect on relational memories. Explicit paired-associate learning of both concrete and abstract word pairs was possible by all groups, with some indication that overall, more concrete words were learnt than abstract. Furthermore, implicit priming effects in the verbal memory task were demonstrated by all groups.

The faces memory task yielded results with a similar theme. A prototype effect was established for all groups, whereby the prototypical face was chosen more times than the actual stimulus seen or by a random item (represented by the unseen exemplar). Damage to the hippocampal system did not appear to interfere with the prototype effect, suggesting that implicit relational learning for faces was able to function regardless of this damage.

Both sets of results would appear to be discordant with previous research that has investigated the effect of damage to the hippocampal system on relational memories. How can these results be accounted for? Interpretations of the findings will be examined next.

Verbal memory paradigm

This task was similar to the one used in Savage *et al.*'s (2002) study of verbal relational processing. As well as an explicit (paired associate-learning) measure of relational memory, an implicit (masked priming) measure was also employed. This allowed relational learning to be detected without the conscious mediation that was involved in the standard paired-associate retention test. However, it may be argued that the recognition judgement required by the implicit task may have involved some conscious mediation of memories. This should be acknowledged when considering the implications the task has on conscious or unconscious processing.

The explicit measure appeared to demonstrate that more concrete words were learnt over time than the abstract words, with this difference being more apparent during trial 2. This may be interpreted as confirmation of Savage *et al.*'s finding and also previous research, which has suggested that concrete words are generally more memorable than abstract words (Walker and Hulme, 1999). In the past, this has been explained by reference to 'dual-coding theory' (Paivio, 1971) in that concrete words are coded using verbal and imagery codes (Wippich, 1977). However, the present study found no difference in performance between the groups as Savage *et al.*'s study did.

Whilst the data may appear to suggest that concrete words are learnt quicker than abstract words, this interpretation is likely to be realistic only until trial 2. Following this, the data for concrete words approached the best performance that participants could achieve in the test (i.e. a ceiling effect). Therefore, the interaction may not be

as lucrative as first thought, with the results more attributable to a ceiling effect than the differences in word representation.

The implicit measure used differing primes to examine for the presence of a priming effect in two ways – primes that facilitated performance (i.e. matched primes versus reassigned primes), and primes that interfered with performance (i.e. old prime-new target and novel prime-new target). Both types of prime indicated that a priming effect had occurred. Matched primes were identified quicker than reassigned primes, although there was no significant difference in terms of accuracy, perhaps due to the ceiling effects. Furthermore, old primes evoked less accurate and slower responses than the novel primes. This may suggest that relational learning was preserved from the initial explicit learning phase and is accessed via implicit means, despite the presence of damage to the hippocampal system in some participants.

The results become more interesting, however, when the priming effects are regarded in combination with word representation. It is well established in the literature that concrete words are easier to remember than abstract words. This pattern was generally observed in the more straight forward conditions of the task, for example initial learning and when words were paired with their original primes. However, for one group of participants in particular, this simple paradigm was not so clear cut. The right temporal group demonstrated a *worse* performance for concrete words than abstract words when the word was preceded by an old prime, than either of the other groups. What can account for this change in performance when considering word representation?

On first glance, this result may be interpreted in terms of lateralisation. It is generally agreed that the left hemisphere of the brain is largely responsible for human language functioning. However, where the processing of different representations of words is concerned, research suggests that the left hemisphere is superior in processing abstract nouns due to the dependency on linguistic analysis to do so (Prior *et al.*, 1984). The literature proposes that the right hemisphere is also involved in linguistic skills to a certain extent, particularly in the processing of concrete words although it is unable to recognise abstract words (Coltheart, 1983).

Such findings help to account for the results from the present paper. Those individuals with right hemisphere damage in the present study demonstrated worse performance for concrete words than abstract words in some conditions. If the right hemisphere is important for processing concrete words and the left hemisphere for abstract words as the research suggests, then it is logical that damage to the right hemisphere may result in deterioration in performance for concrete words but not in abstract words, due to the preserved integrity of the left hemisphere. However, it is important to note that these differences may simply reflect damage to either hemisphere in general as opposed to being specifically related to the temporal lobe.

However, on further consideration of the results, it is not the case that the right temporal group were unable to learn concrete words, but simply made more errors with them. For example, the old and new prime data suggests that the right temporal participants were more prone to interference with the recognition task when old concrete primes were assigned to new target words. It appears that the concrete prime prepares them to expect the matching concrete target word, resulting in the

incorrect answer being given. The results would suggest that such interference does not occur for the same group with abstract words, nor does it occur to such an extent for the other groups on either word type.

One way to understand this result may be to consider the importance of correct activation of the words. One area that may be relevant is the topic of deep dyslexia. This is an acquired disorder due to brain injury, which evokes numerous semantic and visual errors when a word is read. Hinton and Shallice (1991) proposed a model that can account for such errors. They suggested that the wrong semantic item is activated at the time of reading during the search through the semantic system for the correct item, although the item which is activated may not be very different to the item that should have been evoked (Denes *et al.*, 1999).

The participants in this study did not, of course, suffer from deep dyslexia, but the principles of the model suggested by Hinton and Shallice can be applied to the study to understand the errors made in concrete word primes. Perhaps exposure to the old concrete primes also activated the corresponding concrete target word during searches for the correct judgement to be made, but the participant was unable to inhibit such activation. For abstract words, it would appear inhibition of such an error was possible. However, for the explanations of the right temporal group's results to be accepted, they would be required to demonstrate a similar pattern of results with concrete words over all conditions, not just one. Thus caution must be aired when considering these conclusions.

The confidence ratings on recognition judgements were intended to measure individuals' awareness of remembering the actual experience versus a feeling of familiarity. The results indicated no significant differences in ratings over the conditions or between groups. At the very least, differences between patient and control groups were expected. Research suggests that individuals with hippocampal system damage are likely to perform worse on those types of memory task that require conscious mediation (explicit). This would be expected to be reflected in their confidence ratings of how accurate they believed their performance to be on the recognition judgement task (i.e. some level of uncertainty given their poor performance). Alternatively, control groups are suggested to perform better than patients with temporal lobe pathology on such memory tasks, and thus they would be expected to rate their recognition judgements as accurate with some level of certainty, reflecting their awareness of the actual recollective experience. However, no such difference occurred within the confidence ratings results. This may be attributed to the fact that there were no significant differences between overall group performance, for reasons previously explained. Alternatively, perhaps confidence ratings were not measuring conscious recollection but rather the strength of participants' feelings of familiarity with the stimuli presented (Gardiner, Ramponi & Richardson-Klavehn, 1998), a methodological problem that would require careful consideration should the study be repeated.

The verbal paired-associate task employed in this study was used to explore the notion of verbal relational processing with an expectation that presence and location of brain damage would affect such a task in comparison to participants with intact brains. The original paper (Savage *et al.*, 2002) which conducted an identical

experiment found a difference between participants with left and right temporal lobe damage, with the former performing significantly worse than the right temporal group. Even though trends between the groups were identified in the present study, all groups appeared to demonstrate relational processing to a certain extent, with no significant difference between brain damaged and control participants. Why should a replication of the same study produce such diverse results?

The difference in results may be attributable to brain regions affected in each study. Savage *et al.* (2002) used participants who had all experienced anterior temporal lobectomies, which typically involved removing anterior temporal neocortex and medial temporal lobe structures. Only two participants had undergone surgery in the present study, with the majority of participants having hippocampal sclerosis as a result of epilepsy. Even though the hippocampus is damaged in cases of hippocampal sclerosis, it is likely that some functioning is retained. Furthermore, the neocortex of participants in the present study is assumed to be largely intact, although it is acknowledged that continuing epilepsy is likely to affect the neocortex. Perhaps the results may be attributable to partially functioning hippocampal and neocortical systems of the participants in the present study and thus neither region can be ruled out for their contribution to relational memory.

It is, therefore, possible that for the Savage et *al.* participants, the process of removing the medial temporal lobe structures during the surgery actually resulted in more extensive damage than just hippocampal removal. Manns and Squire (2001) make a similar point during their research into contextual cuing. They replicated the study originally conducted by Chun and Phelps (1999) where participants with

hippocampal system lesions were unable to benefit from contextual cuing, despite the task being implicit in nature. However, Manns and Squire found that this was more likely to be the case when participants had extensive damage to the medial temporal lobe (including entorhinal, perirhinal and parahippocampal cortices) and that those with damage purely to the hippocampus benefited from contextual cues and thus performed as well as the controls. Therefore, other structures such as the parahippocampal region may also be important for relational processing in combination with the aforementioned areas (i.e. hippocampal, parahippocampal and neocortical regions) (see Cohen and Eichenbaum, 1993). Further investigation is required to elucidate the exact contribution made by such brain structures.

Faces memory paradigm

The faces task was based on the premise that the presentation of a range of perceptually similar complex visual stimuli would result in individuals implicitly developing a 'gist' or 'prototype' memory of similar stimuli. Earlier research has suggested that in such situations, individuals may choose the prototype more often than the originally presented stimuli. In addition, damage to the medial temporal lobes has been considered to weaken this effect.

The results from the present study demonstrated that prototypical faces were chosen significantly more often than seen or unseen exemplars. Therefore, it is concluded that a prototype effect was present, showing no deficit in relational memory but demonstrating an impairment in accurate recall of actual items shown instead. This supports the findings from the face processing literature, which indicates that the

prototype of a category of faces is usually chosen over the actual stimuli to which participants were exposed (Cabeza *et al.*, 1999).

Surprisingly, no significant difference was found between the groups for the prototype effect, as previous research had suggested. *All* groups showed a similar pattern in choosing the prototype more frequently than actual seen or novel faces, despite previous research stating that individuals with lesions to the right temporal lobe are sensitive to deficits in faces recognition (Morris *et al.*, 1995). In contrast to the current result, previous research has suggested that those individuals with damage to the medial temporal and diencephalic brain structures would produce a weaker gist or prototype effect. How can results in the present paper be accounted for?

The type of stimuli used may explain the findings. Koutstaal *et al.* (1999) used complex shapes to demonstrate the prototype effect in individuals who were classified as individuals with amnesia in comparison to a group of healthy controls. Their findings demonstrated that the individuals with amnesia produced a weaker gist than controls. It is possible that the processing of complex shapes is distinctively different from that involved in processing faces. The literature associated with prosopagnosic participants has highlighted cases where failure in face recognition occurs but not in object recognition (McMullen *et al.*, 2000), which suggests that face and object recognition are separate processes (Gauthier *et al.*, 2003). Even though it was a different type of task, the faces memory task in the present study was considered to be a relational learning task, given the nature of having to implicitly relate the common features of the faces together to build up a gist of them. Further

investigations of relational learning may be pursued by comparing shape and face processing employing a similar paradigm to the present study.

Differences in the aetiology of participant's brain damage may also be responsible for the divergence in results. The Koutstaal *et al.* study used participants with a mixture of aetiology and severity in brain damage. Half of the patient participants suffered from Korsakoff's syndrome, where damage may also be present in the frontal lobes as well as the diencephalic and medial temporal structures (Hodges, 1994). Furthermore, for those participants with mixed aetiology, half had bilateral cerebral pathology whereas the participants in the present study only experienced unilateral damage. The lesions of participants in the Koutstaal *et al.* study were also much more widespread than the selective hippocampal pathology present in the majority of the participants in the present paper.

Summary of the verbal and faces memory test findings

Both the verbal and the faces memory tasks were thought to involve relational memory, given the requirement of each task to make links or relations between stimuli for the participant to remember them when tested. The findings across tasks showed a common theme in demonstrating that, contrary to previous research studies, relational learning is still possible even when damage occurs to the hippocampal and medial temporal lobe system. It seems apparent that this memory process may be accessed via conscious (explicit) measures but it is harder to draw conclusions about unconscious (implicit) measures, given the unclear true nature of the verbal implicit task used. It is assumed that the residual memory systems in

operation after the damage to the brain has occurred may be managing to support such a memory process.

The findings of this study can be considered in the context of the declarative/procedural distinction as proposed by Cohen and Squire (1980). Participants with damage to the hippocampal memory system are not expected to be able to explicitly remember facts and events, just as the participants in the present study were unable to always explicitly recall the correct words or exact faces learnt. However, the relations that were made were achieved through implicit means, with participants not being aware of the links that had obviously been made, as measured by priming and the prototype effect (if indeed these were truly implicit tasks). This does not fit in with the original declarative/procedural distinction or even the relational representational theory, given that these frameworks defined relational memory as a strictly explicit task, whereas the present study has presented some evidence that relational memories may be encoded and expressed implicitly. Perhaps the terminology describing the nature of relational memories needs to be revised.

Methodological issues

Despite efforts to control for possible confounding variables, some factors could not be systematically avoided and may have influenced the results that were obtained. The temporal lobe participants included a range of aetiologies, the majority of whom experienced temporal lobe epilepsy and a few of whom had received surgery (temporal lobectomies). Although every attempt was made to match participants on aetiology, variables associated with the precise location, size and severity of lesion were difficult to control.

Participants were also matched on brief measures of verbal and non-verbal IQ using the NART and Matrix Reasoning subtest from the WAIS-III battery. The use of more detailed assessments to match participants was initially considered, but it was felt that, combined with the time taken for the actual experiments, this would be too time consuming and would exhaust participants, and thus would not obtain the best performance from them. To remedy this, the sessions of assessment could span over several weeks, if the participant and researcher had the time and resources to be able to do so.

The study itself was mostly conducted at the participants' home. Whilst every effort was made to seek out a quiet room with no distractions, interruptions were not always eradicated. Ideally, the study would have been conducted in a clinical environment. However, due to time and resource constraints it was considered more convenient that the researcher visit the participant at home.

Given that many of the participants experienced epilepsy, on a few occasions a participant may have had a seizure either on the day of testing or the day before. Every effort was made to ensure the participant's safety, emphasising that they may withdraw at any time, and a couple of times, alternative appointments were made. However, if participants did decide to continue with the study on the same day, the results may have been potentially affected due to them not performing at their best.

Finally, the sample size was relatively small and data from a larger group of participants may have resulted in more statistically significant findings. However,

the limited number of participants with such selective brain pathology made it problematic to recruit more participants in the time period of the project.

Clinical implications

The present study suggests that impairment in relational memory is not an inevitable consequence of damage to the hippocampal-memory system. This result is likely to have implications from a clinical and rehabilitative perspective. It indicates that learning relational material is still possible when patients experience damage to this brain region. For example, patients may be required to learn important information during memory rehabilitation programmes, such as face-name pairs of information. Whilst learning new declarative and relational information may require multiple learning trials (e.g. Butters *et al.*, 1993), some learning is still possible.

Conclusions

The topic of relational memory has been investigated in this study. Based on previous research, it was expected that hippocampal pathology would interfere with relational learning and memories. Contrary to previous findings, the present study found that damage to the temporal lobes did not appear to effect participant's ability to develop relational memories. Furthermore, participants with left and right sided temporal lobe pathology appeared to perform at a similar level, implying that documented hemispheric differences in functioning were not observed. It is possible, therefore, that residual memory systems (hippocampal and neocortical) could have been supporting relational memories in the sample of neurological patients who were the focus of this study.

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List of tables and figures

Table 1 – Details of participant's lesion aetiology and location

	LTL $N = 10$	RTL $N = 11$
Aetiology		
Epilepsy	8	8
(Post surgery)	(0)	(2)
Tumours	1	3
(Post surgery)	(0)	(2)
Infection (Herpes Simplex Encephalitis)	1	0
Location		
Hippocampal sclerosis	7	7
Lesion/tumour in the temporal lobe region	3	4

(Figures in parentheses refer to the patients within that aetiology category who have received surgery).

Table 2 – Demographic information for participants with temporal lobe pathology and controls

	Participants with Temporal Lobe Pathology		Control Participants
M, (SD), range	LTL $N = 10$	RTL $N = 11$	$N = 11$
Age	38.5, (14.6), 23-64	39.7, (13.5), 22-57	36.5, (12.2), 20-60
Years of Education	13.9, (1.9), 10-16	12.2, (2.0), 10-16	14.6, (2.1), 11-18
NART Full Scale IQ	100.8, (13.4), 82-124	98.4, (13.2), 80-117	110.4, (6.9), 102-126
Matrix Reasoning Scaled Score	9.9, (4.2), 3-17	10.6, (2.4), 6-15	N/A

Figure 1 - Mean recall of concrete and abstract words over time

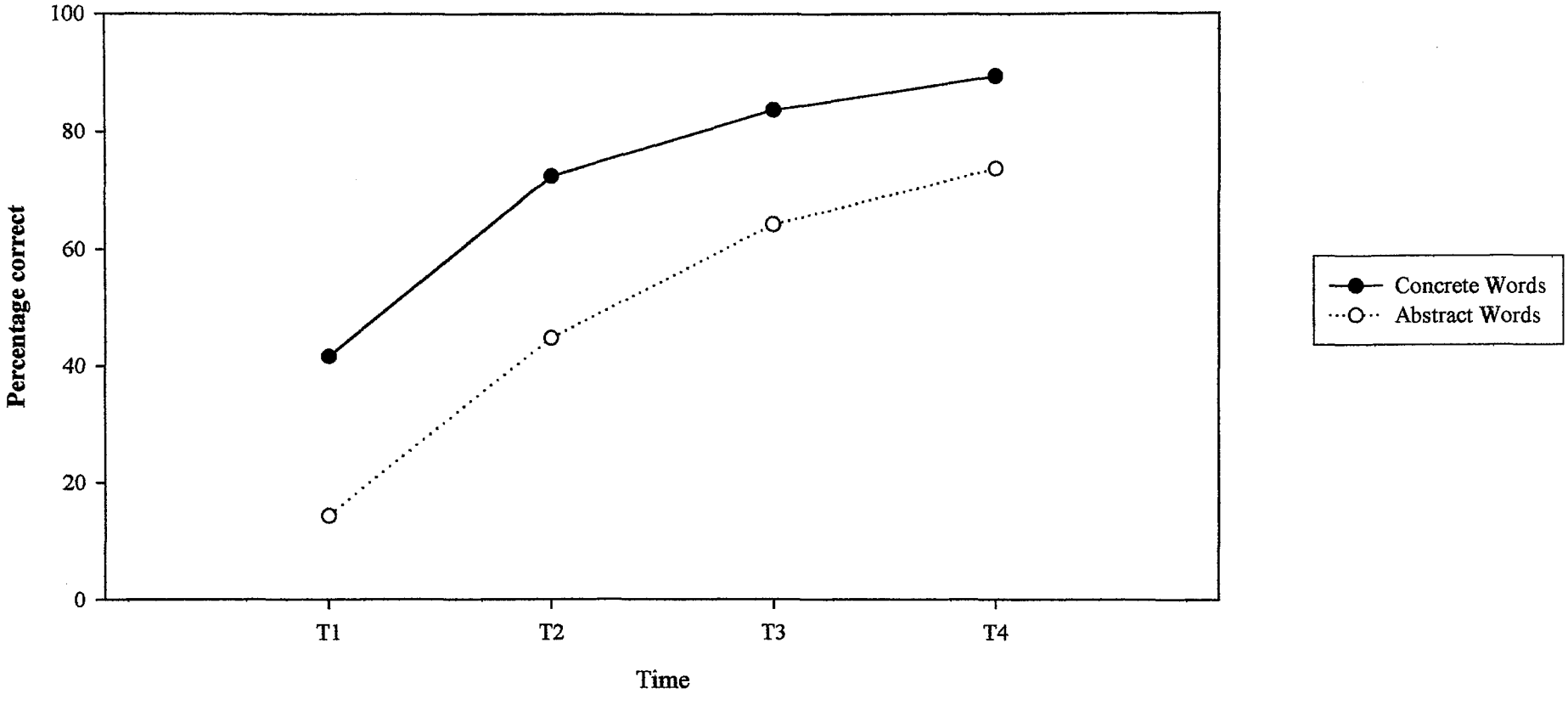


Figure 2 - Mean percentage of correct concrete and abstract words given by each group over time

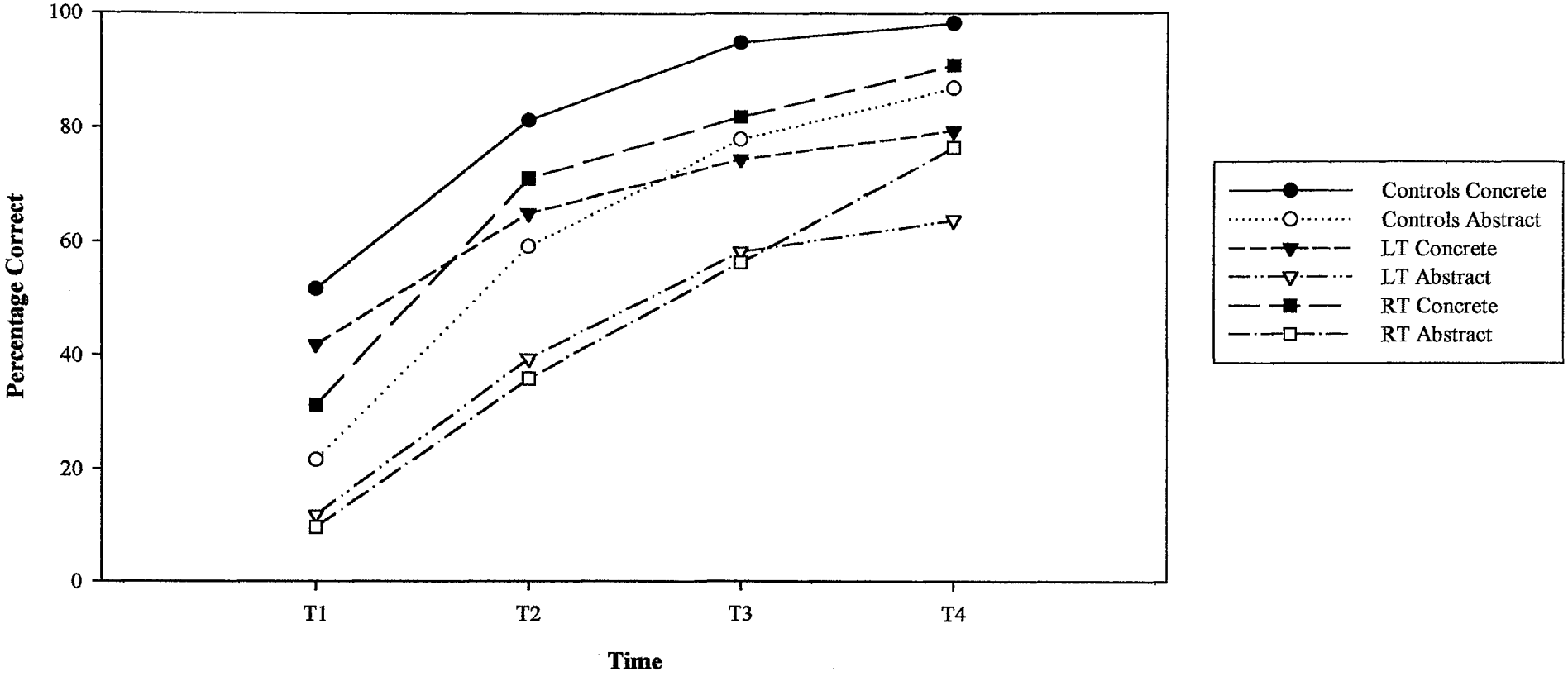


Figure 3 - Mean percentage of correct concrete and abstract words given when preceded by matched or reassigned primes for each participant group

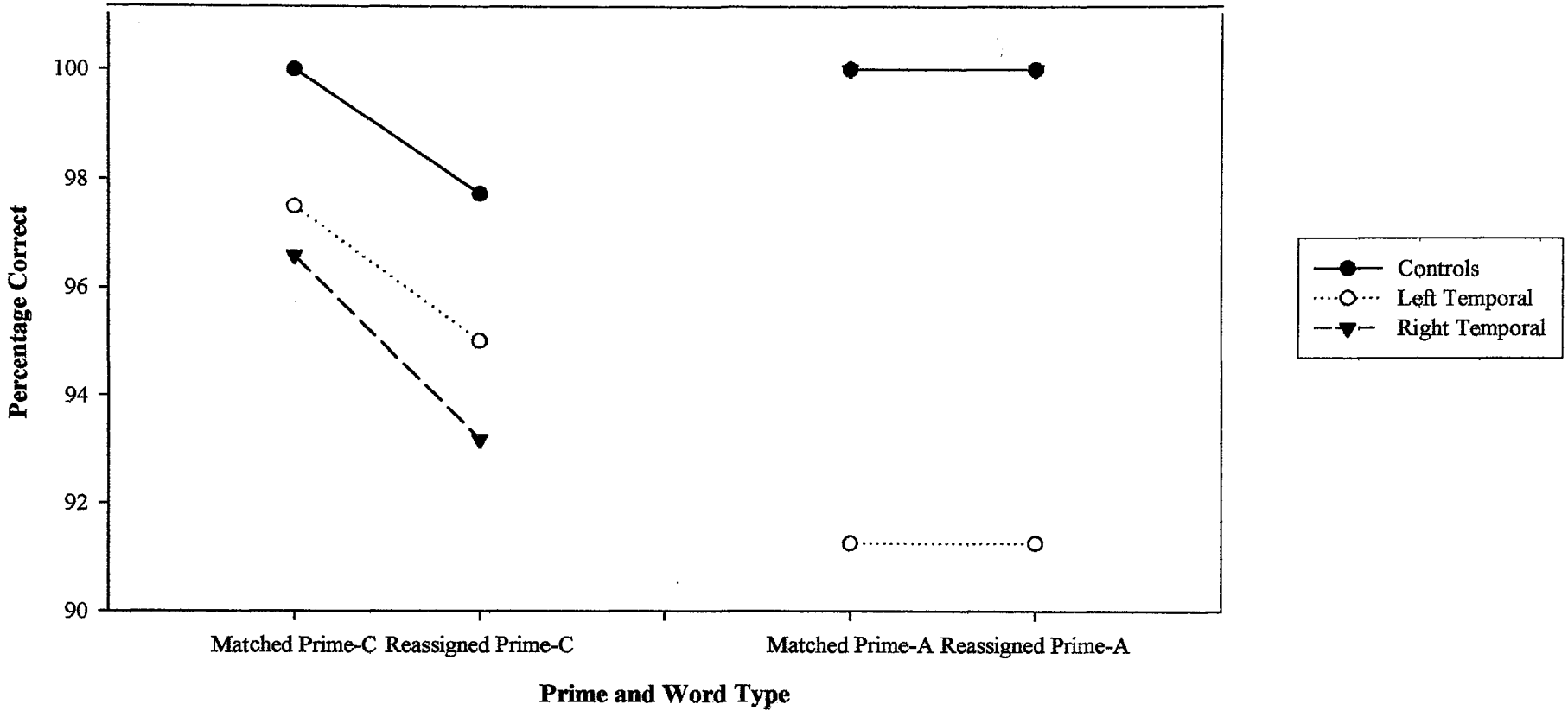


Figure 4 - Mean RT for concrete and abstract words when preceded by matched and reassigned primes for each participant group

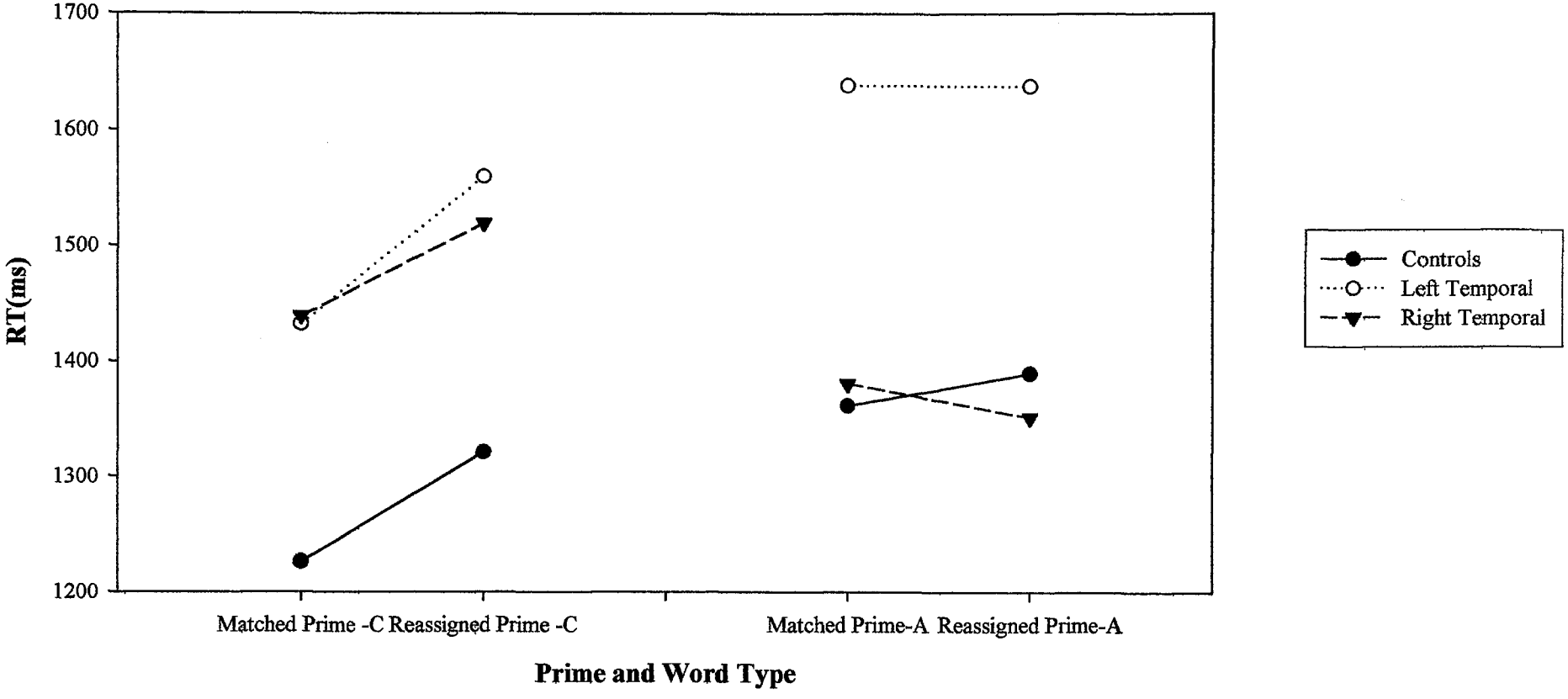


Figure 5 - Mean percentage of correct concrete and abstract words given when preceded by old and novel prime items for each participant group

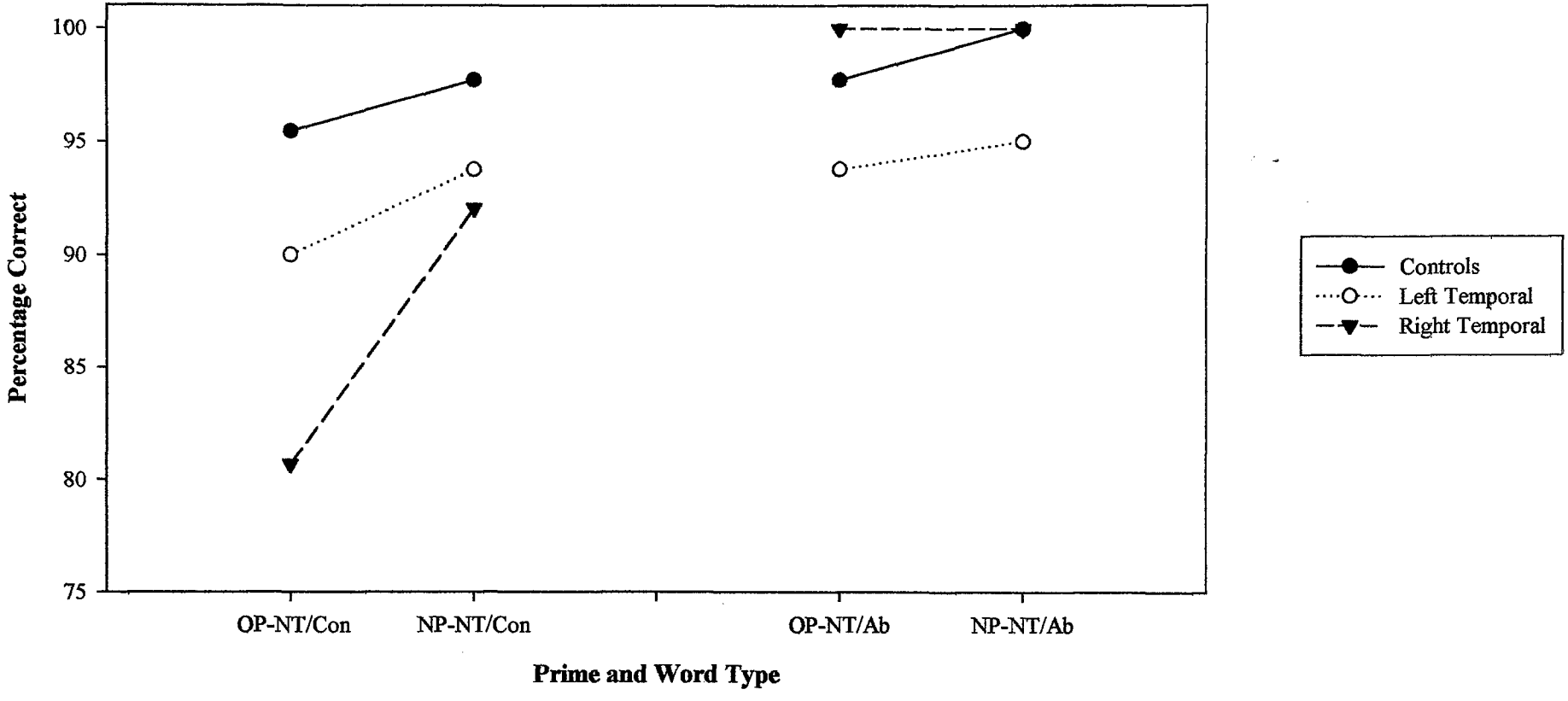


Figure 6 - Interaction between word type and prime

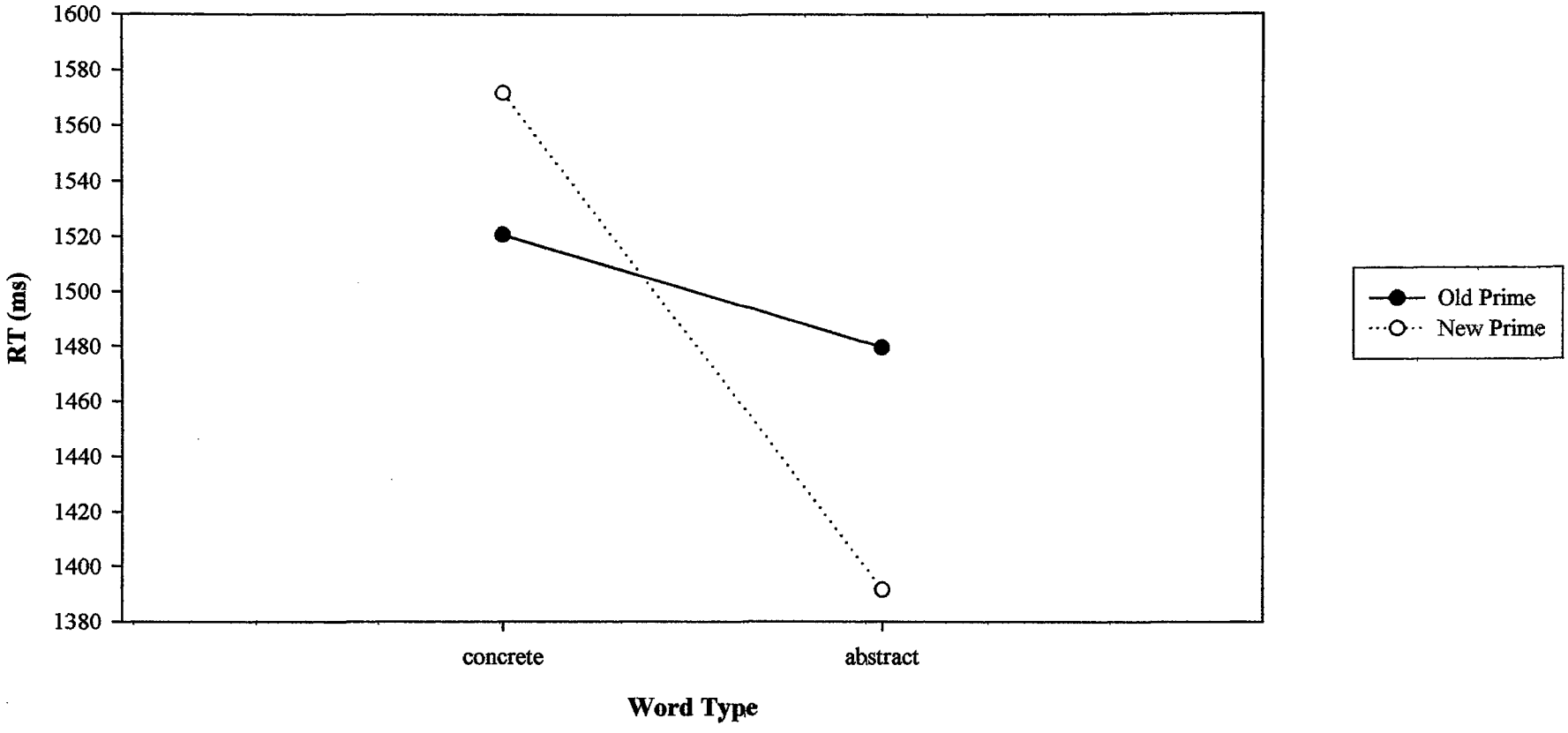


Figure 7 - Mean RT for concrete and abstract words when preceded by old and novel prime items for each participant group

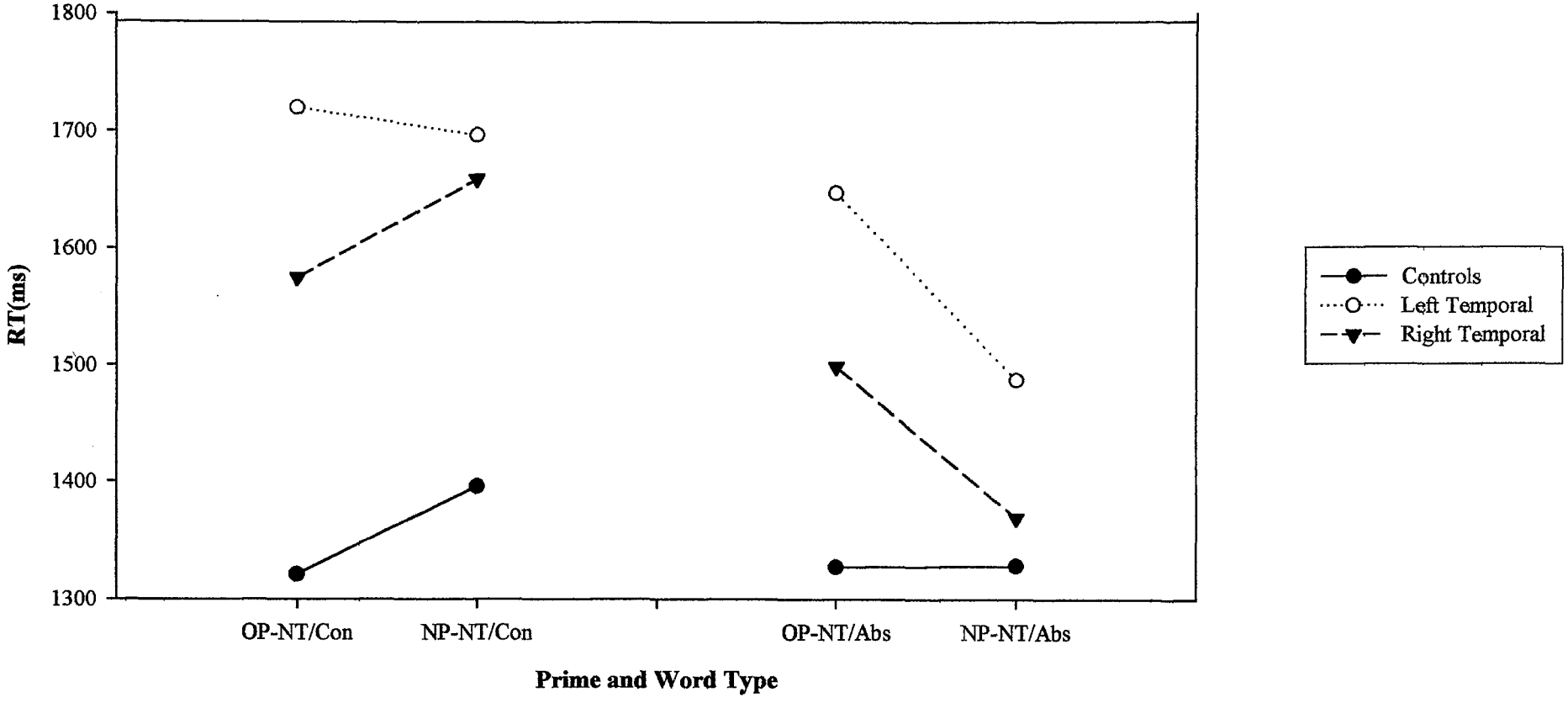
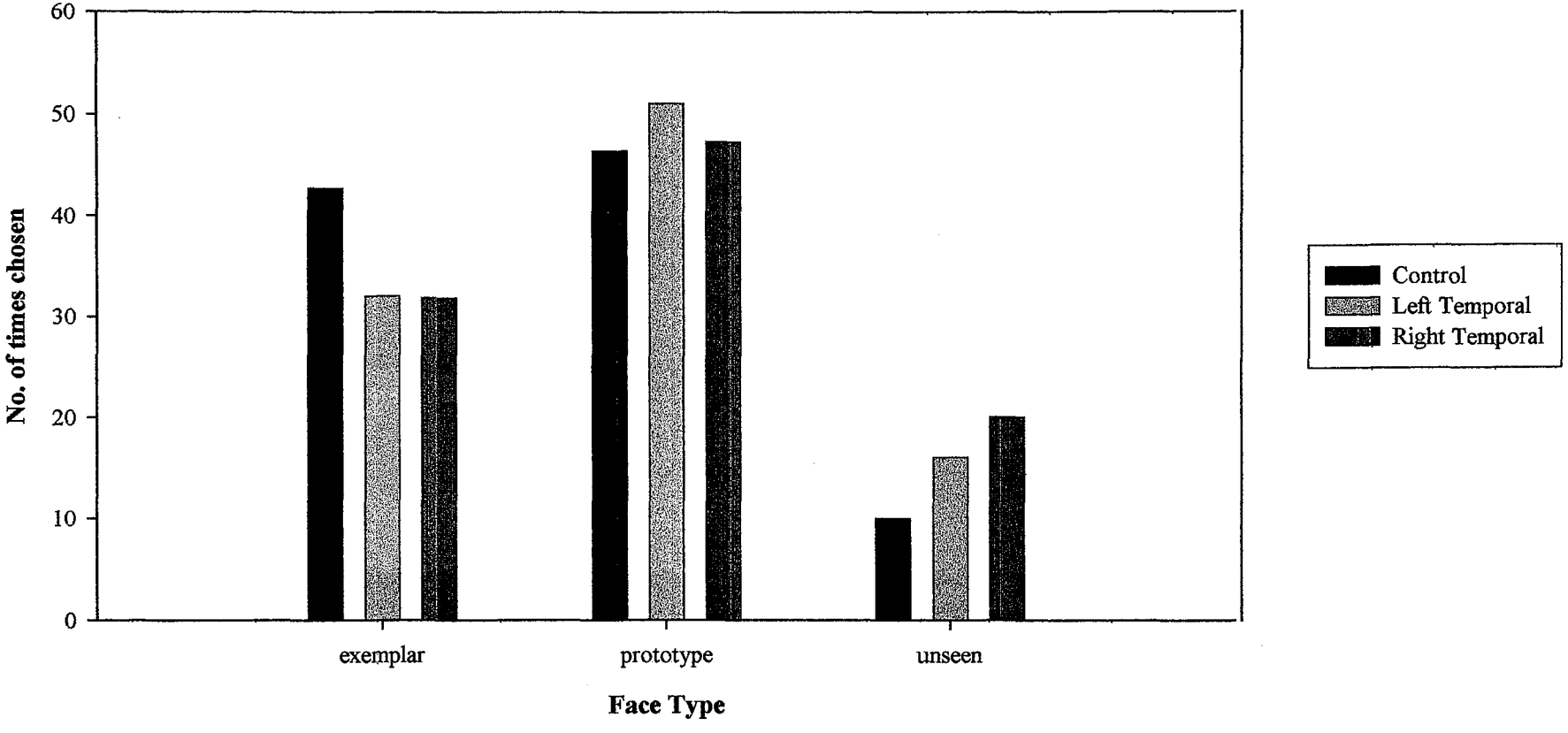


Figure 8 - Frequency of face type chosen for each participant group



Appendices

Appendix I

Instructions to authors submitting to Brain.

Instructions to authors

ONLINE SUBMISSIONS. You are encouraged to submit your manuscript online. Once you have prepared your manuscript according to the instructions below please visit http://brain.manuscriptcentral.com to submit online.

Brain publishes definitive papers on neurology and related clinical disciplines, and on basic neuroscience, including molecular and cellular biology, and neuropsychology when they have a neurological orientation and are clearly relevant to the understanding of human disease. In the field of neuropsychology, *Brain* is particularly interested in investigations which bring together brain structure and function, or which make theoretical contributions to the understanding of cerebral mechanisms. Papers which are predominantly technical or methodological in nature or which present hypotheses or models unsupported by original data, are not suitable.

Brain does not publish preliminary reports of work in progress or brief reports of single cases. More detailed studies of single cases will be considered only when they definitively resolve an important problem in the field or when the data lead to a significant conceptual advance. Studies of single cases which can be readily performed on groups of patients will not be accepted.

Review articles if authoritative and topical will be considered.

Address all correspondence to Professor J. Newsom-Davis, Editor of *Brain*, Institute of Neurology, Queen Square, London WC1N 3BG, UK (Tel: 0207 405 4616; Fax: 0207 405 4617; E-mail: brain@ion.ucl.ac.uk). All submissions will be acknowledged on arrival at the *Brain* editorial office.

PAPERS must be typewritten in the style of *Brain* on one side of the paper only. They should be *double-spaced*, including text, tables, legends and references. In addition to the full title of the paper, which should not exceed 100 characters including spaces, authors should supply a running title which will appear at the heads of the pages. This should not exceed 40 characters, including spaces. A short summary, not exceeding 400 words, followed by appropriate keywords up to a maximum of five, to appear at the beginning of the paper, should also be provided. The total number of words in the text (excluding references, tables and figure legends) should also be indicated. *Brain* does not set an upper limit to the number of words, but also does not encourage prolixity. Authors need to know that space in the journal is strictly limited, and that they will be asked to shorten a manuscript that is judged to be disproportionately long. The full address, telephone and fax number of the corresponding author should appear on the title page.

Papers in which experiments on patients or healthy volunteers are reported must record the fact that the subjects' consent was obtained according to the Declaration of Helsinki (BMJ 1991; 302: 1194) and that the ethical committee of the institution in which the work was performed has approved it. Consent must be also recorded when photographs of patients are shown or other details are given which could lead to the identification of the individuals.

Experiments with animals should be performed in accordance with the legal requirements of the relevant local or national authority, and the name of the authorizing body should be stated in the paper. Procedures should be such that experimental animals do not suffer unnecessarily. The text of the paper should include experimental details of the procedure and of anaesthetics used. The Editorial Board reserves the right to reject papers where the ethical aspects are, in the Board's opinion, open to doubt.

If online submission is not possible, please send a disk and four copies of the paper. These will not be returned if the paper is not accepted for publication. The illustrations will be returned if a request is made at the time of submission. Should the paper be accepted subject to revision, three copies of the revised version must be submitted (two to be highlighted in the places where changes have been made) together with a disk (preferably 3½ inch in PC Microsoft Word) labelled with: name of first author, manuscript number, software and hardware used, and the name of the file(s) to be processed. If a paper is provisionally accepted subject to revision, it should be returned in its amended form within 6 months.

At the time of the initial submission, the paper must be accompanied by the following declaration: 'The work reported in the attached paper entitled . . . has not been and is not intended to be published anywhere except in *Brain*'. It must be signed by *all* authors. Previous publications of the results in abstract form will not preclude consideration. For online submissions this letter must be sent separately by post.

CONFLICT OF INTEREST. Potential financial interests must be disclosed to the Editor in the form of a statement in the covering letter. This statement will be published at the Editor's discretion. The conflict of interest test is simple: is there anything—e.g. shareholding in or receipt of a grant or consultancy fee from a pharmaceutical company or a contract from a medical devices manufacturer—that would embarrass you or any of your co-authors if it were to emerge after publication and you had not declared it? All sources of funding must be disclosed as an acknowledgement in the text.

BIBLIOGRAPHIC REFERENCES should be limited to essential literature. They should be listed at the end of the

paper in alphabetical order and not numbered. For multiple publications by the same author, those by the author alone are listed first, those with two authors listed after these and any with three or more authors must be given up to a maximum of six and any more should be indicated by '*et al.*'. If there is more than one paper for a given year, these should be listed *a*, *b*, *c*, etc. The references should be presented in the Vancouver style (see Uniform requirements for manuscripts submitted to biomedical journals, *The Lancet*: http://www.thelancet.com/authorinfo or Ann Intern Med 1997; 126: 36–47) and journal titles given in their abbreviated forms (see *List of Journals Indexed in Index Medicus*).

Examples of reference style:

Barkovich AJ. Disorders of neuronal migration and organization. In: Kuzniecky RI, Jackson GD, editors. Magnetic resonance in epilepsy. New York: Raven Press; 1995. p. 235–55.

Bushby KMD, Gardner-Medwin D. The clinical, genetic and dystrophin characteristics of Becker muscular dystrophy. I. Natural history. J Neurol 1993; 240: 98–104.

Costa DC, Morgan GF, Lassen NA, editors. New trends in nuclear neurology and psychiatry. London: John Libbey; 1993.

Handwerker HO, Kobal G. Psychophysiology of experimentally induced pain. [Review]. Physiol Rev 1993; 73: 639–71.

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ABBREVIATIONS FOR SCIENTIFIC UNITS should conform to the Système Internationale (SI units). The statistical guidelines advocated by the International Committee of Medical Journal Editors (Ann Intern Med 1988; 108: 266–73) should be followed.

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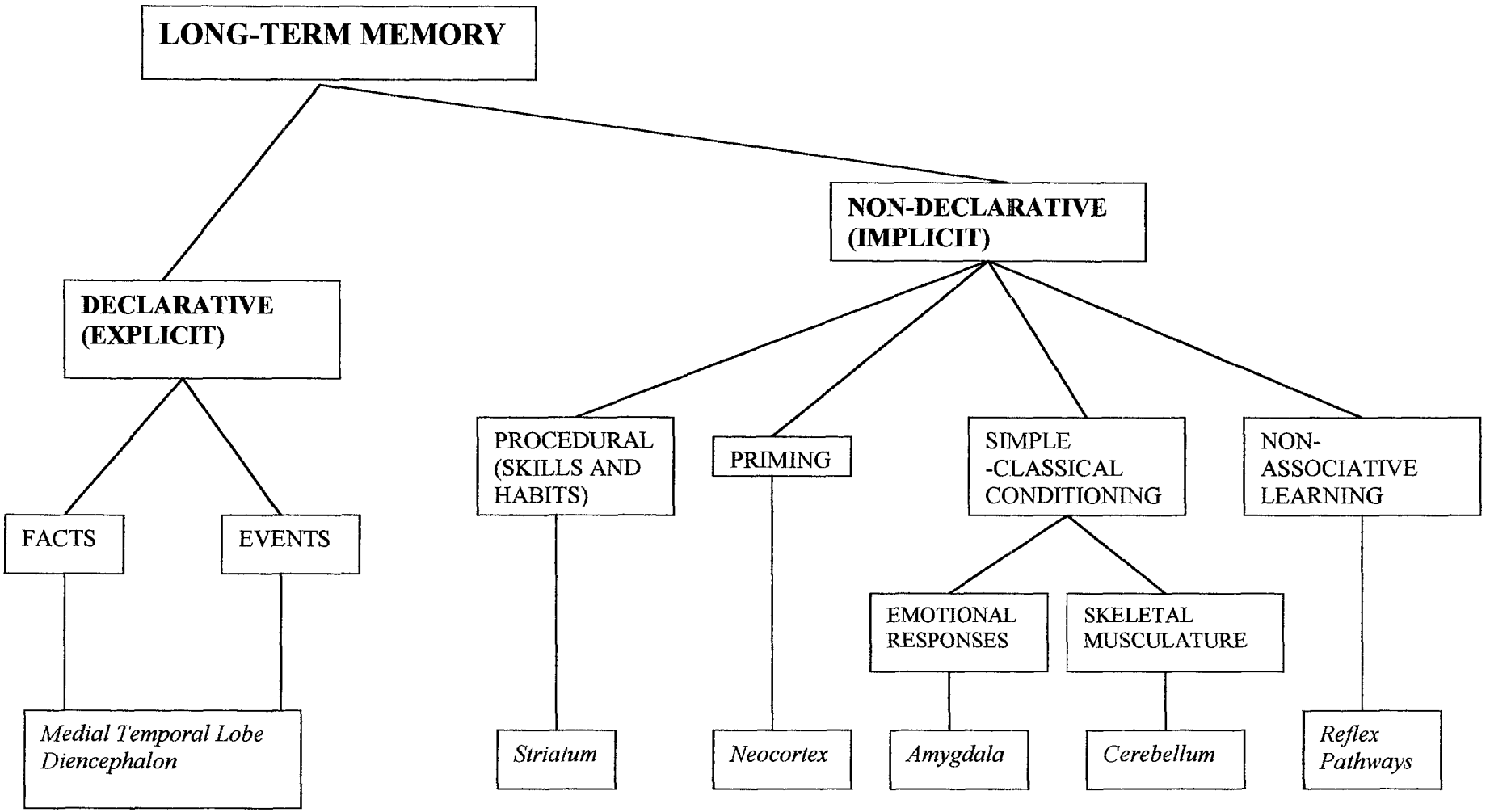
BOOKS FOR REVIEW. Please send books for review to the Book Review Editor: Professor C. M. Wiles, Department of Neurology (C4), University of Wales College of Medicine, Cardiff CF4 4XW, UK.

Appendix II

A taxonomy of long-term memory systems

A TAXONOMY OF LONG TERM MEMORY SYSTEMS

A taxonomy of long-term memory systems together with the brain structures critical for each system (Squire, 1998).



Appendix III

Letter of Ethics Committee approval

SOUTHAMPTON & SOUTH WEST HANTS
LOCAL RESEARCH ETHICS COMMITTEES

Chairman: Dr Audrey Kermode/Dr David Briggs

Manager: Mrs Clair Wright
1st Floor
Regents Park Surgery
Park Street
Shirley
Southampton S016 4RJ

Tel: (023) 8036 2466
Fax: (023) 8036 4110

Ref: CPW/ch

04 July 2002

Miss S Walker
Trainee Clinical Psychologist
Dept of Clinical Psychology
University of Southampton
Southampton

Dear Miss Walker,

Submission No: 148/02: The role of the Temporal Lobes in Relational Processing

Following the conditional approval and in response to your letter dated 27th June 2002, I am pleased to confirm **full approval** having responded satisfactorily to the committees concerns.

The following documents were re-considered:

- Revised Participant Information Sheet, version2
- Revised Carer/Friend Information Sheet, version 2

However, please ensure that the wording on the Carer/Friend Information Sheet **reads 'Assent' and not 'Consent'.**

This approval was granted under Chairman's action by the duty Chairman Dr Audrey Kermode, and will be recorded by the Committee at their meeting in July.

This committee is fully compliant with the International Committee on Harmonisation/Good Clinical Practice (ICH) Guidelines for the Conduct of Trials involving the participation of human subjects as they relate to the responsibilities, composition, function, operations and records of an independent Ethics Committee/Independent Review Board. To this end it undertakes to adhere as far as is consistent with its Constitution, to the relevant clauses of the ICH Harmonised Tripartite Guideline for Good Clinical Practice, adopted by the Commission of the European Union on 17 January 1997.

Yours sincerely

C Wright

Mrs Clair Wright
Research Ethics Manager

Appendix IV

Information sheets for participants (patient and control).

Southampton NHS
University Hospitals NHS Trust

Department of Clinical Neuropsychology
Wessex Neurological Centre
Southampton General Hospital
Tremona Road
Southampton
SO16 6YD

PARTICIPANT INFORMATION SHEET

Memory for Faces and Words

You are being asked to take part in a research study. Before you decide, it is important for you to understand why the research is being done and what it will involve. Take time to read the following information carefully and discuss it with others if you wish. Please ask me if there is anything that is not clear or if you would like more information. Take time to decide whether or not you wish to take part.

What is the purpose of the study?
This study will explore memory for faces and words and will investigate whether this is influenced by health-related problems that have affected the functioning of the brain.

Why have I been chosen?
You have been chosen because you have experienced health-related problems that have affected the functioning of your brain.

Do I have to take part?
It is up to you to decide whether to take part. This information sheet should inform you of what the study is about, which you may keep. Before participating, you will be asked to sign a consent form. Even if you agree to take part you are still free to withdraw at any time and without giving a reason. A decision to withdraw at any time or a decision not to take part will not affect the standard of care that you receive.

What will happen to me if I take part?
If you decide to take part, I will contact you so that we can arrange a suitable time for us to meet. Your thinking and memory skills may have already been assessed as part of your routine clinical care. However, if this has not been done recently, then I will need to conduct a few quick assessments with you in addition to the study. The memory tasks for the study will include one task involving faces and one task involving words. The whole process will take approximately 1.5 – 2 hours to complete. Whatever information you provide will be kept in the strictest of confidence.

What are the possible disadvantages?
There would not normally be any disadvantages associated with performing the tests. However, if at any time you feel distressed by testing, this can be stopped temporarily or altogether, if you so wish.

What are the possible benefits of taking part?
There will be no direct benefits from taking part in the study. However, the more information that we can discover about how the memory works, the better we will be

able to help individuals who experience memory difficulties.

Will my taking part in this study be kept confidential?
All information that is collected about you during the course of the research will be kept strictly confidential. Any information about you, which leaves the hospital, will have your name and any other identifying information for you removed so that you cannot be recognised from it. As a Trainee Clinical Psychologist, my research is supervised by an NHS Clinical Psychologist (Prof. Narinder Kapur) and by two University academic staff (Dr. Kyle Cave and Dr. Nick Donnelly). All three supervisors will keep any information I need to discuss with them entirely confidential.

What will happen to the results of the study?
A report of the study will be written. A summary of the results will be made available on request.

Who is organising and funding the research?
This project is being conducted as part of my training at the University of Southampton.

Who has reviewed this study?
The Southampton and South West Hants Local Research Ethics Committee has reviewed this study, as have the University of Southampton, Department of Psychology Ethics Committee.

Contact for further information
If you have any questions, or you wish to request a summary sheet please contact:
Sarah Walker, Doctoral Programme in Clinical Psychology, Building 44, University of Southampton, Highfield, Southampton. SO17 1BJ.
Tel: 023 8059 5321

Thank you, for your help with this study.

Southampton NHS
University Hospitals NHS Trust

Department of Clinical Neuropsychology
Wessex Neurological Centre
Southampton General Hospital
Tremona Road
Southampton
SO16 6YD

PARTICIPANT INFORMATION SHEET

Memory for Faces and Words

You are being asked to take part in a research study. Before you decide, it is important for you to understand why the research is being done and what it will involve. Take time to read the following information carefully and discuss it with others if you wish. Please ask me if there is anything that is not clear or if you would like more information. Take time to decide whether or not you wish to take part.

What is the purpose of the study?
This study will explore memory for faces and words and will investigate whether this is influenced by health-related problems that have affected the functioning of the brain.

Why have I been chosen?
To see if memory for faces and words is influenced by health problems that have affected the functioning of the brain, people who have not had such problems need to be included in the study too. You have been chosen because you have not experienced health-related problems that have affected the functioning of your brain.

Do I have to take part?
It is up to you to decide whether to take part. This information sheet should inform you of what the study is about, which you may keep. Before participating, you will be asked to sign a consent form. Even if you agree to take part you are still free to withdraw at any time and without giving a reason. A decision to withdraw at any time or a decision not to take part will not affect the standard of care that you receive.

What will happen to me if I take part?
If you decide to take part, I will contact you so that we can arrange a suitable time for us to meet. The task itself will involve completing two memory tasks, one involving faces and one involving words. This will take approximately 1 to 1.5 hours to complete. Whatever information you provide will be kept in the strictest of confidence.

What are the possible disadvantages?
There would not normally be any disadvantages associated with performing the tests. However, if at any time you feel distressed by testing, this can be stopped temporarily or altogether, if you so wish.

What are the possible benefits of taking part?
There will be no direct benefits from taking part in the study. However, the more information that we can discover about how the memory works, the better we will be able to help individuals who experience memory difficulties.

Will my taking part in this study be kept confidential?
All information that is collected about you during the course of the research will be kept strictly confidential. Any information about you will have your name and any other identifying information for you removed so that you cannot be recognised from it. As a Trainee Clinical Psychologist, my research is supervised by an NHS Clinical Psychologist (Prof. Narinder Kapur) and by two University academic staff (Dr. Kyle Cave and Dr. Nick Donnelly). All three supervisors will keep any information I need to discuss with them entirely confidential.

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Sarah Walker, Doctoral Programme in Clinical Psychology, Building 44, University of Southampton, Highfield, Southampton. SO17 1BJ.
Tel: 023 8059 5321

Thank you, for your help with this study.

Appendix V

Consent forms for participants (patient and control).

Southampton NHS
University Hospitals NHS Trust

Department of Clinical Neuropsychology
Wessex Neurological Centre
Southampton General Hospital
Tremona Road
Southampton
SO16 6YD

Researcher - Sarah Walker
Participant Identification Number:

PARTICIPANT CONSENT FORM

Memory for Faces and Words

1. I confirm that I have read and understand the information sheet dated…….. for the above study and have had the opportunity to ask questions. ☐

2. I understand that my participation is voluntary and that I am free to withdraw at any time, without giving a reason and without my medical care or legal rights being affected. ☐

3. I am willing to allow access to my medical records but understand that strict confidentiality will be maintained. ☐

4. I agree to take part in the study. ☐

Name of Participant	Date	Signature
Name of person taking Consent (if different from Researcher)	Date	Signature
Researcher	Date	Signature

Southampton NHS
University Hospitals NHS Trust

Department of Clinical Neuropsychology
Wessex Neurological Centre
Southampton General Hospital
Tremona Road
Southampton
SO16 6YD

Researcher - Sarah Walker
Participant Identification Number:

PARTICIPANT CONSENT FORM

Memory for Faces and Words

1 I confirm that I have read and understand the information sheet dated…….. for the above study and have had the opportunity to ask questions. ☐

2. I understand that my participation is voluntary and that I am free to withdraw at any time, without giving a reason and without my medical care or legal rights being affected. ☐

3. I agree to take part in the study. ☐

Name of Participant	Date	Signature
Name of person taking Consent (if different from Researcher)	Date	Signature
Researcher	Date	Signature

Appendix VI

Word lists used in the verbal memory study.

LIST 1	LIST 2	LIST 3	LIST 4
PR.9. CAT – **BUS** (MP-C)	PR.9. WOOD – **EAR** (MP-C)	PR.9. HOUSE – **FINGER** (MP-C)	PR.9. MAN – **COW** (MP-C)
PR.10. SPEAK – **LOUD** (MP-A)	PR.10. STOP – **DULL** (MP-A)	PR.10. SLOW-**DESIRE** (MP-C)	PR.10. LAZY – **RISK** (MP-C)
PR.19. LEAF – STAR (NPNT-C)	PR.19. GOAT – GARAGE (NPNT-C)	PR.19. DRINK – ROSE (NPNT-C)	PR.19. SQUARE – SINK (NPNT-C)
PR.20. FREE – NOISE (NPNT-A)	PR.20. NICE – LENGTH (NPNT-A)	PR.20. PRETTY – LOVE (NPNT-C)	PR.20. DESTINY – TIRED (NPNT-C)
1. POOL – **TEETH** (MP-C)	1. GAS – **KING** (MP-C)	1. CIRCLE – **WINTER** (MP-C)	1. DUST – **MILK** (MP-C)
2. WATCH – **CHEST** (MP-C)	2. OIL – **ROOF** (MP-C)	2. SLEEP – **VALLEY** (MP-C)	2. BEACH – **WHEEL** (MP-C)
3. DOG – **FOREST** (RP-C)	3. TRUNK – **BRAIN** (RP-C)	3. SHIP – **SUIT** (RP-C)	3. MOON – **RAIN** (RP-C)
4. HORSE – **TRAIN** (RP-C)	4. SHOP – **GLASS** (RP-C)	4. TREE – **SEAT** (RP-C)	4. ARM – **METAL** (RP-C)
5. ESCAPE – **DEGREE** (MP-A)	5. USUAL – **EXIST** (MP-A)	5. EQUAL – **STRANGE** (MP-A)	5. BUSY – **LIMIT** (MP-A)
6. SERVE – **BRIGHT** (MP-A)	6. AGREE – **VISION** (MP-A)	6. GROW – **FAIR** (MP-A)	6. RICH – **TINY** (MP-A)
7. CREDIT – **THEORY** (RP-A)	7. CLAIM – **ACTIVE** (RP-A)	7. TEST – **SILENT** (RP-A)	7. QUIET – **HONEST** (RP-A)
8. RELIEF – **MEASURE**(RP-A)	8. SHAPE –**FRESH** (RP-A)	8. FAST – **DUTY** (RP-A)	8. MOTION – **NOTICE** (RP-A)
11. HORSE – CHAIN (OPNT-C)	11. SHOP – NOISE (OPNT-C)	11. TREE – BABY (OPNT-C)	11. ARM – ROCK (OPNT-C)
12. DOG – KEY (OPNT-C)	12. TRUNK – MOUTH (OPNT-C)	12. SHIP – COFFEE (OPNT-C)	12. MOON – RING (OPNT-C)
13. GUN – PLANT (NPNT-C)	13. LADY – BOAT (NPNT-C)	13. GRASS – DREAM (NPNT-C)	13. BEAR – SALT (NPNT-C)
14. BALL – FILM (NPNT-C)	14. COAST – GARDEN (NPNT-C)	14. CRY – SNOW (NPNT-C)	14. FOOT – LAKE (NPNT-C)
15. RELIEF – CAREER (OPNT-A)	15. SHAPE – TRUST (OPNT-A)	15. FAST – TONE (OPNT-A)	15. MOTION – CHANCE (OPNT-A)
16. CREDIT – DESTROY (OPNT-A)	16. CLAIM – IDEAL (OPNT-A)	16. TEST – CARRY (OPNT-A)	16. QUIET – TASTE (OPNT-A)
17. CAUSE – FORMULA (NPNT-A)	17. HEALTH – SPREAD (NPNT-A)	17. TOUCH – PERFECT (NPNT-A)	17. SAVE – DENY (NPNT-A)
18. POOR – EDGE (NPNT-A)	18. WAIT – HOLY (NPNT-A)	18. JOIN – LISTEN (NPNT-A)	18. BITTER – FAMOUS (NPNT-A)

KEY: N.B. – those target words highlighted in bold and underlined are the word pairs that participants learnt in the initial learning phase

PR – Practice items always shown at the beginning of the condition.

MP-C/A: Matched prime – concrete/abstract (i.e. prime and target were originally matched from learning condition – concrete or abstract word).

RP-C/A: Reassigned prime – concrete/abstract (i.e. prime has been reassigned another target - concrete or abstract word).

OPF-C/A: Old prime-new target – concrete/abstract (i.e. prime learnt in list is paired with a new, unseen target - concrete or abstract word).

NPF-C/A: Novel prime-new target – concrete/abstract (i.e. new, unseen prime is paired with a new, unseen target - concrete or abstract word).

Appendix VII

Testing protocol.

TESTING PROTOCOL

INTRODUCTION TO THE STUDY

Thank you very much for agreeing to take part in this study. My name is Sarah Walker and I'm a Trainee Clinical Psychologist at the University of Southampton. The research that I am conducting is a study about memory for faces and words, more specifically, how the brain works with regards to the memory for these things.

OUTLINE OF THE STUDY

The study will involve you doing 2 types of tasks today: a memory task using faces and a memory task using words. Both tasks will be conducted using this computer. I will also be timing some parts of the study. This is done to ensure that the same conditions are provided for all people that take part in the study. You may find some parts of the tasks more difficult than others, but don't worry as they are designed to be this way. I will explain what I would like you to do as we go along. (If you have not received any neuropsychological assessments recently, we will do a few quick assessments at the end, which is for information only). The whole process should take approx. 1.5- 2 hours, but we will be taking breaks in between the various parts of the study to give you a bit of a rest. However, if at any time you become uncomfortable and wish to stop temporarily or altogether, PLEASE do not hesitate to say so. Your performance in this study will NOT affect the care that you are receiving at the hospital or your patient rights. Furthermore, any information that you do give me is confidential – no individuals' results will be identifiable.

CONSENT

Do you have any questions about the research?

If you feel happy to continue, I need to ask you to sign a consent form before we start. This is to say that you are happy to carry on with the study, that you are willing to allow me permission to view your medical notes if necessary with strict confidentiality being maintained and that I have explained everything to you.

PARTICIPANT INFORMATION

Before we start, I would like to take the opportunity to obtain a few details from you. Please tell me your:

- *Age*
- *Occupation*
- *How old you were when you left school?*
-

For those participants with brain injuries also find out:

- *Any information regarding the location and cause of your brain injury*

EXPERIMENT 1 – THE VERBAL MEMORY TEST

Phase 1

This is an experiment using lists of words - 4 different lists of words in total. Here is what is going to happen:

First of all, 10 pairs of words from the first list will be flashed up on the screen in front of you, one pair at a time. I would like you to learn the words the best that you can because afterwards I will test your memory for them. This will be done by the first word of the pair being given to you on the computer screen and I will ask you to tell me the second word that it was paired with. So, for example, if the pair of words was GOLD – EAST, and then later I said GOLD, the word paired with it would be..(EAST)? The only difference is that the words will be presented on the screen. You will have about 5 seconds to answer. After this time or after you have given your answer, the correct answer will be shown on the screen.

After you have learnt and remembered the words four times, then I will ask you to recognise the words that you have learnt from other words.

First of all, I would like you to concentrate on the learning the words. Any questions?"

Show the first list of words. When this is finished, begin to time 30 seconds to reiterate the instructions for the verbal-paired associates test.

So now the first word of the pair will come up on the screen and I would like you to tell me the second word that was paired with it. You will be given about 5 seconds to answer. Ready?

After all 10 pairs have been recalled, the computer will return to the learning phase of the same word list, but randomly presents them in a different order.

We will have three more goes at learning the same word pairs and then the first word being given to you and you telling me the second word that was paired with it.

Time 30 seconds between each learning and verbal-paired associate phase. After the fourth trial of learning the word list has been and testing of the word list has been conducted, time a further 30 seconds to prepare the participant for the masked priming task:

Phase 2

Now what will happen is a row of symbols will flash up on the screen. This is an indication that a word will follow it. What I would like you to do is to indicate whether the word that you can see on the screen appeared in the list of words that you have just learnt. Please indicate by pressing the button for 'YES' if you think it did appear in the word list that you just learnt and 'NO' if you think it didn't. Point to the relevant buttons on the response box. *After*

this, I will ask you to tell me how certain you are about your answer (certain, think, guess)."

After the masked prime task is completed for the first list:

Now let's have a quick break and then we will do exactly the same thing with a new list of words. There are 4 lists in total.

A break of approximately 2 minutes is taken in between each word list. Take approximately a 10 minute break after the word experiment, before beginning the faces task.

EXPERIMENT 2 – THE NON-VERBAL STUDY

Learning

This is a memory task using faces. Several male faces will appear on the screen in front of you. I would like you to judge how trustworthy each face is using a scale of 1 to 6. So for example, if you see a face and think that he is very untrustworthy, you would press the button 6 on the box in front of you to indicate this. Please do not make your response until the face has disappeared from the screen and the scale appears in its place to prompt you. You will be given about 10 seconds to respond. There are no right or wrong answers, this is just a way to help you to concentrate on the faces because after this has finished, I will ask you to pick the faces you saw from other faces. Any questions?"

Run the programme that shows the faces. After all the faces have been shown, start timing for 30 seconds, to explain the next part of the study.

Test

Three faces will now appear on the screen in front of you at a time, one of which you will have seen in the faces shown to you previously and 2 of which you will not have seen before. I would like you to choose the face that you saw before by pressing the button 'A, B or C' on the box in front of you, depending on which face you think that you saw previously. Then I would like you to tell me how certain you are about your answer– whether you are certain it is the right answer, whether you think it is the right answer or whether it was a guess. Any questions?

NEUROPSYCHOLOGICAL TESTING (if appropriate)

You have not received neuropsychological testing before/it has been a while since you have received neuropsychological testing. If it is OK with you, we will do 2 quick tests now. This will give me an idea of the level at which you perform on verbal and non-verbal tasks.

1. NART (National Adult Reading Scale; Nelson, 1991)

I am going to show you a list of words. All I would like you to do is to read them aloud to me. If you are not sure of how to pronounce them, just have a go at saying them how you think they should be pronounced.

Administer the NART.

2. Matrix Reasoning Subtest (From the Wechsler Adult Intelligence Scale 3rd Edition; Wechsler, 1997).

I am going to show you some pictures. For each picture there is a part missing. Look at all aspects of each picture carefully and choose the missing part from the five choices.

Sample Item A

For example, tell me which of these pictures (point to response choices) *should go here* (point to the question mark). *Make sure you look carefully at the picture at the top and at the response choices below before making your selection. If you think there is more than one correct answer to the problem, choose the best one. Remember you are to choose the one that best completes the picture.*

If the individual responds correctly to sample item A, then turn to sample item B and if that is correct, turn to item C. Administer the test, beginning at item 4.

Once the task is completed:

Thank you for completing that task. It gets quite difficult towards the end, doesn't it?

Well done, that is the end of the session. Thank you very much for giving me your time to help me with my research. Have you got any questions or comments that you would like to make?

Once I have finished testing the other people that have also volunteered to do the study, I will analyse the results and will be able to send you a short summary of the results if you are interested.

Thank you once again for your time and effort today.

Appendix VIII

Examples of faces used from the faces memory study.

A

B

C

Appendix IX

Exploration of the distribution of the data.

EXPLORATION OF THE DISTRIBUTION OF THE DATA

One-Sample Kolmogorov-Smirnov tests revealed that a number of sets of data from the verbal study were not normally distributed (for the learning phase of the study, the third trial of learning the concrete words, z=1.389, p=.042; the fourth trial of learning the concrete words, z=1.707, p=.042; for the masked prime phase, accuracy scores for word pairs one and two, z=2.973, p=.000; accuracy scores for word pairs three and four, z=2.496, p=.000; accuracy scores for word pairs five and six, z=2.995, p=.000; accuracy scores for word pairs seven and eight, z=2.837, p=.000; accuracy scores for word pairs eleven and twelve, z=1.606, p=.012; accuracy scores for word pairs thirteen and fourteen, z=2.420, p=.000; accuracy scores for word pairs fifteen and sixteen, z=2.837, p=.000; accuracy scores for word pairs seventeen and eighteen, z=3.049, p=.000).

All other data sets were considered normally distributed (for the learning phase of the verbal study, the first trial of learning concrete words, z=1.063, p=.208; the second trial of learning concrete words, z=.992, p=.279; the first trial of learning abstract words, z=1.098, p=.179; the second trial of learning abstract words, z=.569, p=.902; the third trial of learning abstract words, z=.849, p=.467; the fourth trial of learning abstract words, z=1.034, p=.236; for the masked prime phase, reaction times for word pairs one and two, z=.407, p=.996; reaction times for word pairs three and four, z=.578, p=.892; reaction times for word pairs five and six, z=.533, p=.939; reaction times for word pairs seven and eight, z=.592, p=.875; reaction times for word pairs eleven and twelve, z=.568, p=.903; reaction times for thirteen and fourteen, z=.821, p=.510; reaction times for word pairs fifteen and sixteen, z=.660, p=.777; reaction times for word pairs seventeen and eighteen, z=.664, p= .771).